3 National Priorities for Science and Technology: A View from the Academic Sector

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Since the creation of the land grant university in the 1860s and the formation of the first research universities in the 1870s, these institutions have played a seminal role in the research agenda of our nation. The understanding and appreciation of this role has had its ebb and flow in our history.

The events of September 11 demonstrated just how exposed we are to danger. But they also emphasized the importance of science and technology to our national security and prosperity. It was only a generation or so ago that another conflict, World War II, showed the value of science and technology in solving problems of importance to our nation's survival. These times bring that message home again.

A plaque outside the National Archives reads, "The heritage of the past is the seed that brings forth the harvest of all the future." Research in science and technology provides a powerful illustration of the meaning and truth of this statement. Our research universities play a critical role in providing the research for that harvest.

At the end of January, National Science Foundation (NSF) director Rita R. Colwell told the annual meeting of the Universities Research Association that the effectiveness of science research in the future will be determined by three components: stable funding, a balanced

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portfolio, and an expanding, talented work force. She identified key issues and I would like to examine them from the perspective of higher education.

Stable Funding

The strong economy we enjoyed during the 1990s was not due to Federal Reserve Board chairman Alan Greenspan or President William J. Clinton or even Bill Gates. It goes back to the commitment the nation made to research following World War II and later during the Cold War. We could even say we owe a lot to that podium-thumping Soviet leader Nikita Krushchev, who challenged us to a space race and an arms race. In the process he stimulated the federal government to invest seriously in university research. We might be in need of a modern-day Krushchev to make the case for us again. (Perhaps that man is Osama bin Laden.)

It is no surprise that the vast majority of the early federally funded research at universities was for defense. But over the years, results from this work spun out into the broader economy and proved to be the seed for the harvest of today, especially in the fields of physics and electrical and computer engineering. Today's semiconductors emerged from federally funded university research in quantum mechanics conducted during the 1940s. Computer networks began as a defense tool. The Defense Advanced Research Projects Agency and the National Science Foundation provided the funding in the 1960s and 1970s to create the Internet from which we have gained so much.

I serve on the executive committee of the Council on Competitiveness, and we track patents as one way to measure innovation. Our work shows that nearly three-fourths of industrial patents cite publicly funded research as the basis for their invention. Under the surface eddies that swirl around the issuance of patents for new products and services, there are deep, steady currents of frontier research and knowledge discovery that run through decades. These currents feed the applications and commercialization efforts that are taking place on the surface. To continue to benefit from innovation, we must have stability and continuity of investment in fundamental research over time.

When we look at funding for science and technology research in the federal budget, we often compare dollar amounts from one year to the next. By that measure, we have seen growth in federal support, which would seem to indicate that funding is stable. But when we look beneath the surface, that stability is not quite so clear. For example, a primary goal of research in science and technology is to stoke our economy. The measure of our economic productivity is the gross domestic product (GDP). If we compare the size of the federal investment in research and development (R&D) to the size of the gross domestic product over the years, we see a picture of decline and erosion. Measured as a percentage of the GDP, federal support for research and development has decreased from 1.5 percent of the GDP in 1987 to about 0.6 percent in 1999. Relative to the size of the GDP it is supposed to drive, the size of our research investment has shrunk by almost two-thirds since the mid-1980s. We are clearly enjoying the harvest from the fundamental research of prior decades. But are we fulfilling our responsibility to develop and plant the seed that the next generation will need to maintain economic strength?

America's leadership in the world economy is based on our leadership in research and innovation. But indicators show that we are losing ground. Sweden, Japan, and South Korea now invest more in R&D relative to the size of their GDPs than the United States does. In fact, South Korea has the fastest R&D growth rate in the world, followed by Singapore, Ireland, Australia, Sweden, Italy, Canada, and then, finally, the United States.

While federal support for R&D as a percentage of the GDP has been declining over the past 15 years, industry R&D has held its own. At the same time, industry has been outsourcing more of its peripheral operations, and has increasingly contracted with higher education for its research needs. As a result, the portion of time and effort that research universities spend on industry-sponsored projects is increasing.

Higher education is now the largest single provider of the fundamental frontier research that provides the seed for the economic harvests of the future. We conduct nearly half of it. This research is funded largely by the federal government rather than by industry.

Getting our research funding from private industry is not the same as getting it from the federal government. It is easy to understand why. Frontier research is a highly speculative and unpredictable venture. It is hard to know when and where new discoveries will appear. Not only are the commercial payoffs some way off in the future, but it is hard to see what form they might take. Government is more tolerant of such risk.

When physicist Richard Feynman introduced the field of nanotechnology to the American Physical Society in 1959 (in a lecture titled "There's Plenty of Room at the Bottom") I doubt that anyone envisioned the products that are emerging today as a result. They include, for example, stain-resistant khaki pants, self-cleaning windows, women's cosmetics, and running boards for vans. By the same token, I doubt that General Motors, Eddie Bauer, or Revlon Cosmetics ever thought of investing in the frontier physics research that generated the nanotechnology from which they are now profiting.

But it is difficult for private industry to justify such investments when they must compete in today's global economy. The National Research Council (NRC) estimates that less than five percent of the research expenditures by the computer and semiconductor industries, for example, goes to fundamental research. So it is important to keep an eye on the balance between fundamental, frontier research and the applied research that translates it into usable products and services.

A Balanced Portfolio

We must maintain balance across disciplines in our national research portfolio. As stated above, federally funded R&D overall declined from 1.5 percent to 0.6 percent of the GDP from 1987 to 1999. But this decline is not reflected consistently across the disciplines. Federal investments in life sciences and computing have increased over the past 15 years. The R&D budget for the National Institutes of Health is in the fourth year of a commitment to double it over five years.

At the same time, however, support for research in the physical sciences and engineering has decreased dramatically, and not just relative to the size of the GDP. In fiscal year 1999, chemistry, physics, and chemical, electrical, and mechanical engineering were down by 20 percent or more compared with FY 1993, according to the NRC's *Trends in Federal Support of Research and Graduate Education*. To quote that report, "Reductions in federal funding of a field of 20 percent or more have a substantial impact unless there are compensating increases in funding from nonfederal sources, which does not appear to be the case." Chemistry and atmospheric sciences experienced smaller decreases over the same time, and materials engineering was up only 1.5 percent from FY 1993 to FY 1999.

The problem with advancing some disciplines at the expense of others is that the most important problems and the hotbeds of discovery and innovation are in the gaps between the traditional disciplines. This convergence of knowledge across the disciplines requires that they all move forward together. For example, a significant level of current federal funding is focused on biomedical research. But advances in biomedical research are grounded in fundamental research, not just in biology, but also in chemistry, physics, and chemical and mechanical engineering. All these disciplines provide insight into the operation of living systems. Yet these disciplines are seeing a declining level of federal support.

An Expanding, Talented Work Force

The third component that will determine the effectiveness of science and technology in the future is human capital, both in the work force and in the research lab. The NSF *Science and Engineering Indicators* show that during the 1990s a declining number of students at both the undergraduate and the graduate levels sought degrees in engineering, the physical sciences, math, and computer science.

In a clear demonstration of the connection between research funding and warm bodies, graduate enrollments decreased in fields that experienced cuts in federal research funds and increased in the life sciences where research funding experienced increases. To quote NRC's recent report *Trends in Federal Support of Research and Graduate Education*, "The effect of cutting research is both direct, in reducing the number of research assistant positions, and indirect, in signaling to prospective graduate students that some fields offer poor career opportunities."

Our decrease in student enrollment takes on more dramatic proportions if we put it in a worldwide context. A year or so ago, *The Wall Street Journal* had a front-page chart showing that while the number of American students enrolled in graduate programs in science and engineering has been declining, the number of international students in those programs has been increasing. International students, who are increasingly likely to return home after graduation, now make up over 40 percent of Ph.D. students in science and engineering at American universities.

The NSF *Science and Engineering Indicators* show the United States ranking 10^{th} behind nations as diverse as the United Kingdom, South Korea, France, Singapore, and Canada in the percentage of our 24-year-olds who hold bachelor's degrees in science or engineering. And many of ours do not go on to graduate school. The average annual stipend for graduate students in science and engineering is now half of the average wage of bachelor's degree recipients. This forces many of our bright students to go directly into the work force. If we are unable to develop a strong and growing cadre of research scientists and engineers, then our innovative capacity will be stunted.

Infrastructure for Commercialization

To Rita Colwell's list of stable funding, balanced portfolio, and talent as the keys to effective science research, I would add appropriate infrastructure to help commercialize the results of research. This step provides a tangible demonstration of the benefits that derive from our efforts and helps justify the case for future funding and support. But commercialization is something of a two-edged sword because it requires us to reconcile conflicts of interest and guard against perceptions that universities are more interested in "making money" than in educational pursuits. Even though these waters require care to cross, we should not allow that to keep us from finding appropriate ways to move our research results into the mainstream of society through the private enterprise system.

A crucial component in the universities' ability to help commercialize research results is the Bayh-Dole Act, passed in 1980. Before its passage, the government retained ownership of the intellectual capital produced by the university research it funded. There were no incentives for researchers and no mechanisms for effective technology transfer other than publications and direct interactions between faculty and industry. Before 1980, barely 10 percent of government patents were licensed to industry for commercialization.

When the Bayh-Dole Act was passed in 1980, it enabled universities to take title to intellectual property generated by federally funded research. But three caveats were applied. First, discoveries must be commercialized. Second, after sharing royalties with the faculty inventor, universities must put their share back into research and education programs. Third, the government would pay no royalties on its use of any resulting technologies.

Organizations like the Council on Governmental Relations and the Association of University Technology Managers have been monitoring the changes in commercialization of university research over the past 20 years since the passage of the Bayh-Dole Act. This is what they report:

- The number of universities engaged in patenting and licensing inventions has increased from about two dozen to more than 2,000.

- Over 2,200 new companies have been formed based on the licensing of university innovations.

- New technology commercialized from university research now generates about $41 billion in economic activity a year, accounts for 270,000 jobs, and generates about $5 billion in tax revenues, all without any government expenditure.

- More than 1,000 products on the market today are based on university discoveries.

Of course, all of this increase in activity cannot be attributed exclusively to the effects of the Bayh-Dole Act. But this legislation certainly had a profound influence on improving the climate for technology transfer. And it does not require a government bureaucracy to run it.

In part because of its success, the Bayh-Dole Act has recently attracted the attention of some in Congress and others who feel improvements or modifications might be needed. In this fast-paced world of change, it is reasonable to ask questions about anything after 20 years. But changing something as useful as the Bayh-Dole Act should be considered very carefully.

The Association of University Technology Managers estimates that in 1999 universities earned about $900 million in royalties and other revenues from research commercialization. This level of money attracts attention, as do the large amounts of revenues earned by a few universities on patents related to drug development. But this $900 million figure represents gross revenue, not net revenue, and large drug royalties are the exception rather than the rule.

Universities have to pay for their intellectual property offices and operations. Virtually all research agencies demand that universities put up large sums of matching funds to get the research funding in the first place. As a result, most universities struggle to break even. Often, their royalties simply offset what they spent in the pursuit of patents and licenses.

Still, given the growing commercialization of university research and the growing royalties that derive from the resulting patents and licenses, universities can expect closer scrutiny of the impact of Bayh-Dole and the use of the funds it generates. Universities need to take the initiative to justify their position based on a sound rationale that works for today and in the future. Otherwise, an important incentive to commercialize university research might be altered in fundamental ways to the detriment of innovation and entrepreneurism in the American economy.

Conclusion

The dynamics surrounding our university research enterprise have changed significantly in the last decade. We are now at the point where we need to think clearly about our role in disseminating knowledge for the good of society. Then we must act accordingly. Providing a stable funding base, balancing the portfolio, enhancing support for graduate study by U.S. citizens, and maintaining a platform for commercialization of research results are keys to refocusing a picture that has become fuzzy with time. This will require universities to state their case clearly and to continue to develop mechanisms for positive collaborations with the federal government, state governments, and industry. To do less will result in a near-term loss of competitiveness and a long-term loss of the innovation capacity of our economy.