CHAPTER

University-Industry-Government Partnerships for a 21st century Global, Knowledge-Driven Economy: An American Perspective

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The powerful forces driving change in our world today — demographics, globalization, technology — are also demanding change in the role, character and relationship of knowledge organizations such as research universities, corporate R & D organizations, federal laboratories, and government. A radically new system for creating wealth has evolved that depends upon the creation and application of new knowledge. We are shifting from an emphasis on creating and transporting physical objects such as materials and energy to knowledge itself; from atoms to bits; from societies based upon the geopolitics of the nation-state to those based on diverse cultures and local traditions; and from a dependence on government policy to an increasing confidence in the marketplace to establish public priorities.

The American system of research and advanced education, relying on a partnership between universities, industry and government, has been highly successful over the past half-century in addressing priorities such as national defence and health care. However today's hypercompetitive, global, knowledge-driven economy, characterized by trends such as the outsourcing of production, services and perhaps even innovation, coupled with the off-shoring of knowledge workers, will demand a substantial restructuring of our economies, while raising serious questions about the relevance of our current research and educational paradigms. More specifically, the shift in national priorities from "guns" (the Cold War) to "pills" (the health care needs of an ageing population) and now to "butter" (the innovation necessary to compete in a global, knowledge-driven economy) raises serious questions about the adequacy of our current knowledge infrastructure.

For example, in an increasingly competitive global marketplace, innovation both in the creation of new products, systems and services, and the management of global enterprises has become more important than conventional assets such as financial capital, natural resources and unskilled labour – at least for developed nations. And innovation requires new knowledge (through research), human capital (through education), infrastructure (both physical and cyber) and new policies (intellectual property, anti-trust, tax), all of which depend both on public and private investment and upon the capacity of knowledge institutions such as research universities, corporate R & D, and national laboratories.

This paper will consider the current status, challenges and concerns characterizing the American system for the conduct of research and advanced education, drawn heavily from several recent studies by the National Academies of Science, Engineering and Medicine.

THE AMERICAN KNOWLEDGE INFRASTRUCTURE

The character of today's American research university was shaped some 50 years ago by the seminal report, *Science, the Endless Frontier*, produced by a World War II study group chaired by Vannevar Bush (Bush, 1945). The central theme of the document was that the nation's health, economy and military security required continual deployment of new scientific knowledge; hence the federal government was obligated in the national interest to ensure basic scientific progress and the production of high-quality scientists and engineers.

Rather than attempting to build separate research institutes or academies, the Bush report recommended instead a partnership among universities, industry and the federal government. The federal government would provide research grants to university faculty investigators through a competitive, peer-reviewed system to conduct basic research on the campus, along with contracts to industrial R & D laboratories for more applied research and development aimed at specific objectives (e.g. national defence). Federal support was channelled through an array of federal agencies: basic research agencies such as the National Science Foundation and the National Institutes of Health; mission agencies such as the Department of Defense, the Department of Energy, the National Aeronautics and Space Administration and the Department of Agriculture; and an assortment of other federal agencies such as the Departments of Commerce, Transportation and Labor. Research universities and corporate R & D laboratories were augmented by a number of national research laboratories with specific missions, such as atomic energy or defence research.

Industrial R & D activities, including cutting-edge basic research, were strongly supported by corporate leadership and the investment community who recognized the importance of research to long-term product development and profitability. Additional federal policies were developed to strengthen further this partnership among universities, industry and the federal government, such as the Bayh-Dole Act, which gave universities ownership of the intellectual property developed through federally sponsored research, thereby stimulating the transfer of knowledge from campuses into the marketplace.

Clearly this research partnership among universities, industry and government has been remarkably successful. Federally supported academic research programs on the campuses have greatly strengthened the scientific prestige and quality of American research universities, many of which now rank among the world's best. Furthermore, by combining research with advanced training, it has produced the well-trained scientists, engineers and other professionals capable of applying this new knowledge. The university-industry-government partnership has not only provided leadership in the pursuit of knowledge in the fundamental academic disciplines, but through the conduct of more applied mission- and product-focused research, it has addressed national priorities such as health care, environmental sustainability, economic competitiveness, and national defence. It has laid the technological foundations for entirely new industries such as microelectronics, biotechnology and information technology (National Academy of Engineering, 2003).

Today most current measures of technological leadership, such as the percentage of GDP invested in R & D, the number and productivity of researchers, and the volume of high-tech production and exports, still favour the United States. Yet worrisome trends are appearing that cast doubt over its longer-term scientific and technological leadership. The accelerating pace of discovery and application of new technologies, investments by other nations in R & D and the education of a technical workforce, and an increasingly competitive global economy are challenging U.S. technological leadership and, with it, future U.S. prosperity and security.

SIGNS OF CONCERN

Despite record levels of federal funding for research, most of the increases over the past 25 years have been focused on a single area — biomedical research — that currently accounts for 62% of all federal research funding flowing to university campuses (with 45% to medical schools). In contrast, federal funding for research in the physical sciences and engineering has been relatively stagnant or declining over the same period. Put another way, 30 years ago federal funding of research in physical science, engineering and biomedical research was roughly comparable at $5 billion a year each. Today, physical science and engineering continue to receive $5b. a year and $8b. a year respectively, while biomedical research has ballooned to $28b. a year (U.S. Department of Energy, 2003). While some growth in the latter area is justified both by the research opportunities in life sciences and by the health care needs of an ageing population, there has clearly been a very serious distortion in the federal research portfolio that is driving similar distortion on the campuses in areas such as priorities for investment in capital facilities and student interest — particularly at the graduate and post-doctoral level.

There has been a similar shift in funding by industry and federal mission agencies such as the Department of Defense away from long-term basic research to short-term applied research and product development. The market conditions that once supported industrial investment in basic research at pre-eminent laboratories at AT&T (Bell Labs), IBM, RCA, GE and other giants of corporate America have been replaced by the demands of institutional investors for cost-cutting and near-term profitability. Ironically this shift has occurred at a time when the federal share of the nation's R & D activity has declined from 75% to less than 25%, implying that the increased emphasis on applied R & D is coming at the expense of fundamental long-term research.

The pressures on discretionary spending associated with a growing federal budget deficit pose a further challenge. Although the federal 2006 Fiscal Year (FY) R & D budget will amount to $132b., the majority of these expenditures (and all of the growth) will be for defence and homeland security, consisting primarily of advanced development in areas such as weapons systems and counter-terrorism measures. In fact, the magnitude of federal investment in R & D that actually creates new knowledge has been stagnant at roughly $60b. for the past three years. This federal funding is likely to decline still further as the administration seeks deep cuts in the research accounts of mission agencies such as the DOD, DOE and NASA (except for manned spaceflight) over the next several years. Of course, this is occurring at a time when many of our economic competitors are ratcheting up their investments in research capacity and graduate education.

The availability of adequate human resources — particularly scientists and engineers — is also a growing concern (National Academy of Engineering, 2004). While there is always an ebb and flow in college enrolment in various disciplines, there has been a noticeable decline in student interest in careers in science and engineering over the past two decades. In the United States, engineering graduates dropped from 85,000 per year in 1985 to 65,000 in the mid-1990s, recovering only recently to 75,000 (National Science Board, 2004). To put this in context, the United States currently accounts for less than 8% of the new engineers produced globally each year, while China and India are each currently producing roughly 200,000 engineers per year. In the United States, only 4.5% of college students major in engineering; in Europe, this rises to 12%; but in Asia, over 40% of college students major in engineering, which, when combined with the dramatic increase in college enrolments in countries such as China and India, implies that the U.S. is currently producing less than 5% of the world's scientists and engineers. (Wulf, 2004).

In the past the United States has compensated for this shortfall in scientists and engineers to some degree by attracting talented students from around the world. But post 9/11 constraints on immigration policies and an increasingly cynical view of American foreign policy have cut deeply into the flow of international students into our universities and industry (Committee on Science, Engineering and Public Policy, 2005). This situation is compounded by our nation's inability to address the relatively low participation of women and under-represented ethnic minorities in science and engineering. As presidential science advisor, John Marburger, concluded: "The future strength of the U.S. science and engineering workforce is imperilled by two long-term trends: First the global competition for science and engineering talent is intensifying, such that the U.S. may not be able to rely on the international science and engineering labour market for its unmet skill needs. Second, the number of native-born science and engineering graduates entering the workforce is likely to decline unless the nation intervenes to improve success in educating S & E students from all demographic groups, especially those that have been under-represented in science and engineering careers."

THE LAW OF UNINTENDED CONSEQUENCES

So how did this happen? Why, at a time when many other nations are investing heavily in building their research and education capacity in science and engineering, is investment in new knowledge and human capital largely stagnant or even declining in the United States? To some degree, it was a consequence of the well-known law of unintended consequences.

For example, although the United States has rarely had a top-down R & D policy successfully proposed and achieved at the presidential level (perhaps with the exception of the Apollo mission to the moon), its democratic system of government is generally responsive to the will of the electorate, at least over the long term. In one sense, then, it is not surprising that as national priorities shifted from the Cold War to the health of an ageing population, there should be a corresponding shift of federal R & D priorities from the disciplines key to national defence such as physical science and engineering to the biomedical sciences. Using this argument, one might also anticipate that as national priorities are focusing increasingly on economic competitiveness in a global economy – perhaps momentarily disrupted by the 9/11 attack – there would be a corresponding shift to funding those disciplines critical to technological innovation such as information technology and systems engineering.

However, the current process for appropriating federal dollars, both in the administration and in Congress, is distributed among a complex array of constituencies and committees that can be easily hijacked by special interest groups and susceptible to lobbying from powerful interests such as the pharmaceutical industry. This highly political approach to federal investment in science and technology is aggravated by the rampant growth of earmarks to the appropriation bills by aggressive institutions aided by skillful lobbyists and sympathetic Congressional representatives that bypass competitive peer review and erode research funding still further (e.g. over $3b. in FY2005 alone).

Yet another example of unintended consequences is provided by the antitrust rulings that led to the breakup of monopolies such as AT&T, thereby subjecting important national research assets such as Bell Laboratories to serious decline in the face of the demands of shareholders more focused on short-term profits than long-term competitiveness. This erosion in the capacity of industry to conduct long-term research will only be aggravated by the accountability demanded by legislation such as the Sarbanes-Oxley Act in the wake of the Enron scandal.

Federal agencies and national laboratories have experienced similar pressures to shift away from basic research toward more short-term development activities. Even DOD's Defense Advanced Research Projects Agencies (DARPA), which supported much of the long-term basic research in electronics, computers and networking that led to technologies such as the Internet, are now constrained to 18-month project cycles. Many national laboratories long ago lost their primary missions (e.g. nuclear power development) and are today drifting without compelling priorities, sustained only by the political pressures of their "marching armies" (e.g. the thousands of scientists and engineers they employ).

Another concern arises from the remarkable success of the Bayh-Dole Act of 1980, designed to stimulate the transfer of intellectual property arising from federally sponsored research into the commercial marketplace. Prior to Bayh-Dole, fewer than 250 patents were issued to universities each year; in 2003, 3,629 patents were issues to U.S. universities, yielding over $1b. in licensing income and 248 start-ups with very positive economic consequences for the nation. (National Science Board, 2004).

Yet this strong incentive to transfer technology from campus research into the marketplace has also infected the research university with the profit objectives of a business, as both institutions and individual faculty members attempt to profit from the commercial value of the products of their research and instructional activities. Universities have adopted aggressive commercialization policies and invested heavily in technology transfer offices to encourage the development and ownership of intellectual property rather than its traditional open sharing with the broader scholarly community. They have hired teams of lawyers to defend their ownership of the intellectual property derived from their research and instruction. On occasions some institutions and faculty members have set aside the most fundamental values of the university, such as openness, academic freedom and a willingness to challenge the status quo, in order to accommodate this growing commercial role of the research university (Press and Washburn, 2000) (Stein, 2004).

Ironically, the complex cacophony of intellectual property licensing negotiations, which vary not only from university to university, but even from company to company, has created a backlash of frustration on the part of American industry. Many major companies are now beginning to outsource their R & D activities along with their university relations to other nations with more attractive and coherent licensing policies.

Yet this is just one example of an even more basic economic transformation likely to reshape in very significant ways the relationship between universities, industry, and government: global sourcing. A new commercial ecosystem is evolving where enterprises will distribute not only production but also creative activities such as design, R & D, and innovation across global networks. As the recent report of the National Intelligence Council's 2020 Project has concluded: "The very magnitude and speed of change resulting from a globalizing world – apart from its precise character – will be a defining feature of the world out to 2020. During this period, China's GNP will exceed that of all other Western economic powers except for the United States, with a projected population of 1.4b. India and Brazil will also likely surpass most of the European nations. Globalization – growing interconnectedness reflected in the expanded flows of information, technology, capital, goods, services, and people throughout the world – will become an overarching mega-trend, a force so ubiquitous that it will substantially shape all other major trends in the world of 2020." (National Intelligence Council, 2005).

Of course, developed nations have long experienced the outsourcing of production and low-skill jobs to other nations with lower labour costs. But today we see the off-shoring of high-skill, knowledge-intensive service jobs to nations like India and China, characterized by both low wages and, perhaps more importantly, an increasingly skilled technical workforce, stimulated by major investments in science and engineering education. Activities such as product design and R & D, which used to be critical components of a company's core competency, are now distributed across global networks. In fact, even innovation itself, long considered the most significant asset of the American business culture, is also being off-shored by many companies. There are growing concerns that such global sourcing, driven not only by low cost but as well technological leadership, could lead to the erosion of the capacity of our nation to add any true value in the business enterprise, beyond financial gymnastics. (Friedman, 2005).

In a global, knowledge driven economy the keys to economic success are a well-education workforce, technological capability, capital investment and entrepreneurial zeal — a message well-understood by developed and developing nations alike throughout the world that are investing in the necessary human capital and knowledge infrastructure.

WHAT TO DO?

So, where is the United States headed? Will we face the same decline and fall that have characterized other brief hegemonies, as we outsource and offshore all of the value-added needed by our economy — at least until China and others stop buying dollars. Or will our concern in the wake of 9/11 drive us inwardly toward the Fortress America characterizing the early 20th century. Or perhaps even more frightening (at least to many), will the United States embark on a "democratize the world" mission. Perhaps we will go to Mars...

Whatever our national priorities and future visions, it is becoming painfully clear that our current partnerships, programs and policies for the conduct of research and advanced education are sorely in need of overhaul. Study after study — from our National Academies, from federal organizations such as the National Science Board and the President's Council of Advisors on Science and Technology, from scientific organizations such as the American Association for the Advancement of Science, from industrial groups such as the Council on Competitiveness and from the media itself — have raised a cacophony of concerns about the possible erosion of U.S. science and technology, now converging into a strong chorus demanding both transformation of and reinvestment in this important enterprise.

Ironically, almost a decade ago, a National Academy of Sciences study suggested a blueprint that addresses many of the concerns today. The report, *Allocating Federal Funds for Science and Technology* (Committee on Criteria for Federal Support of R&D, 1995), aimed at making the research funding process more coherent, systematic and comprehensive; ensuring that funds were allocated to the best people and the best projects; ensuring that sound scientific and technical advice guided the allocation process; and improving the federal management of R & D activities. The report recommended, as a guide to federal research policy, that the nation should achieve and maintain absolute leadership in research areas of key strategic interest to the nation (e.g. those directly affecting national security or economic competitiveness), and should furthermore be among the leaders in all other scientific and technological areas to ensure that rapid progress could be made in any area in the event of technological surprises ("ready to pounce"). According to this principle, for example, it is clear that the nation should strive to be the absolute leader in areas of strategic importance such as biotechnology, nanotechnology and information technology. However it need only be among the leaders in an area like high-energy physics (implying, of course, that the United States should be prepared to build expensive accelerators through international alliances rather than alone as in the ill-fated Superconducting Supercollider).

This report also recommended the use of an alternative to the federal "R & D" budget category that more accurately measured spending on the generation of new knowledge: The Federal Science and Technology (FS&T) budget was designed to reflect the true federal investment in the creation of new knowledge and technologies by excluding activities such as hardware procurement and the testing and evaluation of new weapons systems. In contrast to the federal R & D budget, roughly $130b. today, the FS&T budget amounts to roughly $60b., and has remained relatively stagnant or declining for many years, strong evidence of the erosion in federal investment in true knowledge-generating research (Committee on Science, Engineering and Public Policy, 2002). From these perspectives, it is clear that the current U.S. research portfolio neither provides the magnitude of investment or disciplinary balance necessary to address the nation's key priorities — national security, public health, environmental sustainability, or economic competitiveness.

There is a deeper concern: maintaining the nation's leadership in technological innovation. As the source of new products and services, innovation is directly responsible for the most dynamic sectors of the U.S. economy (Council on Competitiveness, 2004). Here our nation has a great competitive advantage, since our society is based on a highly diverse population, democratic values, and free-market practices. These factors provide an unusually fertile environment for technological innovation. However, history has also shown that significant public investment is necessary to produce the essential ingredients for innovation to flourish: new knowledge (research), human capital (education), infrastructure (facilities, laboratories, communications networks), and policies (tax, intellectual property). Other nations are beginning to reap the benefits of such investments aimed at stimulating and exploiting technological innovation, creating serious competitive challenges to American industry and business both in the conventional marketplace (e.g., Toyota) and through new paradigms such as the off-shoring of knowledge-intensive services (e.g. Bangalore).

A recent National Academy of Engineering study on the capacity of U.S. engineering research summarizes the challenges facing our nation:

"U.S. leadership in technological innovation seems certain to be seriously eroded unless current trends are reversed. The accelerating pace of discovery and application of new technologies, investments by other nations in research and development (R & D) and the education of a technical workforce, and an increasingly competitive global economy are challenging U.S. technological leadership and, with it, future U.S. prosperity and security. Although many current measures of technological leadership — percentage of gross domestic product invested in R & D, number of researchers, productivity level, volume of high-technology production and exports — still favor the United States, worrisome trends are already adversely affecting the U.S. capacity for innovation. These trends include: (1) a large and growing imbalance in federal research funding between the engineering and physical sciences on the one hand and biomedical and life sciences on the other; (2) increased emphasis on applied R & D in industry and government-funded research at the expense of fundamental long-term research; (3) erosion of the engineering research infrastructure due to inadequate investment over many years; (4) declining interest of American students in engineering, science, and other technical fields; and (5) growing uncertainty about the ability of the United States to attract and retain gifted engineering and science students from abroad at a time when foreign nationals constitute a large and productive component of the U.S. R & D workforce." (National Academy of Engineering Committee, 2005, p. 1).

The report concludes: "The United States is at a crossroads. We can either continue on our current course — living on incremental improvements to past technical developments and buying new, breakthrough technologies from abroad — or we can take control of our destiny and conduct the necessary research, capture the intellectual property, commercialize and manufacture the products and processes, and create the high-skill, high-value jobs that define a prosperous and secure nation."

The world and the structure of academic research have changed greatly since Vannevar Bush first proposed the partnership among government, universities and industry that has been so effective in the United States. As Friedman stresses, today "intellectual work and intellectual capital can be delivered from anywhere — disaggregated, delivered, distributed, produced and put back together again. The playing field is level. The world is flat! Globalization has collapsed time and distance and raised the notion that someone anywhere on earth can do your job, more cheaply." (Friedman, 2005). Yet the basic principles undergirding the research partnership among government, universities and industry remain just as compelling as they did half a century ago: national interests and global competitiveness require investment in creating a highly educated and skilled workforce as well as an environment that stimulates creativity, innovation and entrepreneurial behaviour as the key assets of a knowledge economy.

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