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21st Century Innovation Systems for Japan and the United States: Lessons from a Decade of Change: Report of a Symposium

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21ST CENTURY INNOVATION SYSTEMS FOR JAPAN AND THE UNITED STATES

Lessons from a Decade of Change

Report of a Symposium

Sadao Nagaoka, Masayuki Kondo, Kenneth Flamm, and Charles Wessner, Editors

Committee on Comparative Innovation Policy: Best Practice for the 21st Century

Board on Science, Technology, and Economic Policy

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Preface

Recognizing that a capacity to innovate and commercialize new high-technology products is increasingly a key for the economic growth in the case of tighter environmental and resource constraints, governments around the world have taken active steps to strengthen their national innovation systems. These steps underscore the belief of these governments that the rising costs and risks associated with new potentially high-payoff technologies, their spillover or externality-generating effects and the growing global competition, require national R&D programs to support the innovations by new and existing high-technology firms within their borders.

Innovation can be defined as the transformation of an idea into a marketable product or service, a new or improved manufacturing or distribution process, or even a new method of providing a social service. This transformation involves an adaptive network of institutions that encompass a variety of informal and formal rules and procedures—a national innovation ecosystem—that shape how individuals and corporate entities create knowledge and collaborate to bring new products and services to market. If competitiveness can be defined as the ability to gain market share by adding value better than others in the globalized economic environment, the ability of these actors to collaborate successfully within a given innovation ecosystem gains significance.[1] Recognizing this, policymakers around the world are supporting a variety of initiatives to reinforce their national innovation ecosystems as a way of improving their national competitiveness.

[1]The issue of whether nations, like businesses, can capture market share has been the subject of debate since Adam Smith. A more recent critique can be seen in Paul Krugman, "Competitiveness: A Dangerous Obsession," *Foreign Affairs* March/April 1994.

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In the United States, the proliferation of national initiatives to support innovation highlights the need for better understanding by U.S. policymakers of the objectives, structure, operation, funding levels, and trends characterizing some of the major programs around the world. These programs and associated policy measures are of great relevance to the United States both for their potential impact on U.S. competitiveness and for the lessons they may hold for U.S. programs.

With these objectives in mind, the National Research Council's Board on Science, Technology, and Economic Policy (STEP) has embarked on a study of selected foreign innovation programs in comparison with major U.S. programs. As such, the premise of this study is not to consider the possibility of a pure *laissez-faire* approach to fostering innovation, but rather to recognize the importance of targeted government promotional policies relative to innovation.[2] The analysis, carried out under the direction of an ad hoc Committee, is to include a review of the goals, concept, structure, operation, funding levels, and evaluation of foreign programs designed to advance the innovation capacity of national economies and enhance their international competitiveness.[3]

In Japan, there have been significant new developments in Japanese innovation policies since the 1990s. They include the enactment of the Science and Technology Basic Law in 1995 to promote science and technology in a more systematic and coherent way, a significant increase for funding in the science and technology budget, coupled with major institutional reforms in national universities and research laboratories, measures to strengthen industry and academic science partnerships, including the enactment of the Japanese version of the Bayh-Dole Act, and a significant strengthening of intellectual property rights protection. The most important reason for these changes was the recognition of policy makers that Japan needed to strengthen its innovation capability, as an engine of economic growth, given that the catch-up phase of Japanese economic growth was over. The policy priority on innovation increased as the stagnation in Japan's economy extended over almost a decade.

[2]Government programs to promote promising technologies are a well-known and longstanding practice. See, for example, Vernon W. Ruttan, *Technology, Growth, and Development: An Induced Innovation Perspective,* Oxford, UK: Oxford University Press, 2000. For a critique of Ruttan, see Richard Lipsey's review of this book in the *Journal of Economic Literature* 5(2):439-442, June 2007.

[3]Thus, while cognizant of the role of DARPA, and more broadly the Department of Defense, in the U.S. innovation system, the focus of the conference was on civilian technology programs that operate closer to market than does DARPA. In addition, as Alic and Branscomb et al. have described in *Beyond Spin-off*, the earlier military driven model of U.S. innovation is no longer as effective as it once was. DARPA funding of advanced technologies, particularly in IT, have had enormous impact, although largely on platform technologies that had wide and profound spillovers. Indeed the emergence of China and certainly India in the global economy attests to the impact of the Internet, to which DARPA made major contributions. See John A. Alic, Lewis M. Branscomb, Harvey Brooks, Ashton B. Carter, and Gerald L. Epstein, *Beyond Spin-off: Military and Commercial Technologies in a Changing World*, Boston, MA: Harvard Business School Press, 1992.

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THE CONTEXT OF THIS REPORT

In the United States, since 1991 the STEP Board has undertaken a program of activities to improve policy makers' understanding of the interconnections among science, technology, and economic policy and their importance to the American economy and its international competitive position. The Board's interest in comparative innovation policies derives directly from its mandate.

This mandate has previously been reflected in STEP's widely cited volume, *U.S. Industry in 2000,* which assesses the determinants of competitive performance in a wide range of manufacturing and service industries, including those relating to information technology.[4] The Board also undertook a major study, chaired by Gordon Moore of Intel, on how government-industry partnerships can support the growth and commercialization of productivity enhancing technologies.[5] Reflecting a growing recognition of the importance of the surge in productivity since 1995, the Board also launched a multifaceted assessment, exploring the sources of growth, measurement challenges, and the policy framework required to sustain the New Economy.[6]

The current study on Comparative Innovation Policy builds on STEP's experience to develop an international comparative analysis focused on U.S. and foreign innovation programs. The analysis will include a review of the goals, concept, structure, operation, funding levels, and evaluation of foreign programs similar to major U.S. programs. Among other initiatives, this study will convene senior officials and academic analysts engaged in the operation and evaluation of these programs overseas to gain a first-hand understanding of the goals, challenges, and accomplishments of these programs.

In Japan, the research on the innovation process and policy has become very important in the midst of increasing government commitment to the innovation policy. In particular, after reviewing several research proposals made by various institutions, the government asked the National Institute of Science and Technology Policy (NISTEP), the Ministry of Education, Culture, Sports, Science and Technology, to conduct a comprehensive review to see the effects of the First and Second Science and Technology Basic Plans in 2003. NISTEP spent two years to conduct this review. The staff of NISTEP, cooperating with outside think tanks,

[4]National Research Council, *U.S. Industry in 2000: Studies in Competitive Performance,* David C. Mowery, ed., Washington, D.C.: National Academy Press, 1999.

[5]This summary of a multi-volume study provides the Moore Committee's analysis of best practices among key U.S. public private partnerships. See National Research, *Government-Industry Partnerships for the Development of New Technologies: Summary Report,* Charles W. Wessner, ed., Washington, D.C.: The National Academies Press, 2003. For a list of U.S. partnership programs, see Christopher Coburn and Dan Berglund, *Partnerships: A Compendium of State and Federal Cooperative Programs,* Columbus, OH: Battelle Press, 1995.

[6]National Research Council, *Enhancing Productivity Growth in the Information Age: Measuring and Sustaining the New Economy,* Dale W. Jorgenson and Charles W. Wessner, eds., Washington, D.C.: The National Academies Press, 2007.

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analyzed how public funds were spent, how science and technology systems, such as funding channels, were changed, what outputs, such as research papers and patents, were created, what were the outcomes and impacts of the two Plans in regions and the society, etc. In conducting this exercise, NISTEP employed international comparisons against the United States and European Union countries. The other research institutions, such as Research Institute of Economy, Trade and Industry and the Institute of Innovation Research of Hitotsubashi University, have also undertaken a number of innovation related studies, including that on the research consortium and on the interaction between innovation and intellectual property rights.

Based on the activities mentioned above both in Japan and the United States, in January 2006, a major international symposium on "21st Century Innovation Systems for the United States and Japan: Lessons from a Decade of Change" was organized by NISTEP and STEP and was held in Tokyo in cooperation with the Institute of Innovation Research of Hitotsubashi University.[7] The Symposium was opened by two distinguished addresses. Rep. Donald A. Manzullo, Chairman of Committee on Small Business, U.S. House of Representatives, made a speech titled "Challenges in the U.S. Innovation System." Professor Taizo Yakushiji, a Member of the Council for Science and Technology Policy, made an address titled "Evolution and Challenges to the Innovation Systems in Japan—Innovation by Emulation." This Symposium reviewed government programs and initiatives to support the development of small- and medium-sized enterprises, government-university-industry collaboration and consortia, and the impact of the intellectual property regime on innovation. While the symposium could not cover every issue in this complex and changing area, every effort was taken to ensure that the issues selected were significant for the two innovation models being discussed. This book brings together the papers presented at the conference and provides a historical context of the issues discussed at the symposium.

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We are grateful for the participation and the contributions of the Defense Advanced Research Projects Agency, the National Institute of Standards and Technology, the Office of Naval Research, Sandia National Laboratories, the National Institute of Science and Technology Policy, and the Institute of Innovation Research of Hitotsubashi University.

We are grateful for the members of the Planning Committee in Japan, chaired by Masayuki Kondo and including Sadao Nagaoka, Akira Goto (Professor, Research Center for Advanced Science and Technology, University of Tokyo), Hiroyuki Tomizawa, and Masaru Yarime (both of whom are the Senior Research Fellows at the Second Theory-oriented Group, NISTEP) for organizing and imple-

[7]The symposium agenda and planning committee can be found in Appendix A. Unless noted otherwise, all affiliations listed in this volume are as of January 2006.

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menting the conference. We are also thankful for the support of the staff of the NISTEP and of the Institute of Innovation Research of Hitotsubashi University for their key role in organizing the conference.

NRC REVIEW

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Academies' Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for quality and objectivity. The review comments and draft manuscript remain confidential to protect the integrity of the process.

We wish to thank the following individuals for their review of this report: Arthur Alexander, Georgetown University; William Bonvillian, Massachusetts Institute of Technology; Randall Goodall, SEMATECH; Thomas Howell, Dewey & LeBoeuf LLP; and Nicholas Vonortas, The George Washington University.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the content of the report, nor did they see the final draft before its release. Responsibility for the final content of this report rests entirely with the author(s) and the institution.

Sadao Nagaoka   Masayuki Kondo   Kenneth Flamm   Charles Wessner

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I

INTRODUCTION

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Introduction

The Chrysanthemum Meets the Eagle: The Co-evolution of Innovation Policies in Japan and the United States

Sadao Nagaoka
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When the U.S. Navy sailed into Tokyo Bay prior to the U.S. civil war, technology was a key element on the national policy agendas in both nations. The military were the primary U.S. government patron for technological innovation. In the early 19th century, the U.S. Army had invested substantial resources in developing the technology required to mass produce firearms with interchangeable parts. This effort had played an important role in the development of the "American system of manufactures," which fostered the growth of machine tools and trained machinists in the U.S., and had already begun to propel American manufacturing technology to the fore in global competition by the time Commodore Perry arrived in Japan. In the last quarter of that same century, the U.S. Navy worked closely with the U.S. steel industry to secure access to European know-how in high performance steel, needed in the manufacture of advanced armor plating for American warships, and underwrote the development of U.S. steel makers' capabilities in high quality steels.

During World War I, the Army acted to create an American aircraft industry virtually overnight, where previously there had been none. During that very same war, the Navy became concerned with the security of the long distance radio communications that had become essential to command and control in naval warfare. In the 1920s, it stepped in to create a patent pool for all major American radio patents, and formed industrial giant RCA to serve as guarantor that leading edge radio technology would remain in American hands.

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FIGURE 1 Photograph taken on the Washington Navy Yard when the first official delegation from Japan visited the United States in 1860.
SOURCE: <*http://www.history.navy.mil*>.

World War II was a war that was ultimately won by disruptive advances in technology—the first electronic digital computers, radar, nuclear weapons, among other advances. For the first time, the entire scientific enterprise in the United States—in universities, in industries, in research labs—was mobilized and harnessed to the war effort, developing new technologies for military use. What had been episodic support by the government for the development of technologies critical to defense was transformed into a broad and sustained commitment. The wartime compact between American government and industry, to team in developing new technology to serve the national defense, was sustained into the Cold War that followed.

In the United States, many of the great research universities that were to become the backbone of the U.S. innovation system had developed in part with subsidies from the Federal government, as grants of land to the states. One explicit mission given to the land grant colleges was to serve in advancing the useful technical arts, and by the early twentieth century, many land grant schools—MIT, for example—had established important outreach programs that connected their faculty and students to industry. The role of the military in supporting technological development useful for defense had already been well established, but advances in medical technology had also played an important role during the Second World War, and after the war, a large scale program of research grants to universities

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through the civilian National Institutes of Health was also ramped up. While the United States in the middle of the nineteenth century had relatively weak protections for intellectual property (like many other developing economies), by the beginning of the twentieth century, with its growing technological prowess, U.S. industry was supporting much stronger protections for IP.

In late nineteenth century Japan, events took a different, but parallel course. Japan—living in self-imposed isolation from foreign contact for centuries—was now faced with the new problem of an Asia increasingly patrolled by foreign military forces armed with state-of-the-art technology, delivered by sophisticated and technically advanced national industries at home. In order to preserve its independence in an epoch of unrestrained European colonial expansion, it was imperative to achieve parity with the foreign technology it faced, and create modern institutions that would support and deliver the technologically advanced industrial base required to maintain a first rate military. A crash industrialization program in the late nineteenth and early twentieth centuries was successful in achieving this goal.

In the pattern of development in Japan and the United States in the late nineteenth century can be seen many of the features that were to shape the interplay between the U.S. and Japanese innovation systems in the late twentieth century. In Japan, the tradition of scanning the globe for the best available technology, then importing, adapting, and improving the foreign technology, was born out of the necessities of its crash industrialization program. A relatively weak system of intellectual property protections was natural, given its position mainly as an importer of foreign technology. The government took an active role in subsidizing and supporting the industrial infrastructure it strove to develop in the national interest. A strong and highly capable, elite bureaucracy was created to coordinate and support the efforts of the private sector in reaching this target. Japan's drive for industrialization and the adoption of Western technology led to the establishment of its national university system and the founding of elite private universities, like Keio and Waseda, modeled after institutions their founders had observed abroad.

World War II was enormously costly for Japan and Japanese industry, and much of the early postwar history of Japanese innovation policy marked a rebuilding of the institutions that had led its earlier drive to industrialization. Rapidly importing and adapting foreign technology was once again key, as Japan strove to rebuild a modern, technologically advanced economy out of the wartime rubble.

The United States, perceiving a newly minted peer technological competitor in Japan in the 1980s, undertook some major changes and policy experiments, some of which were intended to copy perceived successes in postwar Japanese innovation policy. These changes in the United States had visible effects, and in the 1990s, perceptions of American success led Japan to alter some of its innovation policies and institutional arrangements. This co-evolution of innovation policies in the United States and Japan continues today.

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CHANGES IN U.S. INNOVATION POLICIES IN THE 1980s

Japanese technological capabilities first came onto the U.S. radar screen in the late 1950s, when the Japanese electronics industry succeeded in mastering the production of transistors for use in consumer electronics. To some extent, Japanese success in this arena was dependent on U.S. antitrust policy—as a price for dropping its antitrust litigation against AT&T, the Justice Department had required AT&T to license critical patents on the transistor for a reasonable fee to all comers, a mandate interpreted to include foreign companies. Massive U.S. imports of Japanese transistors, primarily assembled into inexpensive consumer electronics—like transistor radios, provoked the first public campaign against high-tech Japanese imports. In a preview of debates to come, the U.S. electronics industry divided over how to react—some component makers called for restrictions on Japanese imports, while the more advanced producers of the highest tech devices (high performance silicon transistors, and early integrated circuits) argued that the key was to invest in newer, more advanced technology, leaving more mature, and hence less profitable, products for followers—like the Japanese—to fight over.

Through most of the 1960s and early 1970s, a series of high-tech products—primarily in consumer electronics, and including televisions, then calculators, then digital watches, fell into this cycle of American product innovation, followed by Japanese imitation, adaptation, and improvement. The cycle time between an initial American innovation and successful Japanese improvement, and ultimately, market dominance, seemed to get shorter and shorter. A similar story also played out in a product with a distinctly more mature and less high-tech character, the automobile. The common denominator in both cases was that Japanese improvements seemed to typically focus on continuous improvement of manufacturing processes and product quality, and use in delivery of a higher quality product at lower cost. An explosion of interest, and books, on Japanese manufacturing techniques, and Japanese industrial policies, was highly visible in U.S. industrial and policy circles in the late 1970s and early 1980s.

The result was a series of trade battles over Japanese exports over this period. In addition to the more obvious weapons of trade policy—dumping cases, retaliatory tariffs and quotas—some more creative armaments were also deployed. Japanese exporters of high-tech products into U.S. markets were sued over infringement of patents, through the Federal courts and through the U.S. International Trade Commission. Others focused on Japanese use of home market protection as an indirect method of subsidizing its high-tech industry, and urged that political pressure be applied to Japan to lower the formal and informal barriers surrounding its high-tech markets, particularly for semiconductors and computers, where U.S. firms seemed to hold a clear technical lead.

A seminal event for U.S. innovation policy was Japanese success in the global market for leading edge semiconductor memory chips in the late 1970s and early 1980s (see Flamm 1996). These memory chips, DRAMs (dynamic random access memories) were the technology driver for the entire semiconductor industry—the

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highest volume product, making use of the most advanced available manufacturing equipment. U.S. DRAM producers were shocked by the rapid advance of Japanese producers into manufacture of the highest tech current generation chips in the early 1980s. Worse yet, customers were reporting that the reliability and quality of the Japanese chips exceeded that of the U.S. product. Even worse, the Japanese DRAM makers in some cases seemed to be selling at prices below U.S. producers' costs, and were using Japanese production equipment that seemed better than that available to U.S. makers.

In addition to the now-traditional trade policy remedies, many U.S. academics and policy analysts focused on the apparent success of some of the strategies used by Japan to move to the leading edge. The superior DRAM manufacturing technology, in particular, was perceived by many in industry to be linked to cooperative government-industry R&D projects that had been organized by the Japanese government in the 1970s. Elements of these projects included joint labs, supported by both government and industry funds, to which companies sent R&D personnel; the participation of elite government labs in these joint R&D programs; and dissemination of research outcomes on a preferential basis among the membership of the joint R&D consortia. The success of Japanese producers in employing these strategies in their rapid ascent to the leading edge of semiconductor technology led many in the U.S. industrial and the policy communities to urge that similar steps be taken in the United States.

A number of concrete legislative measures were passed in the 1980s to facilitate these suggestions, and fundamentally altered the contours of U.S. innovation policy. The first was the passage of the Stevenson-Wydler Technology Innovation Act, passed in 1980. In an effort to speed the rollout of technology "sitting on the shelf" in government labs, and to facilitate collaboration of government researchers with their industry counterparts under the Stevenson-Wydler Act, government labs created the Cooperative Research and Development Agreement (CRADA) as a legal vehicle to enable government researchers in national laboratories to undertake joint projects with industry. Thousands of CRADAs were active, annually, within a decade of the passage of Stevenson-Wydler.

A second major change was passage of the Bayh-Dole University and Small Business Patent Act, also in 1980.[1] Some had argued that a unique strength of the American innovation system—its great research universities—was contributing too little to its high tech industrial muscle. Great technology was sitting on the shelves of our universities, it was argued, because university professors had too little incentive to patent, and universities too little incentive to license, when

[1]In the United States, as in Japan, the scope of patentable subject matter has increased dramatically. In the case of the U.S., this has in part been a result of judicial decisions since 1980 (such as *Diamond v. Chakrabarty*, which extended patents to microorganisms, and *Diamond v. Diehr*, which held that the execution of a process, controlled by running a computer program was patentable). These rulings, arguably, have made possible the emergence of major new industries such as biotechnology and software.

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funded by government grants. Bayh-Dole granted patent rights on government-funded research grants to universities, and encouraged them to actively transfer technology to private industry.

A third major effort culminated in the National Cooperative Research Act (NCRA) of 1984, which gave U.S. joint industry R&D consortia that registered with government some limited immunity from prosecution under U.S. antitrust laws. Hundreds of U.S. R&D consortia registered under this law in the decade following passage of the act. In 1993, the act was amended and limited antitrust immunity also extended to production joint ventures.

Two consortia formed in the 1980s were particularly well known. One, the Microelectronics and Computer Technology Corporation (MCC) was one of earliest, and ultimately, least successful of these experiments. Japan's announcement of a government-funded, "Fifth Generation" computer R&D program in 1982, explicitly intended to put Japanese computer producers at the leading edge in computer technology, stimulated American fears that the competitive achievements of Japanese producers in DRAMs were about to be duplicated in computers. U.S. electronics firms formed the consortium in late 1982, and lobbied hard for the NCRA as part of the launch process. MCC was mainly privately funded, and had an "a la carte" menu of projects that its members could choose to fund and participate in. It shut down in 2001 and is largely viewed as a failure today.

The second such R&D consortium was SEMATECH, founded in 1987 by U.S. semiconductor makers, with support from the Department of Defense. In response to the alarms being raised about U.S. semiconductor producers no longer dominating the production of the most advanced chips, a 1986 Defense Science Board report had called for DoD to fund an R&D consortium with industry intended to assure U.S. supply of the most advanced chips. With 50/50 industry/defense funding, SEMATECH ultimately settled on a common R&D program designed to improve the manufacturing technology base, funded jointly by all members. SEMATECH was widely perceived by industry to have had a significant impact on U.S. semiconductor manufacturing performance in the 1990s—when its federal subsidy ended in 1997, SEMATECH continued with purely private industrial funding. SEMATECH went international in the late 1990s. It admitted non-U.S. firms as full members, and became the administrative home of a highly influential and innovative contribution to the global innovation system—the International Technology Roadmap for Semiconductors—that has since become a major force coordinating R&D across both industrial and national boundaries within the global semiconductor industry.

A fourth development was a policy change within the National Science Foundation, which historically had marked a sharp boundary between pure academic research and more applied industrial research and development in its funding policies. In 1984, the NSF began to allocate substantial resources to a series of Engineering Research Centers, designed to foster collaboration between university scientists and engineers and their industrial counterparts, in jointly funded efforts.

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A fifth development in the 1980s was a strengthening of the U.S. patent system. The creation in 1982 of a Court of Appeals of the Federal Circuit (CAFC) ultimately tipped the scales toward a vastly more "pro-patent holder" legal system than had previously existed. As the result of the rulings of this court, for example, the patentability of software had been established by the early 1990s, in a departure from earlier practice. While not explicitly targeting foreign competitors, the changes in the patent system in the early 1980s initially were felt most directly by foreign companies with relatively skimpy U.S. patent portfolios to use to countervail lawsuits. Whether these changes in the patent system were ultimately beneficial or detrimental to innovation is today the subject of heated discussion, and patent reform legislation is currently being actively debated in the U.S. Congress.

Finally, the traditional tool of postwar technology policy in the United States—funding of R&D by the Department of Defense—continued to play an important role supporting innovation in some key areas, even as the relative importance of U.S. government funding of R&D continued to decline, dwarfed by a booming high-tech economy. A good example of how this funding had an impact was DoD's reaction to Japan's "Fifth Generation" computer R&D program, described above. At roughly the same time the Fifth Generation program was announced, the three large Japanese electronics firms manufacturing mainframe computers had began to sell substantial numbers of supercomputers at home and abroad. While the Fifth Generation program ultimately was to create little threat to U.S. computer companies (because of other developments in the industry, including the advent of the low cost commodity microprocessor and personal computers based on it), it was one stimulus to a substantial government effort in the United States to accelerate the pace of high performance computing innovation. In the 1980s this program, led by the Defense Department's Defense Advanced Research Projects Agency (DARPA), funded a massive (over a billion dollars of funding over 1983-1993) Strategic Computing Initiative (SCI) that transformed the face of the U.S. supercomputer industry (see National Research Council 2005).

The prospect of serious competition from Japanese computer companies in mainstream markets also led to a series of trade policy responses. In the 1980s, U.S. trade negotiators signed agreements with the Japanese government designed to open up government procurement in Japan (where, as in the United States, the government was the bulk of the market for supercomputers) to U.S. supercomputer producers. In the mid-1990s, the U.S. government also supported U.S. supercomputer makers in bringing an antidumping case against Japanese supercomputer sales in the U.S. market. That case ultimately forced Japanese companies out of the U.S. market until 2003, when a suspension agreement was signed.

While one part of the U.S. government reacted by building walls around the U.S. market, DARPA and its SCI program (in concert with active cooperation and funding from other government agencies) took the opposite tack, attempting to stimulate a burst of innovation that would qualitatively alter the industry.

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The United States could not regain a significant qualitative lead in computing technology (the assumed cornerstone of qualitative superiority for U.S. weapons systems) merely by introducing faster or cheaper computer components, it was argued, since Japanese producers had clearly achieved technological parity, if not some element of superiority, in manufacturing these electronic building blocks at this point.

Instead, the idea was to fund an intense effort to do what had not previously been done—to create a viable new architecture for computers built around massively parallel processors, in contrast to previous approaches to improving supercomputers reliant on the use of ever faster processors. Once the architectural details of how to scale these systems up were worked out, very large parallel machines could be put to work, and supercomputers orders of magnitude faster would confer new qualitative technological advantages to government agencies charged with national security.

Dozens of new industrial flowers bloomed in DARPA's Strategic Computing hothouse from the mid-1980s through the early 1990s. Old players and new ones received substantial support for experiments with new, parallel architectures. While there was an extraordinarily high mortality rate among the companies that took the government funds and developed parallel computer architectures in the 1980s and early 1990s, important architectural and conceptual problems were confronted and parallel systems were made to work, on at least some scale. The lessons learned were absorbed by other U.S. companies (who typically hired key technical staff from defunct parallel supercomputer pioneers). At the end of the day, there were five major new U.S. entrants into the HPC market in the 1990s—IBM, SGI, Sun, DEC/Compaq (merged into HP recently), and Convex/HP—which today have survived with the lion's share (measured in numbers of systems) of the global high performance computing marketplace. All but one of the Japanese producers marketing supercomputers in the early 1980s have basically exited from this market today.

Assessment of the net impact of these changes on the effectiveness of the U.S. innovation system remains the subject of great debate in the United States. There is no academic consensus on the merits of most of the changes described above (see Mowery, Nelson, Sampat and Ziedonis [2001]) on the effects of the Bayh-Dole act and see Jaffe and Lerner [2006] and Hall [2006] on the patent system). However, there clearly has been a "revealed preference" of industry at home and abroad for some of the changes. SEMATECH, for example, continued to be funded by a variety of companies from around the globe, even when there were no government subsidies being collected. A large number of semiconductor and semiconductor equipment companies from around the globe invest significant resources in the International Technology Roadmap for Semiconductors R&D coordination process. Perhaps, most importantly, the perceived success of these U.S. innovation policy changes led Japan to alter some of its policies in the mid-1990s.

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NEW DEVELOPMENTS IN JAPANESE INNOVATION POLICIES SINCE THE 1990s

There have been significant new developments in Japanese innovation policies since the 1990s, strongly influenced by developments in the United States in the 1980s. They include a significant increase for funding in the science and technology budget, coupled with major institutional reforms in national universities and research laboratories, measures to strengthen industry and academic science partnerships, including the enactment of the Japanese version of the Bayh-Dole Act, and a significant strengthening of intellectual property rights protection. The most important reason for these changes was the recognition of policy makers that Japan needed to strengthen its innovation capability, as an engine of economic growth, given that the catch-up phase of Japanese economic growth was over. This perception was widely shared, as shown by the fact that the "Basic Law on Science and Technology," which set the new framework for science and technology policymaking, received unanimous support from all political parties in its enactment in 1995. The policy priority on innovation increased as the stagnation in Japan's economy extended over almost a decade.

The U.S. model of an innovation system has strongly influenced the development of Japanese innovation policy. It is widely believed in Japan that the strong basic research capability of U.S. universities, supported by a high level of federal support, close collaboration between industry and universities, and strong protection of intellectual property rights, have been major contributing factors to the impressive recovery of the U.S. economy since the early 1980s. Japan's perception of the U.S. model of an innovation system may basically be characterized as follows (recognizing that there is no complete unanimity in Japan on the validity of all points). Significant government support for basic or generic research, combined with strong research competition, has enabled U.S. research universities to continuously create scientific discoveries, to retain leadership in global scientific research, attract the best talent in the world, and to accumulate the know-how and human capital in technological frontier areas. Close partnerships between universities and industry have enabled basic scientific capabilities to be transformed into emergent new industries in such areas as biotechnology and IT (information technology). The Bayh-Dole Act, encouraging patent ownership by universities, is believed to have been an important reform stimulating this process, by enhancing the incentives for university professors to engage in technology transfer. Finally, strong protection of intellectual property rights in the United States is thought to have stimulated private R&D investments in risky frontier areas. There are three categories of major policy initiatives taken by the Japanese government which were stimulated by this common interpretation of the U.S. experience.

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Increased Funding and Institutional Reform in Science and Technology Policy

Four major changes in science and technology policy have taken place. First, there has been a significant expansion of government support for research in the budget, prescribed in the Science and Technology Basic Plans (for five year periods), starting in 1996. This happened despite the dire fiscal situation created by continuing economic stagnation. As a result, the ratio of government-funded research to GDP increased over the last decade by 10 percent, from 0.60 percent in the first half of the 1990s, to 0.67 percent in the latter part of the 1990s, and then to 0.69 percent in the first half of 2000s. This compares with 0.83 percent of GDP in the U.S. in 2004, and 0.76 percent in Germany (including military R&D budgets in these figures). The expansion of budgets helped modernize the research facilities in national universities and laboratories, which had become increasingly obsolete due to underinvestment in previous years. The expansion in budgets also enabled a significant amount of new research investment in four priority areas (life science, information and communication, environment and nanotechnology/materials). The share of the R&D budget allocated to these priority areas increased from 29.1 percent in early 1990s to 38.6 percent in early 2000s.

In semiconductors, in particular, Japanese government funding for R&D consortia in this area had dimmed in the face of trade friction with the United States in the 1980s. By the mid-1990s, however, as the U.S. SEMATECH effort seemed to produce results and the competitive fortunes of U.S. semiconductor producers rebounded, the Japanese semiconductor industry began a decline in the face of intensified global competition. Japan launched a new round of industrial, university, and private R&D consortia (with names like SELETE, STARC, and ASET, see Fujimura and Chuma 2006 for some details) that seemed modeled, in part, on SEMATECH and growing government-industry-university collaborative efforts in the United States (which in turn had been based on the perceived success of the earlier Japanese VLSI efforts)!

Second, there have been a number of important institutional reforms. The portion of research funding allocated through competition has increased significantly. It rose almost sixfold during the period from 1991 to 2005. Perhaps most importantly, national universities and national research institutes have been transformed into nonprofit, starting in April 2004. This transformation was motivated in large part by a government target for reductions in the total number of national civil servants by the end of FY2003. However, it has also greatly increased freedom in activities undertaken at Japanese universities. Since national universities and laboratories account for the bulk of scientific and technological research within the Japanese university system, their corporatization should have a long-term effect enhancing flexibility and efficiency in allocation of resources to research.

Since one might expect a significant lag before policy reforms affect research performance in national universities and laboratories, it is too early to assess their impact. However, there are some statistical indicators available. The White Paper

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on Science and Technology (2006) suggests that research performance of Japanese scientists has improved, although the gain may not be impressive. The share of Japanese researchers in both numbers and citations of scientific papers in major scientific journals has increased significantly over the last two decades. Japan's share increased from less than 7 percent in 1981 to around 10 percent in 2004 in terms of the total number of publications (vs. 32 percent for the United States), while it increased from less than 6 percent in 1981 to around 9 percent in 2004 in terms of forward citations (vs. 48 percent for the United States). There remain, however, doubts over the impact of the increases in government expenditures for science and technology in enhancing industrial innovations in Japan to date.

Strengthening University-Industry Partnerships

There once was strong collaboration between universities and industry in Japan (see Kondo 2006). For an example, the Department of Engineering of Tokyo University was established in 1873 as the first engineering department in a university in the world, and played a major role in facilitating the absorption of foreign advanced technology within Japan. University professors also contributed as industrial inventors when the R&D capability of Japanese firms was weak. A good example is the former RIKEN (Institute of Physical and Chemical Research), which successfully incubated a number of new firms in Japan, derived from the inventions of university professors. However, university-industry partnerships had become less important by the late 1960s and 1970s, as the absorptive and R&D capability of Japanese firms strengthened, and as student political activism and turbulence on campus discouraged such partnerships.

The importance of the university has re-emerged in Japanese research in recent years, since it is now expected to play a central role in creating the foundation for industrial innovation. In both the United States and Japan, a university is a major player in basic R&D: accounting for 62.0 percent and 46.5 percent of basic research, respectively, in the United States and in Japan. Thus, improved efficiency in technology transfer from university to industry could play a major role in strengthening science-driven industry. There has been significant institutional reform in Japan designed to pursue this objective.

First, Japanese policymakers have adopted a system of technology transfer based on the principle of university ownership of patent rights, following precedents set out in the Bayh-Dole Act of 1980. In particular, the Japanese Bayh-Dole Act (*The Law on the Special Measures for Revitalizing Industrial Activities*) was enacted in 1999, and permits the retention by the grantees or by contractors of the patents to the inventions derived from publicly funded research. In 1998, legislation to promote the establishment and activities of Technology Licensing Organizations (TLOs) was enacted. Today there exist organizations responsible for technology transfer at all universities with major scientific and engineering research capability. After national universities were incorporated in 2004, most of

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them adopted employment contracts containing an invention disclosure obligation for faculty members, and a transfer of ownership of inventions to the university. As in the United States, an inventor owns patent rights, unless otherwise agreed, even employed by another entity. In the past, it used to be that when a university professor made an invention, patent rights to the invention were transferred to a private company when supported by a research grant, since universities did not have institutional capabilities to support filing, licensing, and enforcing patents.

Second, the government has encouraged collaborative research between industry, and universities, and national research laboratories, as well as the incubation of new business entities derived from these organizations. The government started by helping to establish Collaborative Research Centers in national universities after 1987. The government has also provided research grants targeting university-industry joint research, such as Research Grants for University-Industry Collaborative Research from FY1999. It has also supported the establishment of "Venture" (meaning startup) Business Laboratories (VBLs) after 1995. Finally, it has relaxed regulations preventing national university professors from serving as board members of private companies, particularly when this is helpful for technology transfer (*the Law on the Enhancement of Industrial Technologies* in 2000).

Again, it is too early to assess the full impact of this reform. However, there are hints of some notable changes. The number of annual domestic patent applications by universities and approved TLOs has increased substantially, from 641 in 2001 to 8,527 in 2005. The number of domestic patent applications is at a level equivalent to those by U.S. universities (6,509 in year 2002). In addition, the number of university-industry joint research projects increased from less than 1,500 annually in 1995 to more than 10,000 in 2005. The number of academic industrial spin-offs has also increased significantly (179 in Japan in 2003, compared with 364 in the United States in 2002).

On the other hand, the amount of the licensing revenue received by Japanese universities is still tiny (it was less than 0.5 percent of that in the U.S., according to Kondo 2006), and the number of academic startups which have reached the IPO stage is also tiny. The apparent impact of university research on industrial innovation, measured by these measures, is still very small. Besides a short history of university ownership of patents, this may also reflect the absence of really valuable university inventions, lack of experience in patenting and licensing strategy, and a weak infrastructure for supporting high-technology startups, including limited availability of risk capital and professional services.

Strengthening the Protection of Intellectual Property Rights

While Japan has a long history of intellectual property rights (IPRs) protection (the first full-fledged patent law was enacted in 1885), IPRs protection in Japan has been significantly strengthened since the early 1990s (see Nagaoka 2006). Initially the impetus for such change came from abroad: a U.S.-Japan

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agreement in 1994 and the TRIPs (Trade-Related aspects of Intellectual Property rights) agreement negotiated in creating the World Trade Organization in 1995. Subsequently, however, further changes have been a core domestic reform initiative in Japan. Extensive reforms in Japan in the 2000s include the implementation of the series of action plans coordinated by the Intellectual Property Policy Headquarters headed by the Prime Minister since 2002 (including the enactment of the Basic Law on Intellectual Property in 2003), and the establishment of the Intellectual Property High Court in 2005, with the U.S. Court of Appeals of the Federal Circuit (CAFC) as a model.

Stronger penalties to deter infringement have been a major policy change. The patent law was revised in 1998 to reinforce the private damages system, increase criminal sanctions, and to improve the ability of a patentee to collect evidence of infringement. The amendments introduced a new provision which allows a patentee to presume the amount of damages due to infringement, based on the sales made by an infringer and on the profit rate of the patentee. The law was further amended in 1999, again strengthening the power of a patentee to collect evidence needed to show infringement of a patent.

Second, there has been an expansion of patentable subject matter in the field of computer programs. Although the issue of patentability of software was also a major issue in the United States, given that an algorithm or mathematical formula itself is not patentable, the issue was resolved after the early 1980s in the United States. A major constraint in Japan was that the patent law defines an invention eligible for patent as a "technical idea utilizing natural laws." Reflecting this qualification, a computer program per se was not patentable until 1993, unless it was a part of an invention using hardware. It became patentable in 1997, when recorded in a computer-readable storage medium. In 2000 a computer program itself became fully patentable as a product patent.

Third, the Japanese Supreme Court affirmed the "doctrine of equivalents" in 1998. The Supreme Court ruled, among other things, that "equivalence" should be determined based on technologies available at the time of the infringement, not at the time of the patent application. Thus, the modifications that are obvious given the technologies available at the time of infringement are deemed equivalent. After this ruling, 140 cases involving the issue of equivalence were initiated from 1998 to 2003, and equivalence was recognized by the courts in 15 cases during this period.

Fourth, there was a switch from a pre-grant opposition system to a post-grant opposition system in 1994. The pre-grant opposition system allowed any person to oppose a patent before its grant. It was one source of delays in patent examination in Japan in the early 1990s. Even though it provided a mechanism for a third party to add valuable information on prior art, it also opened the door for a competitor to file opposition without substantial merit. The post-grant opposition system was integrated into invalidation trials after 2004, in order to provide a definitive resolution of conflicts between a patent applicant and opponents.

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The level of IPRs protection in Japan is now widely recognized to be very high. According to the assessment of the level of business software piracy by the Business Software Alliance, Japan is the third lowest (25 percent) in 2006, following the United States (21 percent) and New Zealand (22 percent). The effect on innovation is more difficult to assess. The number of patent examination requests has increased substantially over time. This may indicate that the value of patents have risen, encouraging R&D by Japanese firms. Stronger protection of IPRs may have also strengthened R&D rivalry among firms, and therefore increased R&D. On the other hand, the increasing complexity of patent claims and the increasing number of the requests for patent examinations are putting strong pressure on scarce examination capacity at the JPO. The proliferation of patents and other intellectual property rights can deter rather than promote innovation, by hindering a firm from combining technologies efficiently, due to high transaction costs, holdup risk, and inefficiency in chains of vertical monopolies, given the difficulty of forming and coordinating coalitions to exploit elements of technology owned by different firms.

CONCLUSIONS

There have been significant changes in Japanese innovation policy since the 1990s, influenced by the perceived success of U.S. innovation policy initiatives in the 1980s. These U.S. policy changes of the 1980s in turn were developed in response to increased high tech competition from Japanese firms. Although it will require significantly more evidence and research in order to evaluate the full effects of these changes on both U.S. and Japanese innovation policies, some preliminary observations can be made with respect to the lessons learned, and challenges faced, in both systems since the 1990s.

First, policy reform in Japan has placed priority on strengthening competitive mechanisms in creating innovations—a process that is likely to be one of the main sources of the strength of U.S. innovation system. A significant expansion of competitive research funding, the corporatization of both national universities and public laboratories, and stronger protection of intellectual property rights are best interpreted as important steps in that direction. Since efficient production of knowledge benefits from competition based on the priority of publications and inventions (such competition not only strengthens the intensity of a race for research results, but also helps avoid duplication in research, and facilitates the division of labor in research, both locally and globally), this policy shift seems to be clearly pointed in the right direction.

Second, recent innovation system reforms in Japan also put priority on strengthening university and industry partnerships, another major source of strength in the U.S. innovation system. Although there is a long tradition of university-industry collaboration in Japan at the individual professor level, Japanese universities did not provide institutional support for such collaboration

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until recently. Stronger institutional support for collaborative research, licensing and high-tech startups would strengthen technology transfer from university to industry. Even in the United States, however, how a university can best contribute to industrial innovation remains controversial. Some argue that universities can best contribute through research excellence, transmitted via good scientific publications, and education, and that university and industry partnerships may crowd out these more traditional but core activities. In addition, the effectiveness of these partnerships may depend on the availability of complementary institutions, such as infrastructure for supporting high-technology startups, including the availability of risk capital and professional services. This suggests that a model which works well in the United States may not work in Japan. More research—and experience—may be needed to resolve this complex issue.

Third, while intellectual property rights protection is an important stimulus to innovation, current systems seem far from perfect. How effectively IPR protection serves the goal of innovation may depend on details of institutional design and management. Excessive protection of IPRs under a low standard of non-obviousness or inventiveness may motivate firms to apply for patents for low quality inventions, which can stifle innovation. High standards for granting patent protection, and efficient utilization of the third-party information in patent examination, may be very important. Furthermore, the proliferation of intellectual property rights can deter innovation in technology areas where progress is cumulative, if this exacerbates the "patent thicket" problem. It is important to improve the efficiency of technology markets, including licensing mechanisms for patents related to industrial standards.

Fourth, it is important to strengthen mechanisms for international collaboration. Since knowledge flows do not respect borders and high-tech competition has become global, efficiency in knowledge production and use will often involve global solutions. The success of International SEMATECH in coordinating and accelerating global semiconductor innovation through the international semiconductor technology roadmap is a good example of how a global approach to coordinating private and public innovation investments can be effective. International sharing of databases and international coordination of patent examinations among major national patent offices may also help improve the quality of patent examinations, worldwide, and contribute to an improved global innovation system.

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II

OVERVIEW

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Overview

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Innovation is a key driving force for economic growth and competitiveness in the 21st century. Aiming at strengthening their respective innovative capabilities, the United States and Japan have in recent years sought to encourage university-industry collaboration, protect of intellectual property rights, and stimulate innovation by startup companies. This volume shares the experiences of practitioners and analysts in both countries in exploring the future direction of the U.S. and Japanese innovations systems. It is based on the international symposium held in Tokyo in January 2006 that was convened by the U.S. National Academies' Board on Science, Technology, and Economic Policy and Japan's National Institute of Science and Technology Policy at the Ministry of Education, Culture, Sports, Science and Technology. Held in collaboration with the Institute of Innovation Research at Hitotsubashi University, the Symposium brought together the leading experts from academia as well as senior managers from business and the policy sector in both countries.

The presentations made in each of the six sessions of this symposium are summarized below.[1]

[1]For a summary in Japanese and presentation slides in English, see NISTEP, "21st Century Innovation Systems for the United States and Japan: Lessons from a Decade of Change—International Symposium Report," NISTEP Research Material No. 121.

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SESSION I: REFORM AND NEW DEVELOPMENTS OF THE JAPANESE SCIENCE AND TECHNOLOGY POLICIES SINCE THE 1990s

There have been series of significant reforms of the Japanese science and technology policies since the 1990s. These reforms have been driven by several factors. First is the view—widely shared and supported—that investment in science and technology will be vital to the long-run economic growth of Japan. Supporting this view is the revitalization of economic growth driven significantly by the growth of information technology and biotechnology industries in the United States. Second is the recognition that underinvestment in research infrastructure in national universities and public research institutes over the long run were having negative effects for Japan. The ratio of government research funding to gross domestic product (GDP) in Japan in 1994 was 0.59 percent, compared with 0.88 percent in the United States.

In the chapter on *Technology Policies in Japan*, Professor Akira Goto and Kazuyuki Motohashi provide an overview of how Japanese technology policy has changed in response to the economic and technological challenges of the 1990s. They describe Japan's 1995 "Basic Law on Science and Technology," as well as the policy changes, which revamped the R&D tax credit, reformed technology policy as regards small and medium enterprises (SME), and addressed the corporatization of national universities and research institutes and the promotion of their links with industry. They conclude that the enactment of the Basic Law and the university reform are likely to have long-lasting impacts on the Japan's national innovation system, since they involve significant institutional changes.

In the chapter on *Reform of University Research System in Japan: Where Do They Stand?* Ryuji Shimoda reviews the trends and current issues surrounding the reform of the university research system. He concludes that budget increases have helped universities improve the research environment that had deteriorated over the 1980s and early 1990s. He also notes that the corporatization of national universities has given an unprecedented degree of freedom to university administrators. These reforms already appear to be improving research results, have created a more competitive environment, and are promoting greater industry-university cooperation. Shimoda also points out four emerging issues for Japanese faculty and researchers, university and industry leaders, and policymakers: These are—

- Maintaining the diversity in university research in the environment of the increase of competitive research funding and the strategic prioritization of S&T research by the government. This question is related to the role of institutional appropriations.
- Managing competitive funding by funding agencies. Currently these agencies have only very limited professional staffs, with the evaluation function being delegated mainly to outside experts.
- Managing competitive funding by national university corporations given multiple sources of research funding.

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• Maintaining university openness while protecting propriety information from industry-university cooperation and the intellectual property rights of a university.

SESSION II: GOVERNMENT'S EVOLVING ROLE IN SUPPORTING CORPORATE R&D AND ENTREPRENEURSHIP

While the business supports nearly two-thirds of R&D in both Japan and the United States, appropriability constraints lead to sub-optimal levels of corporate investment. Small innovative firms in the early stages of development face particular challenges in attracting capital. At the same time, the successes of U.S. firms like Microsoft, Intel, AMD, FedEx, Qualcomm, Adobe, Google, Genentech, Chiron, which grew rapidly from small beginnings, offer convincing evidence of the potential contributions of small startup firms. Encouraging more such high-tech startups is important to sustain the enhanced productivity growth rate of the U.S. economy seen over the past ten years.

In the chapter on *Theory and Practice in the Advanced Technology Program,* Stephanie Shipp and Marc Stanley discuss the theoretical rationale for the Advanced Technology Program (ATP). ATP awarded over $2 billion over the course of its existence from 1990 to 2007, funding to early stage technology projects, while encouraging collaboration among firms and other organizations. ATP's project evaluation has been widely recognized as "best practice." Project selection, based on scientific and technological merit, cost sharing, and continued monitoring, ensured support for high-risk R&D projects with potential for broad-based economic benefits.

In the chapter on *Innovation Awards*, Charles Wessner of the National Academies summarizes the policy rationale, major structures as well as management principles of the U.S. Small Business Innovation Research Program (SBIR). This program sets aside 2.5 percent of the extramural R&D budget of eleven federal agencies for innovation awards for small firms (i.e., less than 500 employees). These awards amounted to $2 billion in 2004. Major features of this program include a two-phase structure (feasibility study stage and prototype development stage), early support to new entrepreneurs (one-third of the recipients are new to the program each year), almost full control of the intellectual property by a firm, certification effects based on competitive selection.

While Japan's policies to support SME are well developed, only recently have policy measures been specifically designed to address the needs of startup companies, notes Takehiko Yasuda. These include the removal of minimum capital regulation, educational and informative support to entrepreneurship, financial support measures for startup stage and bankruptcy law reform. He also points out that the government needs to establish a new route of policy transmission for business startups different from the one for existing SMEs.

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SESSION III: R&D COORDINATION AND COLLABORATION—U.S. AND JAPANESE EXPERIMENTS IN SEMICONDUCTOR CONSORTIA

With semiconductor technology becoming increasingly complex, the success of R&D increasingly requires the coordination of many tasks spread over different fields, covering manufacturing, software, material and equipments. Research consortia can play an important role in improving such coordination. The chapter by Kenneth Flamm discusses the experience of the U.S. SEMATECH consortium and its role in semiconductor innovation from a 3-year to a 2-year cycle. Flamm also notes that this acceleration played a significant (if not predominant) role in the decline of quality adjusted price of microprocessors in the late 1990s and early 2000s.

The chapter by Shuzo Fujimura discusses the lessons from the experiences of the Semiconductor Consortia in Japan. Successful consortia requires collaboration at the pre-competitive stage of research When projects that are too close to current generation technologies, firms become reluctant to share competitively sensitive information with the others and are less likely to collaborate effectively. Vertical collaboration among manufacturers, equipment producers and material producers is also important. Fragmentation can hamper the effective integration of knowledge across sectors. Finally, Fujimura notes that effective collaboration requires the protection of proprietary information

SESSION IV: INTERACTION BETWEEN INTELLECTUAL PROPERTY AND INNOVATION SYSTEMS

The patent systems of the United States and Japan face serious challenges. The increase in the number and the complexity of patent applications (patent examination requests in Japan) over the last decade threatens the quality and timeliness of patent examinations. Another emerging issue for the U.S. and Japanese patent systems is the "thicket problem," which can deter innovation in cumulative technology areas by impeding the combination of new ideas and inventions.

Bronwyn H. Hall reviews the changes to the U.S. patent (and innovation) system that have led to the current situation and the rationale behind the calls for reform. Major reform proposals to the U.S. patent system include a change from the "first to invent" standard to "first inventor to file," the elimination of the subjective "best mode" requirement, a reduction of the scope of willful infringement, the limitation of the injunction, the restriction of continuations applications, and the strengthening the post-grant opposition system. She also points out the emerging role of the patent system in facilitating the vertical disintegration of knowledge-based industries and the entry of new firms that possess only intangible assets.

Discussing recent reforms of the Japanese patent system reform, Sadao Nagaoka identifies three issues for the efficient design of a patent examination system: These are capping examination requests for low-quality inventions, promoting efficient use of patent examination resources, and reducing the patent thicket problem. He discusses, in this connection, the relevance of the high

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inventive step standard, the utilization of the third party's information in patent examinations, the need for discipline on continuation (divisional) applications, the use of exemptions on the use of patented information for research on subject matter, and mutual recognition of search results would be very important. He also points out the importance of strengthening the patent policy of standard bodies, including the clarification of the RAND conditions. Furthermore, he points out the importance of facilitating the efficient utilization of disclosed information for R&D and patenting decisions by a firm.

SESSION V: UNIVERSITY-INDUSTRY COLLABORATION

Universities in the United States and Japan account for (respectively) 16.8 percent and 12.6 percent of the total national investments in research and development. Traditionally, universities have played a larger role in basic research: 62.0 percent and 46.5 percent of the basic research in the United States and in Japan. Moving research ideas from the university to the marketplace is a key challenge for innovation-driven growth. In the United States, the Bayh-Dole Act sought to encourage this transfer by giving U.S. universities intellectual property control of their inventions that resulted from federal government-funded research. Bayh-Dole is widely seen in Japan to have had a major positive impact on the U.S. innovation system—leading to the adoption of similar measures in Japan's 1999 Law on Special Measures for Industrial Revitalization, sometimes referred to as the Japanese Bayh-Dole law.

Describing the recent tensions between university and industry over the ownership of intellectual property and the economic terms for licensing sought by universities, Irwin Feller suggests that the industry and university relationship be guided from three general principles—

1. Successful university-industry collaboration should support the mission of each partner. Any effort in conflict with the mission of either party will ultimately fail.
2. Institutional practices and national resources should focus on fostering appropriate long-term relationships between universities and industry.
3. Universities and industry should focus on the benefit to each party that will result from collaborations by streamlining negotiations to ensure timely conduct of the research and the development of the research findings.

In his paper on *University-Industry Partnerships in Japan* Masayuki Kondo describes the significant changes of the university-industry partnership in Japan. Describing the historical relationship, he points out that there was a strong tie between the two before the Second World War. The Department of Engineering of Tokyo University was the first engineering department of a university in the world. The former RIKEN (Institute of Physical and Chemical Research) was

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a very successful national research institute which was managed by university professors that incubated a number of new firms in Japan.

While the university-industry collaboration stagnated in Japan in recent years, especially, compared to that in the United States, a number of policy measures have been taken to strengthen them in recent years. These measures have resulted in the increasing number of collaborative research centers established in national universities, the increase of the number of collaborative research projects and the increase of paper co-authoring and increasing academic spin-offs. At the same time, Japanese universities seek to maintain their identities as centers of higher education and the advancement of human knowledge. In this connection, Kondo concludes, Japanese universities need to establish rules to avoid conflicts of interests at the working level.

SESSION VI: GOVERNMENT AND INDUSTRY COLLABORATION IN TWO SECTORS

In his chapter entitled *The Connected Science Model for Innovation: The DARPA Role,* Bill Bonvillian describes the organizational and managerial characteristics underpinning DARPA effective as an incubator of breakthrough radical innovations. DARPA is a flexible and flat organization of only 100-150 professionals made up of world-class scientists and engineers who have substantial autonomy and freedom from bureaucratic impediments. In addition, it employs a connected science model for innovation, linking fundamental research, development, prototyping, and access to initial production. Furthermore, it organizes a significant part of its portfolio around specific ambitious technology challenges although its projects typically last 3-5 years.

However, today's DARPA faces significant challenges. Increasing importance of addressing the short-term military have resulted in a cut back of university research, making it more difficult to sustain the hybrid approach bridging the gaps between academic research and industry development. In addition, as more of its portfolio focuses on classified "black" research, participation by most universities and non-defense tech firms is not possible. As a result, DARPA has been moving from its history of radical innovation to more incremental innovation.

In the final chapter, Yosuke Okada, Kenta Nakamura and Akira Tohei analyze *Public-Private Linkages in Biomedical Research in Japan*. Moving biomedical research from universities and public research institutions to commercialization is complex. Producing and transmitting scientific knowledge can take a wide variety of forms depending on research areas, organizations, participants, and other factors. Accordingly, there is no set method to organize public support for biomedical research. Public support for research, pro-patent policy measures in particular, must be designed on a case-by-case basis with sufficient attention to the characteristics of institutional and organizational features of the public sector. The authors believe that flexible funding schemes and higher mobility of researchers will be necessary to improve public-private linkage in Japan.

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III

SYMPOSIUM PAPERS

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Technology Policies in Japan: 1990 to the Present

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1. INTRODUCTION

The purpose of this paper is to review Japan's technology policies and their relation to economic conditions during the 1990s and the first half of the 2000s. After the collapse of the so-called bubble economy in 1992, the Japanese economy went into a long and severe recession, which lasted more than a decade. As shown in the Figure 1, in contrast to the booming 1980s, the 1990s was really a "lost decade."[1]

The seemingly obvious cause of this prolonged stagnation was the excess capacity built up during the boom years of 1980s and the resulting sharp decline of investments in plants and equipments in the 1990s,[2] which led to a steep decline in asset prices and to loan defaults. However, the "real side of the economy" may also be responsible. According to Hayashi and Prescott (2002), the real cause of the lost decade was the decline of productivity.[3] Other researchers confirmed that

[1]See Hayashi and Prescott (2002).

[2]The amount of Japan's investment in plants and equipments surpassed that of the United States in the 1980s.

[3]For a contrasting viewpoint, see Hoshi and Kashyap (2004). Adam Posen argues that the prolonged Japanese stagnation was caused by the bubble collapse and inadequate fiscal and monetary responses. See Posen (1998).

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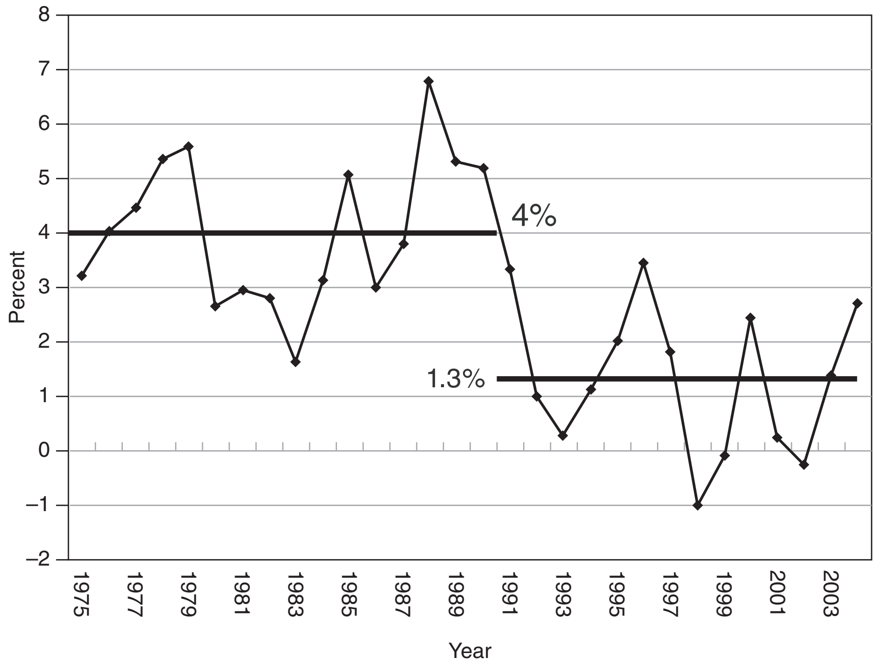

FIGURE 1 GDP growth ratio.
SOURCE: K. Motohashi, *Empirical Analysis of IT Innovation: Has IT Changed Long-term Japanese Economic Performance?* Toyokeizai, 2005.

productivity did decline to some degree in the 1990s and that this decline was greater than one would expect even in years of low economic growth.

The natural question concerns why productivity declined in the 1990s and several experts have proposed answers. One possible cause is the misallocation of resources, or "unnatural selection"[4]; efficient firms exited while inefficient firms, or "zombies," remained with the help of government and the banks, which wanted to prevent bankruptcies. Peck, Levin, and Goto (1988) show that this has happened in the past.

Another popular explanation, held mostly by management theorists, business people, and policy makers, is the reduced technological capability of the Japanese firms.[5] They contend that still-high R&D expenditures in the 1990s seem not to have produced the new products and processes that would have generated profits. The large market share once held by technology-intensive Japanese industries

[4]See Peek and Rosengren (2005) and Nishimura et al. (2003).
[5]See, for instance, Porter and Sakakibara (2004).

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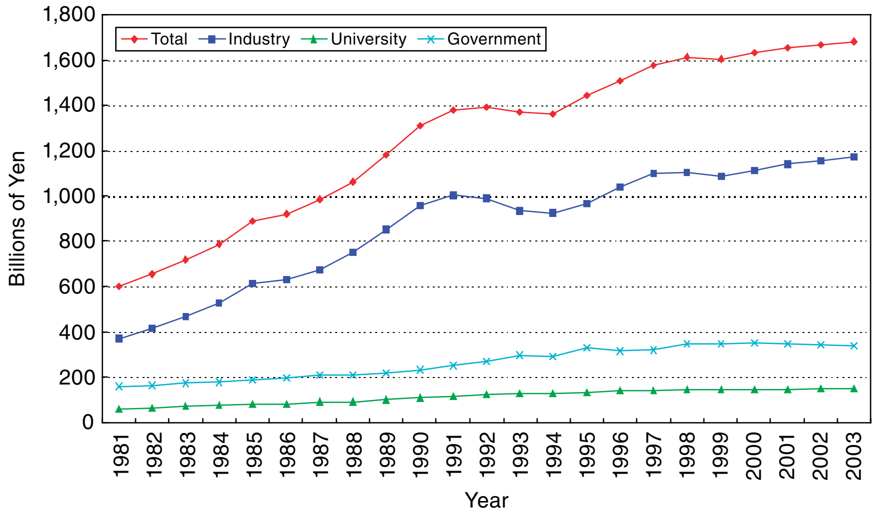

FIGURE 2 R&D expenditure in Japan.
SOURCE: Statistics Bureau, *Report on the Survey of Research and Development*.

such as semiconductors and semiconductor manufacturing equipment industries eroded significantly, and Japan was not able to keep pace with the United States in the newly emerging high technology industries such as biotechnology and information technology. These analysts believe that something seems to have gone wrong with Japan's once-successful innovation system.

An assessment of the state and effect of Japan's innovative capability is beyond the scope of this paper,[6] but the data in Figures 2, 3, 4 and 5, suggest that there was no significant drop in R&D activities in the 1990s. The amount of R&D expenditure and the number of patents remained high in the 1990s. The exports of technology actually increased sharply in the latter 1990s, probably reflecting the increased outward foreign direct investments, and Japanese scientists increased their output of highly cited papers beginning the late 1990s.

Still, some argue that there may be a mismatch between Japan's innovation system, which worked well for large manufacturing firms in industries such as automobiles and electric appliances. And the new requirements of biotechnology and information technology, where small startups and universities play a larger role.[7] This might be a part of a larger and more long-term problem: how to design a "post-catch-up" innovation system in Japan.

[6]See Posen (2002).

[7]Some argue that the days when small firms played a significant role in the biotechnology was over in the United States.

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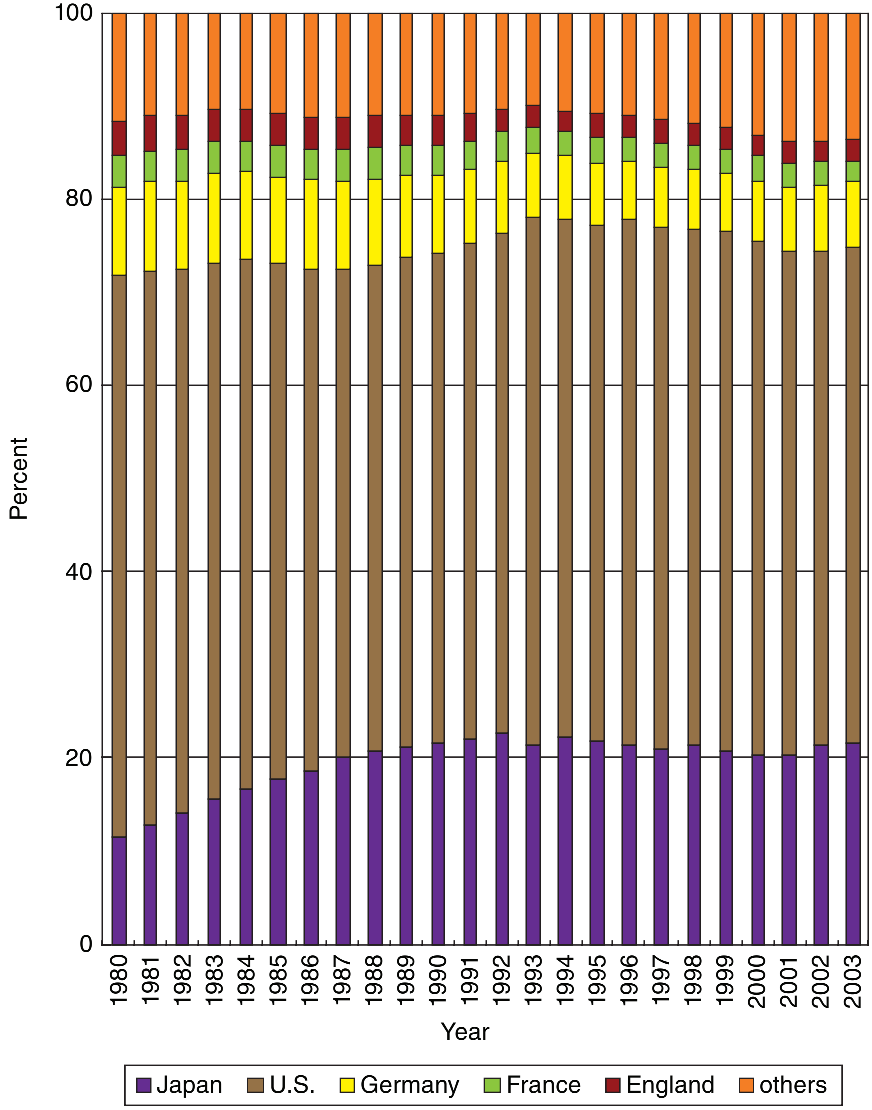

FIGURE 3 Japan's share in the U.S. patents.
SOURCE: NISTEP, *Science and Technology Indicators*.

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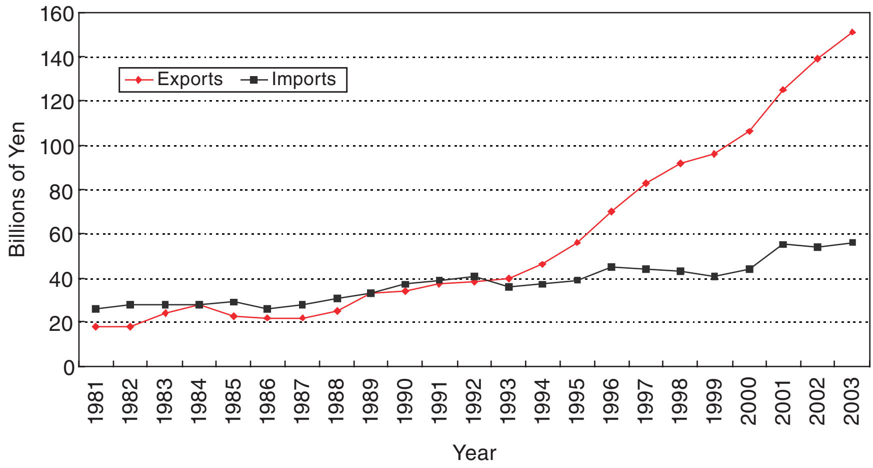

FIGURE 4 Japan's technology balance of payments.
SOURCE: NISTEP, *Science and Technology Indicators*.

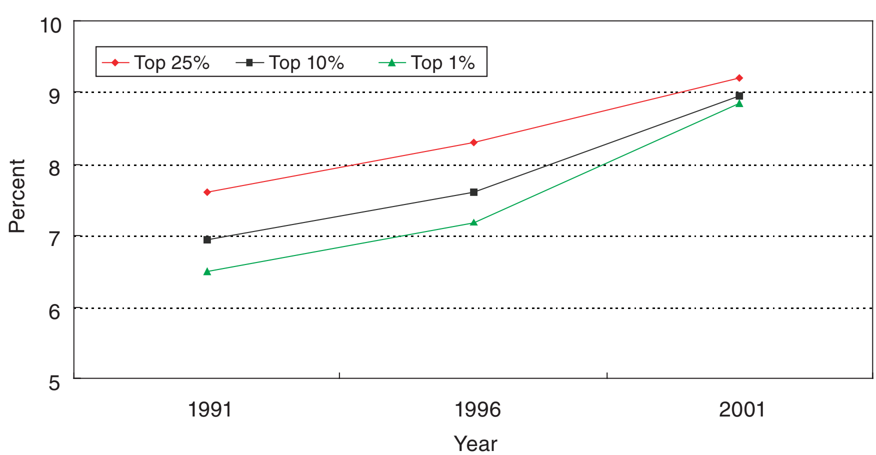

FIGURE 5 Japan's share among most highly cited papers.
SOURCE: NISTEP.

Our aim is to provide an overview of how Japanese technology policy responded to the economic and technological challenges described above. It will examine Japan's new framework of technology policymaking, government R&D programs, the R&D tax credit, technology policy toward small and medium enterprises (SMEs), and efforts to promote links between university and government labs and industry.

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2. REVIEW OF TECHNOLOGY POLICIES

2.1 New Framework of S&T Policymaking

In 1995, Japan enacted the "Basic Law on Science and Technology," under which the government's Council for Science and Technology Policy develops the 5-year Science and Technology Basic Plan. The first Plan covered 1996-2000, and two additional plans have followed.

Under the first Basic Plan, government spent 17 trillion yen on science and technology during the 1996-2000 period. The Second Plan (2001-2005) called for spending 24 trillion yen, and Third Plan (2006-2010) predicts that the government will spend 25 trillion yen.

All these new policy frameworks and actual policy planning reflect the strong commitment of the government to science and technology. The feeling is generally shared by the business community and the public, as science and technology are considered the only way for resource-poor Japan to maintain its high standard of living with a rapidly aging and eventually declining population and the challenges from other Asian countries, notably China.

Under the Basic Plans, universities received funding to modernize their old equipments and facilities, an increase in the budget for competitive research grants, and additional positions for postdoctoral fellows. Thus, not only was funding increased, but the system of supporting researched was changed to become more like the U.S. system with its reliance of peer review and evaluation. These changes will be discussed in more detail below.

The Basic Plans designated the following four fields as the important and promising areas that deserve increased support: life-science, information and communication, environment, and nanotechnology. One important side effect of this new S&T policy planning scheme was that it practically forced the S&T community to review and reflect on Japan's national innovation system in a major way every five years. The National Institute of Science and Technology Policy played a key role in providing basic data for the review and discussion.

Still, each ministry pays a key role in planning and enforcing its own S&T policy. Of the government's 3,626-billion yen FY2004 budget, 63 percent was spent by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), mostly on basic science, 17 percent by the Ministry of Economy Trade and Industry (METI), mostly on industrial technology, 5 percent by the Defense Agency, and 4 percent by the Ministry of Health, Labor, and Welfare.

2.2 Government R&D Programs; METI's R&D Projects

METI is in charge of organizing R&D programs for industrial innovation, and a typical project involves a group of companies working on a large-scale R&D initiative. The research funding is provided by METI, and public research institutions such as AIST can also be involved. The very large scale integrated circuit

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(VLSI) project is one of METI's most successful R&D projects. It started in 1976 to improve the technological capabilities of Japanese semiconductor manufacturers, which were lagging substantially behind U.S. firms. In this project, the of AIST also played an important role, and This three-year project, which also involved AIST's Electro Technical Laboratory, pushed Japanese electronics companies to world leadership in LSI technology. Other METI projects focused on advanced materials, mechanical engineering, energy development, and environmental technologies.

However, due to the advancement of technological complexity, it became difficult to identify common technological targets among participating companies. In addition, as Japanese firms have gained their own technological capabilities, the government's role in supporting their industrial competitiveness became marginal. As a result, most of METI's R&D projects in 1980s and 1990s did not achieve substantial results.

Therefore, METI revised the style of R&D projects in 2000. Under the new system, the R&D projects are organized to meet specific social and policy needs, instead of focusing on specific technological development. For example, "assuring longer and healthy life" is one of the important social needs. In order to meet this need, METI organized an R&D program in medical services. And in recognition of the fact that technological progress alone is not enough to achieve social needs, the government instituted a parallel package of regulatory reforms of the healthcare industry.

2.3 R&D Tax Credit

Among the fiscal measures to promote private sector R&D, the R&D tax credit was considered to be more market friendly because it allows firms, not government, to choose research projects. The tax credit, which was granted for annual increases in R&D spending, was effective when the economy was growing, but as the recession continued after 2000, companies found it difficult to maintain, never mind increase, R&D spending. In 2003, Japan revised the R&D tax credit system to provide incentives that are more generous and to base it on total R&D spending rather than annual increases. The new system also included the special provision to increase the tax reduction for three years, from 2003 to 2005, as a temporary measure to counter recession.

The introduction of the new system resulted in 600 billion yen of corporate income tax reduction. With the help of this new measure, and thanks largely to the recovery of the economy, private sector R&D spending has begun to recover from its long slump.

2.4 Innovation Promotion Policy Toward SMEs

SME innovation promotion policy is managed by METI's Small and Medium Enterprise Agency. To understand recent developments in SME innovation policy,

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it is important to be aware of the fundamental revision of the SME policy framework that occurred in 1999, along with the revision of the SME Basic Law. Before this revision, SMEs had been treated as "weak enterprises" in the economy, and the SME policy goal was to improve the performance of SMEs as a whole so that they could compete with large firms. The main point of revision of the SME Basic Law is to throw out this social welfare style of SME policy and to treat SMEs as the source of entrepreneurship, innovation, and job creation. Rather than protecting SMEs from large firms, the new policy aims to stimulate SME innovation. The components include special R&D grants, greater tax incentives than for large firms, and special debt-guarantee insurance for innovative activities.

One example of an SME innovation-promotion scheme is the Japanese SBIR (Small Business Innovation Research) program, named after the U.S. program. This system was established in 1999 to help SMEs enhance their technology-development capability and to support their creative business activities. Specifically, ministries in charge of R&D grants and nonprofit special corporations, such as the Small and Medium Enterprise Corporation, a nonprofit funding agency for SMEs, are to allocate a designated share of their R&D grant funding for SMEs. As Figure 6 shows, from 1999 to 2005, this amount has been increased three times, and actual appropriation of budget has also been rising very quickly.

Under the scheme of the Japanese SBIR, SMEs receiving a grant by designated subsidies are also entitled to the following favorable treatment for the commercialization activities related to the technologies developed with the grant:

- Expansion of debt-guarantee lines by the special debt insurance for SMEs.
- Expansion of debt size by the Law on Subsidy for Facility Introduction Funds for Small-Scale Enterprises.
- Special loan system of the Japan Finance Corporation for Small Business.

2.5 Public Research Infrastructure Reforms and Linkages with Industry

In the course of the 2001 national government reform, most national research institutes, which used to be part of the national government, have become independent administrative institutions (IAIs). IAIs are granted more management flexibility in the hope that they will be able to enhance their efficiency and productivity.

The ministry in charge of each IAI has to provide a mid-term objective over three to five years, and the IAI has to draft a mid-term plan based on the objective. This plan is evaluated by an committee with external members and must be authorized by the ministry. In addition, the IAI has to delineate its planning and checking process in an annual plan and an annual report, both of which are reviewed by the evaluation committee. An annual budget will be provided to each IAI based on the results of the mid-term plan evaluation as well as the annual planning and checking process.

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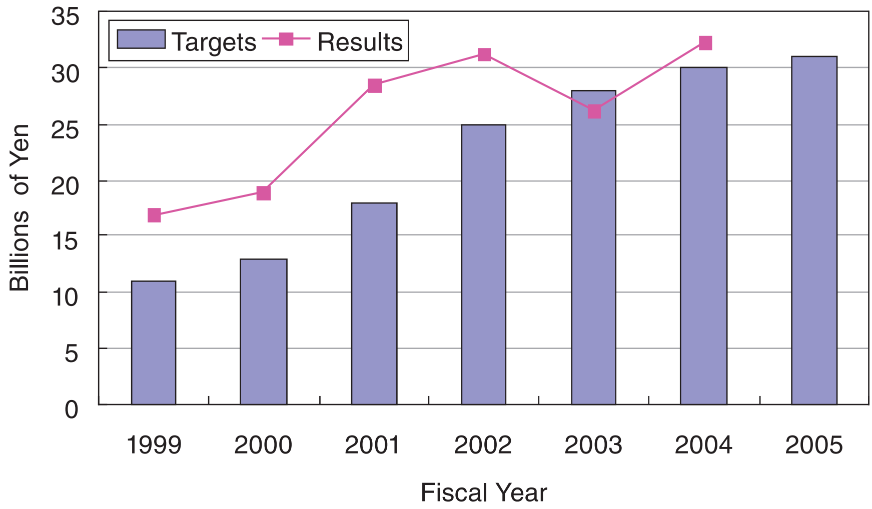

FIGURE 6 Implementation of SBIR.
SOURCE: METI.

At the same time, an IAI is given freedom in its management of financial and human resource allocation. Corporate accounting rules are applied, which allows it to carry over an annual surplus to the next year, in contrast to the government budget rule in which such carry-over is strictly regulated. In addition, it does not have to comply with the seniority-based pay scale of government officials, making it possible to offer higher salaries to outstanding scientists.

In 2004, all national universities, which used to be considered government organizations, were converted to National University Corporations, which are similar to IAIs. Since then, national universities in Japan have been given more autonomy, Block funding for the universities has been decreased, while the pool of competitive funding has been increased to provide an incentive for universities to compete on the basis of the quality of educational services and research activities.

Thanks to such institutional reforms in government laboratories and national universities, commercialization activities of public research results have been progressed substantially. In addition, the Japanese government has introduced incentives to promote linkages between researchers and industry. In 1998, the Law for Promotion of University-Industry Technology Transfer was enacted to support technology licensing offices (TLOs) at universities and research institutes. Under this law, the registered TLOs can receive financial support for their activities as well as other special treatment such as reduced patent application fees. Before this law was enacted, patent applications by national universities were almost

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nonexistent, because as governmental institutions the national universities were not allowed to hold patent rights. However, now that TLOs have been established in many universities, the number of patent application and loyalty revenue has increased dramatically.

In 1999, Japan enacted the Industrial Revitalization Law, which includes a "Bayh-Dole" clause to encourage patenting of research results. Since then, Japanese universities and public research institutions, which receive most of their R&D funding from government, have been eligible to claim the ownership right of most of their research outputs.

In terms of university-industry linkages, joint research centers have been established at universities since fiscal 1987 as the footholds for the promotion of industry-academia cooperation. These centers provides physical places to conduct collaborative research projects between university and private firms, as well as an inside-university focal point of interaction with industry representatives. There were 62 centers as of the end of October 2003.

Finally, the spin-offs from university are increasing. 1,503 new firms had been spun off by the end of fiscal year 2005. Biotech firms have the greatest share (37.8 percent), and IT hardware companies come next (30.3 percent). With biotechnology accounting for more than half of the firms established in 2005, the industry's hare is continuing to grow. Although the number of university spin-offs is steadily increasing, their average size is still small (10.9 employees and 132 million yen in sales). These average figures include 16 IPO firms, so that there are many firms with very small scale of operation.

3. CONCLUSION

In the late 1980s, when the Japanese economy was booming, technology policy started to emphasize the importance of science. There was a rather widely held view that the catch-up era was finally ending, that science was becoming even more important for innovation, and that Japan's research system lacked the human resources, equipment, and management structure to thrive in this new environment.

This policy orientation was somehow maintained after the collapse of the bubble economy, and the enactment of the Basic Law on Science and Technology was the manifestation of this determination. In the face of the severe and prolonged recession, technology policy actions such as the temporary increase in the R&D tax credit were used as a tool to boost the economy. Although in principle science and technology policy should take a long-term perspective, the pursuit of short-term stimuli was understandable given the severity and length of the recession.

Two major changes occurred in the 1990s through 2000s and could have a long-lasting impact on Japan's national innovation system were the enactment of the Basic Law and university reform. The introduction of the Basic Law strength-

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ened the role of Council for Science and Technology Policy (CSTP). Even though each ministry still maintains strong influence on technological development in its area, overall technology policy planning and coordination at the CSTP became visible and important. The long-term consequences of this remain to be seen.

The reform of higher education began with the rather short-term focus of encouraging universities to work more closely with industries as a means of revitalizing the economy. In response to the prominent role that universities played in strengthening the U.S. information technology and biotechnology industries, Japan placed an early emphasis on the creation of technology licensing offices at the universities, Bayh-Dole type arrangements to encourage patenting, and efforts to stimulate the creation of spin-offs. It is needless to say that the basic roles of universities in a national innovation system are creating and pooling knowledge and educating students. From this viewpoint, the early policies were not enough. More policy emphasis should be directed to strengthening these fundamental functions of universities.

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Reform of University Research System in Japan: Where Do They Stand?

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1. UNIVERSITY RESEARCH IN JAPAN AND ITS GOVERNMENT SUPPORT

Essential information about Japanese university research in Japan can be found in the Report on the Survey of Research and Development, Statistics Bureau, Ministry of Internal Affairs and Communications, which includes data on the natural sciences and engineering.[1,2]

1.1 Researchers in Universities

At the end of March 2005, Japanese universities had 291,000 researchers in all fields, including 190,000 in the natural sciences and engineering. Universities in Japan are classified into three categories: national universities founded by the central government, public universities founded by local governments, and private universities founded by private initiatives. (See Table 1.)

[1]Natural sciences and engineering (*Shizen-kagaku*) in Japan include physical sciences, agricultural sciences, engineering and technology, mathematics and medical sciences.

[2]International comparison of research systems and university research may be found in National Science Board (2008), Chapter 4. Accessed at <*http://www.nsf.gov/statistics/seind08/*>.

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TABLE 1 University Researchers in Japan (as of the end of March 2005)

	Total Number (Thousands of Persons)	Natural Sciences and Engineering (Thousands of Persons)	Social Sciences and Humanities (Thousands of Persons)
National Universities	134	104	30
Public Universities	22	17	5
Private Universities	135	70	65
Total	291	190	101

SOURCE: Statistics Bureau, Ministry of Internal Affairs and Communications, *Report on the Survey of Research and Development 2004,* 2005.

1.2 Research Expenditure in Universities

The three types of universities differ significantly in the source of their research funding and in the emphasis of their research. (See Table 2.)

Looking at the breakdown of research expenditures, the ratio of labor costs (*Jinkenhi*) to the total is shown in Table 2. In the field of social sciences and humanities, the labor cost ratio was high throughout all three categories of universities. In natural sciences and engineering, the ratios in private and public universities were comparatively high, while the ratio in national universities was low. It can thus be said that national universities have the strongest presence in Japan's university research in terms of research expenditure especially in natural sciences and engineering.

TABLE 2 Use of Research Expenditure in Universities in Japan

	Total (Billions of Yen)	Natural Sciences and Engineering (Billions of Yen)			Social Sciences and Humanities (Billions of Yen)		
	Intramural Expenditure	Intramural Expenditure	Labor Cost Ratio (%)	Self-funding Ratio (%)	Intramural Expenditure	Labor Cost Ratio (%)	Self-funding Ratio (%)
National Universities	1,368	1,114	54.5	75.1	254	77.2	90.4
Public Universities	188	137	70.1	88.8	51	85.2	97.7
Private Universities	1,718	796	64.7	86.1	921	76.	92.8
Total	3,274	2,048	59.5	80.3	1,226	76.7	92.5

SOURCE: Statistics Bureau, Ministry of Internal Affairs and Communications, *Report on the Survey of Research and Development 2004,* 2005.

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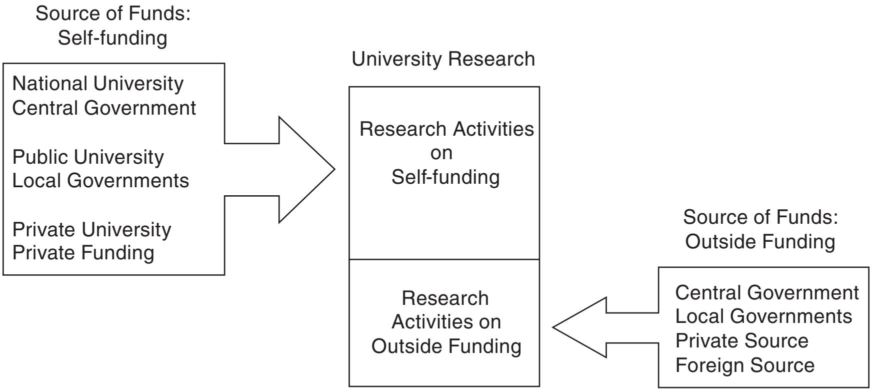

FIGURE 1 University research and its sources of funds.

1.3 Source of Funding for University Research

Figure 1 explains the general structure of research funding in Japanese universities. In the Report on the Survey of Research and Development, sources of research funding are classified into three main categories: central and local governments, the private sector, and foreign countries.[3] In addition, from the point of view of performers of research, funding sources may be classified into self-funding and external funding. In these statistics, the support that national universities receive from the national government and that public universities receive local governments is classified as self-funding. For all three classes of universities, self-funding accounts for a high proportion of total funding. Research funding from the central government other than institutional funding is distributed to universities directly from the central government or via government related organizations such as funding agencies.

1.4 Government Support for University Research

How much support for research at national, public, and private universities is provided by the central and local governments? Table 3 shows the relevant figures for natural sciences and engineering. Looking at the total amount provided by the governments, it can be seen that the total has been steady since FY1998 and above the levels before FY1998. The total amount of government support for private universities has increased. The share of central and local government funding for universities in total research expenditures has been gradually declining

[3]There is little funding from foreign countries to Japan.

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TABLE 3 Government Support for University Research in Natural Sciences and Engineering

		Billions of Yen by Fiscal Year										
Categories of Universities	Fiscal Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
National	Central and Local Governments Support (A)	880	1,015	990	992	1,075	1,065	1,056	1,053	1,093	1,070	1,037
	Ratio of (A) to All Research Expenditure (%)	95.1	95.3	95.2	94.9	95.6	95.3	94.9	94.0	93.6	93.3	93.1
Public	Government Support	106	125	115	126	126	125	129	125	123	123	130
	Ratio (%)	97.4	97.7	97.2	97.6	97.6	97.4	97.4	96.3	95.6	95.0	95.0
Private	Government Support	55	64	65	69	80	79	80	80	82	85	85
	Ratio (%)	804	9.4	8.9	9.5	10.6	10.6	10.7	10.5	10.6	10.9	10.7
Total	Government Support	1,041	1,202	1,170	1,187	1,281	1,269	1,265	1,258	1,298	1,278	1,253
	Ratio (%)	61.8	64.1	62.1	62.3	63.7	63.8	63.6	62.4	62.7	62.2	61.2

SOURCE: Statistics Bureau, Ministry of Internal Affairs and Communications, *Report on the Survey of Research and Development,* (various years).

for national universities and public universities. This decline is associated with a gradual increase in private funding.

1.5 Increasing Role of Outside Funding

In terms of both funding and personnel, national universities play a prominent role in university research in natural sciences and engineering, and thus in Japan's innovation system.

Table 4 shows how funding from the central government is distributed among national universities in natural sciences and engineering. The total sum has fluctuated year by year, primarily as a result of supplementary budgets. However, when the past 10 years' figures are observed, the amount of government support since FY1998 remained high. As to the amount of self-funding, it is hard to find a trend, though it is clear that the ratio of self-funding has been declining. This

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TABLE 4 Central Government Support for National University Research in Natural Sciences and Engineering in Japan

	Billions of Yen by Fiscal Year										
Fiscal Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Central Government Support	879	1,014	989	990	1,074	1,064	1,055	1,052	1,092	1,069	1,035
Of which Self-funding	826	942	910	898	973	948	927	930	943	895	837
Ratio of Self-funding (%)	93.9	92.9	92.0	90.7	90.6	89.2	87.9	88.4	86.4	83.8	80.8

SOURCE: Author's calculation based on the data of Statistics Bureau, Ministry of Internal Affairs and Communications, *Report on the Survey of Research and Development,* (various years).

means increasing role for funding other than institutional and self-funding of central government support. It should be noted that, the effects of corporatization of national universities in FY2004 appear only in FY2004 data.

2. POLICY BACKGROUND

The policy background to the changes in government support for university research described in Section 1 may be summarized as (i) increase of university research expenditure and government budget based on the Science and Technology (S&T) Basic plans and (ii) increasing role of competitive research funding in government-supported university research.

2.1 Science and Technology Basic Law and Science and Technology Basic Plan

The Basic Law for Science and Technology of 1995 (S&T Basic Law) is crucial in explaining the change in science and technology policy in the past decade in Japan. According to the 2004 Science and Technology White Paper, the first consideration was a relatively small size of government research funding. The ratio of government research funding to gross domestic product (GDP) in Japan in 1994 was 0.59 percent, relatively low compared with 0.88 percent in the United States. Because the burden of research funding was mainly borne by the private sector, there was concern that basic research, expected to produce seeds for the middle to long term, could be insufficient. It was also recognized that there was little research money allocated to each researcher. In addition, the deterioration of the basic research infrastructure also attracted much public attention. The ratio

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of research facilitates older than 20 years to the total facilities was 50 percent in national universities and 35 percent in national laboratories. A lack of research support personnel was also perceived.

Against this background, the proposed Basic Law for S&T was submitted to the Japanese Diet (Parliament) by cross-party coalition of Diet members and, with the unanimous approval of all parties, the law was passed in November 1995. The Law states the basic principles for S&T promotion, such as harmonious development of basic research, applied research, and development. In addition, the responsibilities of the central and local governments in promoting science and technology are clearly stated. Furthermore, the Law prescribes that the central government should formulate an S&T Basic Plan that defines government measures for promoting S&T in a comprehensive and planned manner. Before formulating the S&T Basic Plan, the Government should ask formerly the Council for Science and Technology (*Kagaku-gijutu-kaigi*), later the Council for Science and Technology Policy (*Sougou-kagaku-gijutu-kaigi*), to develop its content.

2.2 Reorganization of the S&T Administration of the Central Government

In explaining the changes of science and technology policy in Japan, the reorganization of ministries and agencies of the central government is also relevant, especially the January 2001 reorganization when S&T administration underwent a dramatic change.

2.2.1 Council for Science and Technology Policy

First of all, the establishment of the Council for Science and Technology Policy (CSTP) within the Cabinet Office was an important development. The CSTP is designed to develop basic and comprehensive policy for science and technology, resource allocation and to evaluate big research projects of national importance. The CSTP consists of the prime minister as the chairperson, cabinet ministers related to science and technology policy, and prominent figures in S&T. Before the reorganization, the Council for Science and Technology (CST) within the prime minister's office existed as an advisory body on science and technology policy to the prime minister. Except for the increased number of the council members from private and academic sectors, the basic composition of the CSTP is almost the same as that of the CST.

Compared with the CST, however, the CSTP seems to have much more influence on S&T policy formulation. For instance, the CST held plenary meetings where the prime minister was present only once or twice a year, whereas the newly established CSTP holds almost monthly plenary sessions attended by the prime minister where substantial discussion between the prime minister and the members is possible. Closeness to the prime minister means political power for the CSTP. However, because CTSP is closer to the prime minister, it is also more influenced

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by the prime minister and political insiders. Science and technology policy promoted up to now by the CSTP seems to put emphasis on reform of S&T systems and on prioritization of resource allocation in line with the current prime minister's emphasis on structural reform.

2.2.2 Creation of Ministry of Education, Culture, Sports, Science and Technology (MEXT)

In January 2001, the Science and Technology Agency (STA) of the Prime Minister's Office and Ministry of Education, Science, Sports and Culture (Monbusho) were merged to form the new Ministry of Education, Culture, Sports, Science and Technology (MEXT). Formerly, Monbusho had about a half and the STA had one quarter of the total government S&T-related budget, and both were active in S&T policy formulation and implementation; clearly, the MEXT continues these important roles in S&T administration.

Before the 2001 reorganization, universities were under the jurisdiction of Monbusho, and direct support by the STA to university research was difficult. Although research contracts were possible between national universities and affiliated research institutes and organizations under the STA, not all were implemented smoothly, and there was no systematic and institutional way of providing funding to universities from the STA. The merger of Monbusho and the STA made it possible for the programs formerly administrated by the STA to provide support to universities smoothly. From the point of government research support to universities, therefore, government reform seems to have had a positive impact.

2.3 S&T Basic Plans and S&T-related Budget

2.3.1 S&T Basic Plans

The first S&T Basic Plan covered five years from FY1996 to FY2000. The single most important point of the first plan was its commitment to increase the allocation of government resources; it aimed to allocate a total of 17 trillion yen of S&T-related budgets (*Kagaku-gijutsu-kankei-keihi*). This objective was achieved. A second objective was institutional reform to establish new R&D systems. The second plan covered FY2001-2005 and set an objective for government R&D investment (*Seihu-kenkyuu-kaihatu-toushi*) of 24 trillion yen. Other important points included a clear definition of a desirable state of nation's future, strategic prioritization of S&T research, and S&T system reform.

The third S&T Basic Plan covers FY2006-2010. The third plan places a greater emphasis on personnel. Other items stressed in the third are continuations of the second plan, namely strategic prioritization of S&T research and S&T system reform. The target of government R&D investment (*Seihu-kenkyuu-kaihatu-toushi*) in the third plan is set at 25 trillion yen.

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TABLE 5 Government R&D Investment (*Seihu-kenkyuu-kaihatu-toushi*)

	Government R&D Investment (*Seihu-kenkyuu-kaihatu-toushi*) Unit: Billion Yen (T trillion Yen) (Note 1)			
Fiscal Year	Central Governments (Note 2)	Local Governments (Note 3)	Total	Target
1996	2,966	Not Available	Not Available	
1997	3,003	Not Available	Not Available	
1998	4,136	Not Available	Not Available	
1999	3,761	Not Available	Not Available	
2000	3,754	Not Available	Not Available	
1996-2000 total	17.6T	Not Available	Not Available	17T (Note 2)
2001	4,077	5,047	4,584	
2002	3,868	4,899	4,358	
2003	3,602	4,475	4,049	
2004	3,639	4,453	4,084	
2005	3,578	4,374	4,015	
2001-2005 total	18.76T	2.33T	21.09T	24T (Note 1)

SOURCE: Compiled by the author based on the document of the CSTP (24-11-2005, Document No. 1-3).
NOTE 1: The second S&T basic plan aims at "Government R&D Investment (*Seihu-kenkyuu-kaihatu-toushi*)" of 24 trillion yen. "Government R&D Investment" is explained as the sum of the S&T-related budgets of the central government and local governments.
NOTE 2: The first basic plan aimed 17 trillion yen of S&T-related budget of the central government.
NOTE 3: The data of S&T-related budget of local governments are available only for the term of the second basic plan.

Various policy measures have been taken to promote science and technology, throughout the periods of the first and second basic plans. Among those measures, particular emphasis has been placed on creating a more competitive research environment and competitive research funding (see section 2.3.4).

2.3.2 S&T-related Budget

The trends in total annual S&T-related budgets for the periods of the first and second S&T basic plans are shown in Table 5. According to this table, S&T-related budgets of central government generally have increased. In particular, S&T-related budgets from the central government have remained high since FY1998 after they enjoyed a notable increase. In terms of the budget from local governments, the data are only available for the period of the second basic plan.

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During this period, the budgets from local governments declined reflecting their severe financial situations.

2.3.3 Change of University-related Budgets

Budgets from the central government for university research in the S&T-related budget is given in Table 6, based on the report of the National Institute of Science and Technology Policy (NISTEP) and Mitsubishi Research Institute (MRI) in 2005. In that report, the items in the S&T-related budget are categorized into three parts:

(i) Budget items handled by the Ministry bureaus themselves.

(ii) Budgets for national research institutes (*Kokuritu-siken-kenkyuu-kikan*), special corporations (*Tokushu-houjin*), and independent administrative agencies (*Dokuritu-gyousei-houjin*).

(iii) Institutional support for universities including subsidies to public and private universities. (Budget items for competitive funding are not included in the third category.)

As observed in Table 6, the total university budget fluctuates year by year partly because of supplementary budgets. Nonetheless, observing data over the past ten years, its total sum has gradually increased, and its ratio to the total S&T budget has been decreasing gradually.[4] Some of budget items in the first and second categories may be provided as competitive research funding as discussed in the next section.

2.3.4 Competitive Research Funding

A major policy trend in recent years has been the increasing role of competitive research funding in government support for university research. In the first basic plan, a more competitive research environment was regarded as one of the important objectives. In the second plan, this objective was quantified by establishing a target to double the budget of competitive research funding.

Actual results are shown in Table 7. In Japan, competitive research funds are defined as the research funds distributed by the following processes:

(i) The organizations responsible for the distribution of funding first solicit R&D proposals;

(ii) A group experts then selects the best proposals of the basis of scientific and technological merit; and then,

(iii) Research funds are allocated to the researchers who have submitted the selected proposals.

[4]Values of Table 4 and values of Table 6 are not necessarily identical. Amount on the budget is not necessarily equal to research expenditure which is actually used because of carry-over or unused amount.

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TABLE 6 S&T-related University Budget

Fiscal Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total Amount (Billions of Yen)	966	1,241	994	1,329	1,152	1,123	1,432	1,350	1,304	1,589	1,370	1,239	1,210
Share (%) of all S&T budget	43.2	44.1	42.0	41.7	38.8	37.4	34.4	35.9	34.7	39.0	35.4	34.4	33.4

SOURCE: National Institute of Science and Technology Policy and Mitsubishi Research Institute, *Government S&T Budget Analysis during the First and Second S&T Basic Plans.* (*Dai-ikki oyobi dai-niki Kagaku-Gijutu-Kihonkeikaku kikanchuu no kenkyuu-kaihatu-soushi no naiyou-bunseki*). NISTEP Report No. 84, March 2005.

TABLE 7 Budget for Competitive Research Funding

Fiscal Year	1991	—	1995	1996	—	2000	2001	2002	2003	2004	2005
Basic Plan Period	n.a.		n.a.	1st		1st	2nd	2nd	2nd	2nd	2nd
Amount of Budget (Billions of Yen)	78.5	—	124.8	170.1	—	296.8	326.3	345.7	349.0	360.6	467.2

SOURCE: National Institute of Science and Technology Policy and Mitsubishi Research Institute, *Government S&T Budget Analysis during the First and Second S&T Basic Plans,* (*Dai-ikki oyobi dai-niki Kagaku-Gijutu-Kihonkeikaku kikanchuu no kenkyuu-kaihatu-soushi no naiyou-bunseki*), NISTEP Report No. 84, March 2005.

The growth of competitive funding has resulted in increased outside funding of university research expenditures as is clearly observed in national universities.

2.3.5 Prioritization of S&T Research

In the second S&T Basic Plan, a strategic prioritization of S&T was an important task. Table 8 shows the eight main fields of S&T included in the Plan, of which four fields (life science, information and communication, environment, and nanotechnology/materials) received special priority with extra R&D resource. In contrast, in the remaining four fields (energy, production technology, social infrastructure, and frontier), the Plan states that R&D in these fields should focus on the subfields where involvement of the government is essential.

The report mentioned above (NISTEP Report No. 84 2005) gives the proportion of the total R&D budget for the priority four fields as 29.1 percent during the

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TABLE 8 The Fields of S&T in the Second S&T Basic Plan

	Fields
Four priority fields	Life science Information and communication Environment Nanotechnology / materials
Four other fields	Energy Production technology Social infrastructure Frontier

period of FY1991-FY1995, 38.6 percent during the period of FY1996-FY2000 (the first plan period), and 42.1 percent during the period of FY2001-FY2004 (the second period). It is clear therefore that resource allocation has been prioritized in accordance with the Plan. Determining the exact influence of the strategic prioritization of S&T on university research is difficult because there is much room for different classification of budget items into particular research fields and because it is not clear how much of R&D budget has been allocated to universities. However, it is safe to say that university research is likely to have been influenced by the prioritization through the mechanism of competitive research funding.

2.4 Industry-University Cooperation

Another point emphasized in S&T policy in the past decade has been the promotion of cooperation between industry and universities. Because this topic is discussed in other chapters of this book, I will keep my discussion short. Various actions have been taken to facilitate industry's utilization of intellectual property rights (IPRs) generated from university research and to help industry utilize the research capability of universities. In this context, creation, management, and utilization of university IPRs is stressed. Increasing industry funding of university research becomes government policy objective, and it has actually increased. Government also encouraged the creation of startup companies using university research.

2.5 Corporatization of National Universities

In 2004 national universities, were converted into "National University Corporations" with much greater management control. Freed from the accounting, personnel, and property rules of the central government, the national universities are better able to reform themselves to improve research effectiveness. It should be noted here that the original intention of corporatization of national universi-

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ties was to help reduce the total number of national civil servants by the end of FY2003. The law incorporating the national universities was passed July 2003 and implemented only nine months later. The universities had so little time to prepare that many of the anticipated management reforms have yet to be achieved.

Speaking of the management structure of a national university corporation, the president (*Gakuchou*) is the head, and several directors (*Riji*) of the board are appointed by the president. The MEXT appoints the president of a national university corporation based on the proposal of a national university corporation which sets up president nomination committee to select a candidate. The term of office of the president is from two to six years and decided by the corporation based on the deliberation by the president nomination committee. Apart from the government controls of universities, most managerial matters used to be decided on a consensus basis by professors. However, now top-down management has become possible because the government control is no longer directly applicable and the board system has been introduced. The introduction of private enterprise management methods is also possible.

For administration, a Management Council (*Keiei-Kyougikai*) is generally established to deliberate important matters of management. It consists of both, university members and non-university members. In addition, an Education and Research Council (*Kyouiku-Kenkyuu-Hyougikai*) is established to deliberate important matters on education and research. The faculty members and staffs of a national university corporation are also no longer public employees, and strict government rules limiting taking outside part-time jobs have been lifted. It is expected that through these reforms and industry-university cooperation, talent and research results originated from universities will increasingly be fed into the industry and society.

A Mid-term Objective (*Chuuki-Mokuhyou*) generally guides the activities of a corporation. Presented to a corporation by the MEXT, it covers six-year term. It sets objectives concerning important matters such as the improvement of quality of education and research, improvement of administration, improvement of efficiency and financial matters, conduct of self-evaluations and promotion of information dissemination. Before finalizing the Mid-term Objective, the MEXT has to invite opinions from the corporation and to give due consideration to these opinions. A national university corporation makes a Mid-term Plan in line with the Mid-term Objective and has to receive authorization from the MEXT. Based on this Mid-term Plan, a yearly budget appropriation of administration grant (*Un'eihi-Kouhu-kin*) is given to the corporation by the MEXT.

In order to enhance administrative efficiency of university corporations, certain portions of budget appropriation from the MEXT are to be reduced by one percent year by year. A management effort is inevitably required by this reduction. Further, pressures are building up on national university corporations to secure funding sources other than an administration grant, for instance, competitive research funding of the government and research funding from companies.

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3. EVALUATION OF PAST DECADE AND CURRENT ISSUES

3.1 General Evaluation of the Past Decade

Looking at government support for university research over the past decade in Japan, it is evident that research expenditure provided by the government to universities has increased thanks to the S&T Basic Plans. The increase in budget helped universities improve research environment which had been deteriorated during the 1980s and early 1990s. In addition, the corporatization of national universities has given an unprecedented degree of freedom to university administration. On these grounds, government support for university research over the past decade can generally be evaluated highly.

Several important issues, however, emerge as a result of current policy directions as discussed below.

3.2 Current Issues

3.2.1 Diversity of University Research

The first issue is how to maintain the diversity in university research while the increase of competitive research funding and the strategic prioritization of S&T research are policy priorities. The increasing role of competitive funding together with the cut in institutional funding in university research could make it difficult to maintain research diversity, because the limited amount of competitive funding makes it extremely difficult for various researchers to work continuously to secure competitive funding to continue their research. In addition, except for Grand-in-Aid-for-Scientific-Research (*Kagaku-kenkyuhi-hojokin* or *Kakenhi*), all competitive funding programs invite proposals in the areas of importance for each ministry or agency based on their own policy priorities. Policy priorities are not necessarily amenable to research diversity.

A recent report[5] of the Science Committee of the MEXT's Council for Science and Technology[6] (*Kagakugijutu-gakujutu-singikai*) points out that prioritized investment under the Basic Plans has had a great influence on science research in general. It points out, on one hand, several favorable points such as improving research results, creating a more competitive environment and promotion of industry-university cooperation. On the other hand, it also points out that there has been misunderstanding that research in the four priority fields of the Second Basic Plan has received increased funding at the expense of basic research based on the free ideas of researchers. With that in mind, it points out two policy directions:

[5]Science policy supporting research diversity (*knekyuu-no-tayousei wo sasaeru gakujutu-seisaku*), October 13, 2005.

[6]Although English name is the same, this is different from the former CST of the Prime Minister's Office.

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(i) To promote diversity in research; and

(ii) To nurture an environment where individual researchers are able to develop their full potential to the maximum extent.

The report stresses that in Japan the government provided secure fundamental or institutional appropriations to universities so that they could secure their own existence, employ the necessary personnel and create the appropriate research environment in order to raise diversified "seeds." The report points out that with only the support of competitive funding of limited duration it is difficult to raise "seeds" of important research, and that research diversity should be protected by fundamental or institutional appropriations. How to maintain research diversity in universities is thus an important policy question posed to the central government as well as to university presidents who need to manage to guarantee research diversity in a competitive funding environment.

3.2.2 Management of Competitive Funding by Funding Agencies

The second issue concerns how effectively organizations responsible for the distribution of competitive funds are able to manage their funding processes. In order for competitive funding to be effective, it is necessary for the evaluation of proposals and distribution of funds to be properly managed. In the current Japanese competitive funding systems, the evaluation and selection of proposals has been mainly led by outside experts, while the importance of managing from the proposal stage through final evaluation of results has also been recognized.

For this purpose, program officers (POs: persons with research careers in charge of management of programs or of selection of proposals, evaluation thereof and follow-ups) and program directors (PDs: persons in senior position with research careers in charge of the management of funding systems and their operation) are appointed for each funding program inside the competitive funding agencies. Such agencies have been established as independent of (or at least not a part of) the government ministries. This is also recognized as an important policy issue, especially in the Third Basic Plan. The distribution function of competitive research funds is likely to shift further from the government to independent funding agencies. This will make it important to secure qualified POs and PDs, especially for large programs where fulltime POs and PDs are required. Such competent experts are the main foundation on which competitive research funding systems function effectively. Thus, policy needs to be implemented towards this direction.

3.2.3 Management of Competitive Funding by National University Corporations

The third issue arises from the increasing role of competitive funding and its impact on the management of universities. Competitive funding for university

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research is a clear policy trend which will continue at least in the near future. Therefore, universities, especially national university corporations, have to be prepared to follow this trend.

There are various types of competitive research funds:

1. Grants-in-aid for Scientific Research (*Kakenhi*) are the largest in terms of its total annual budget and supports basic research via the subsidy (*Hojo-kin*) to researchers and/or universities.

2. Many competitive research funds are based on contract where a university performs research activities under the specific terms and conditions specified in a contract. Such terms and conditions are governed by strict government rules and regulations or similar ones of funding agencies. These regulations include that money provided under the contract should be spent solely for the fulfillment of contractual obligations, that equipment purchased under the contract should not be used for purposes other than performing contractual obligations, and that researchers have to receive approval of funding agencies in using their research results.

Concerning management, this is relatively easy for universities when a researcher receives only one source of competitive funding. However, when multiple sources are involved at the same time, proper management is essential in terms of accounting, personal management, the management of research results, and the use of equipment. This poses challenges for the management system of national university corporations, because the systems were established at the time of national universities when they were part of the government, and have been maintained to a large extent in national university corporations. This means that they are most accustomed to managing a system where most of the fund comes as institutional funding from the government with little contractual obligations.

In addition, the personnel management system is built upon the premise that most researchers are employed at institutional funding as tenured staffs, not at competitive funding as fixed-term staffs. Furthermore, researchers employed at competitive research funding from outside are treated differently in social welfare schemes within universities. There is insufficient institutional connectivity of pension and other welfare schemes between employment at competitive funding and employment at institutional funding. When research is performed concurrently by the same researcher using multiple competitive research funds, university management faces several new challenges in personnel management issues to fulfill contractual obligations, and needs to improve its function compared to the time when competitive funding was limited.

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3.2.4 University Openness and Emphasis on Industry-University Cooperation and Intellectual Property Rights

The fourth issue arises from the tension between the traditional openness of university research and education, and the recent policy emphasis on industry-university cooperation and on IPRs. Recent trends include specific support from the government to universities to promote cooperation with industry and to secure IPRs from research results, and a general encouragement for universities to secure IPRs from their research and to license them to industry. It is now widely accepted that university-industry cooperation, such as licensing IPRs together with cooperative research and technology advice to industry, plays important roles in effective use by industry of IPRs originated from universities.

The result is that many cooperative relationships are being established between universities and industry. Cooperative research partly funded by industry is often performed within universities and, in some cases, commercially sensitive information from private firms may be introduced into universities. In such research, tight information management is required to secure IPRs and commercially sensitive information. The Ministry of Economy, Trade, and Industry (METI) published "a guideline for making policy for trade secret management in universities." Industry requires that universities should properly manage important information. This is because companies are exposed to severe competition in the market, and in order to secure competitive advantage, they are eager to secure IPRs including know-how and trade secrets. On the other hand, the basic mission of universities is education and research, where an open atmosphere is generally considered essential. In addition, publication of research articles is extremely important, especially so for doctoral programs.

We therefore need to recognize that an appropriate management of IPR-related information on research not yet published and the information brought from private firms may conflict with the fundamental values of universities. According to these values, free publication of research results and openness in education and research are critical to the role of universities as a source of knowledge readily accessible by society. Universities need to properly manage these potentially conflicting interests and ensure an appropriate balance.

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Government's Evolving Role in Supporting Corporate R&D in the United States: Theory, Practice, and Results in the Advanced Technology Program

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ABSTRACT

The Advanced Technology Program (ATP) supports early-stage technology development efforts by U.S. companies.[1] The ATP provides funding support to high-risk R&D projects that have potential for broad-based economic benefits for the nation. The rationale for government support of R&D rests on theory and evidence that the social benefits of R&D are greater than the private returns. The role of ATP as a public-private partnering program extends from providing critical funding to early-stage technology projects, and also includes aspects of encouraging collaboration among firms and other organizations, fostering information exchange, and facilitating technology entrepreneurship activities. ATP's multi-faceted evaluation program provides evidence that ATP is meeting its mission to support high-risk and innovative research by U.S. companies.

[1]The Advanced Technology Program at the National Institute for Standards and Technology (NIST) ceased to exist in 2007. Its successor is the Technology Innovation Program. For an account of its demise, see "Congress Cancels Contentious Program to Bolster Industry," *Science* 314(5800):752-753, November 3, 2006.

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I. THE ADVANCED TECHNOLOGY PROGRAM—OVERVIEW AND IMPLEMENTATION

Overview

The Advanced Technology Program (ATP) at the National Institute of Standards and Technology (NIST) was established by the Omnibus Trade and Competitiveness Act of 1988, with the mission of supporting U.S. companies in pursuing early-stage, high-risk research to develop new technologies that have great potential for producing broad-based national economic benefit. The ATP funds industry-led research and development (R&D) projects that have high technical risk and inventiveness and promising potential for broad economic impact.

ATP began in 1990 in response to the erosion of U.S industry's international competitiveness in strategic markets and the relative slowness of U.S. firms in translating inventions created in universities, national laboratories, and corporate laboratories into innovative products and processes (National Research Council 1999; Ruegg and Feller 2003). ATP provides cost-shared funding to industry to accelerate the development and broad dissemination of challenging, high-risk technologies that promise significant commercial payoffs and widespread benefits for the nation. This unique government-industry partnership helps companies accelerate the development of emerging or enabling technologies. Those technologies, in turn, lead to revolutionary new products and to new industrial processes and services that can compete in rapidly changing world markets.

By assisting in the funding of early-stage technology development, ATP helps propel promising technologies from *invention* to *innovation*—that is, make the transition from the laboratory to the marketplace, from demonstration of technical "proof of concept" to commercial introduction of a new technology product or service in the marketplace. During the process of early-stage technology development, when technical feasibility and economic viability are yet to be proven, great risk and fundamental uncertainty characterize the endeavor, and in this context, funding for R&D is often unavailable.

In a study commissioned by ATP, this transition from invention to innovation has been described as a "Darwinian Sea," where good technical ideas may not emerge from the laboratory due to the inability to find funding (see Figure 1). In the Darwinian Sea, success depends critically on the availability of funding, timely information and contacts, and entrepreneurial ability. For startup technology innovators, the primary sources of support are "angel" investors (wealthy individuals with experience in starting up new companies), venture capital firms specialized in early-stage or "seed" investments, and state and federal government programs aimed at supporting technology and innovation.

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FIGURE 1 From invention to innovation: The Darwinian Sea.
SOURCE: Lewis Branscomb and Philip Auerswald, *Between Invention and Innovation: An Analysis of Early-Stage Technology Development*, NIST GCR 02-841, Gaithersburg, MD: National Institute of Standards and Technology, 2002.

Implementation

ATP challenges industry to take on projects that have higher technical risk, and commensurately higher potential payoffs for the nation, than they otherwise would pursue. The ATP project selection criteria reflect this philosophy. Half of the criteria are based on scientific and technological merit and include an explanation of the innovation, a detailed research plan, and justification that the approach is feasible and has the potential to overcome the technical hurdles. The other half of the criteria are based on the potential for broad-based economic benefits, including benefits to the economy and society that would result from developing the new technology, justification for the need for ATP funding, and a plan for how the technology, once developed, will be commercialized. Proposals that are submitted in response to ATP's announced competitions are peer-reviewed against the published selection criteria. On average, one out of eight proposals met ATP's criteria for funding.

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ATP accepts applications from single companies and joint ventures. For-profit companies may apply as single applicants to receive an award for up to $2 million over three years to cover project costs. Single-company applicants are required to cover their indirect costs; this requirement encourages the participation of small firms that have low overhead costs. In fact, small businesses (those employing fewer than 500 workers) are thriving in the program (nearly half of all ATP-funded small firms have fewer than 20 employees) and lead two out of three of all projects.[2] Single-company applicants often bring in subcontractors (universities or other companies) to participate in the project. Large Fortune 500 companies applying as single-company applicants must cover at least 60 percent of total project costs; this requirement encourages large firms to formally collaborate with others and apply as a joint venture.

At least two separately owned for-profit companies may apply as a joint venture, with both companies substantially contributing to the research effort and to the requirement to cover at least half of the total project costs. Additional organizations (universities, nonprofits, or other companies) may join the joint venture either as formal participants or as subcontractors. Joint ventures can receive ATP funding for up to five years, with no funding limitation other than the announced availability of funds and the organizations' ability to cover half the total project costs.

ATP announces competitions through the *Federal Register* and held 44 competitions between 1990 and September 2004. ATP has provided $2.2 billion in awards, and industry has provided an additional $2.1 billion as cost share, for a total of $4.3 billion for high-risk research. Of the 768 projects awarded to date, 550 are to single-company applicants and 218 are to joint ventures. More than 165 universities and 30 national laboratories have participated in ATP projects, reflecting the collaborative nature and the diversity of the projects' participants. Projects that are awarded are organized into four broad technology areas: advanced materials and chemistry, information technology, electronics and photonics, and biotechnology. Manufacturing is a subset in all four categories. Technical topics under each of the main categories are broad and diverse.

The ATP selects projects through a competitive, peer-review process. Technical and business reviewers evaluate each proposal against ATP's published selection criteria. Technical reviewers look for significant innovation in technology and high technical risk, as well as feasibility, quality of the R&D plan, and the experience and qualifications of the technical staff assigned to the project. Business reviewers look for the potential of the proposed technology to produce broad-based economic benefits to the nation, the need for ATP funding support, the proposed pathway to commercialize the technology and deliver economic benefit, and the experience and qualifications of the business staff assigned to

[2]For the U.S. Small Business Administration's definition of "small business," see <*http://www.sba.gov/services/contractingopportunities/sizestandardstopics/faqs/index.html*>.

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the project. Although ATP encourages companies to plan for commercialization of technology from the start of the project, ATP will not pay for product development or activities related to commercialization; these expenses are left to the private sector.

The ATP has been active in supporting entrepreneurial startup firms. The role of ATP as a public-private partnering program extends from providing critical funding to early-stage technology projects and includes encouraging collaboration among firms and other organizations, fostering information exchange, and facilitating technology entrepreneurship activities.

II. THE ADVANCED TECHNOLOGY PROGRAM—THEORY[3]

Rationale for Public Support of Early-Stage Technology Development

The rationale for public-private partnerships is that there exists a funding gap for entrepreneurs who seek transition from scientific invention to commercial innovation. Some argue that only minimal intervention by the government is needed to ensure economic efficiency. This argument assumes that there is perfect information and thus Adam Smith's invisible hand leads to efficient outcomes. Joseph Stiglitz (2005) notes that in a market economy with imperfect and asymmetric information and incomplete markets, economies are not efficient on their own, which "leads to the conclusion that there is a potentially significant role for government." Arrow (1962) argued that there exist numerous market failures, especially in the market for new ideas and technological information. Market failures exist when "we expect a free enterprise economy to under-invest in invention and research (as compared to the ideal) because it is risky, because the product can be appropriated only to a limited extent, and because of increasing returns in use." Arrow highlights the role of uncertainty, which leads to contracting problems that result in a funding gap. The conversions of inventions to commercial innovations face many obstacles and risks.

The fundamental rationale for government support of R&D rests on the idea that the social rate of return on R&D investment is greater than the private rate of return. That is, the overall benefit to society, when all benefits are considered, exceeds the private benefit that accrues to the individual firm that performs the R&D. What this means from the policy perspective is that the private sector or individual firm does not have as much incentive to carry out R&D as is socially optimal because it cannot capture all of the benefits of its R&D investment (Mansfield 1996; Griliches 1993; Stiglitz 2005).

The overall benefit of R&D exceeds the private individual return because much of the benefit of R&D accrues to those other than the company carrying out the R&D. The innovating company captures a portion of the total value generated

[3]This section is primarily from Chang, Shipp, and Wang (2002).

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by a new technology in the form of new profits. But an additional large portion of the total value of a new technology is not captured by the innovating company, but by other firms inside and outside of the industry of the innovating companies.

Downstream Value from New Technology

Downstream users and consumers receive benefits when they adopt new technology introduced by innovating companies. This value accrues to users and consumers, and not to the innovating companies. Since companies cannot capture all of the value from R&D that leads to new technology, they will not pursue projects that have substantial and broad benefits. These projects do not offer sufficient private profits for a company to justify its private investment. These are cases for public-private partnership. A public program such as the ATP can partner with private industry to provide the funding necessary to carry out the R&D and technology development that has high potential for broad economic benefit.

Knowledge Spillovers From R&D

An important aspect of investment in R&D is that the knowledge benefits tend to "spill over" to others not directly involved in the original R&D work. When one company conducts research, other companies also receive benefits because the results of R&D often become more generally known through patents, publications, and other means of industry knowledge dissemination. Researchers can learn from research conducted at other companies and become more productive in their own research endeavors. Because of such knowledge spillovers, when one company conducts R&D, the overall benefit is greater than what this one company receives. Because other companies (as well as consumers and the general public) also benefit, there is a strong policy rationale for encouraging company R&D investment through a public program such as ATP.

Empirical Estimates of the Social Rate of Return on R&D

A number of economic studies have assessed the magnitude of the social rate of return on R&D investment and the extent to which the social return exceeds the private rate of return. Although any given study may have limitations, the general conclusion from the combined body of evidence is that the social rate of return on R&D is much higher than the private rate of return[4] (Griliches 1993; Jaffe 1998). In absolute terms, the social rate of return on R&D is most likely 15 to 30 percentage points greater than the private rate of return. In relative terms, the social rate of return is most likely 50 to 100 percent the magnitude of the private rate of

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[4]Nadiri concluded that R&D activity renders, on average, a 20- to 30-percent annual return on private (industrial) investments. See Nadiri (1993).

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return. The empirical evidence from economic studies therefore shows that there is a strong case for public support of industrial R&D and that the social benefits from R&D are very great (Mansfield 1996).

The Funding Landscape for Early-Stage Technology Development

The ATP's niche in the U.S. innovation system as a funding source for early-stage technology development lies between basic scientific research and commercial product development. Basic research is publicly supported by government because benefits from basic research are broadly diffused; the benefits are largely *social* benefits not limited to any person, firm, or organization conducting the research. Commercial product development, on the other hand, is carried out by companies motivated by the opportunity for private profits. Early-stage technology development is situated between these two activities and is characterized by high technical and business risk to the innovating company—since outcomes are uncertain and returns are far in the future—and also high potential for delivering great social value and private returns from the successful development of promising new technology. It is in this "space" that ATP plays an important role in supporting and funding new technology development.

How important is the public role in funding early-stage technology development? Who are the players in funding early-stage technology development? In a report commissioned by ATP's Economic Assessment Office (EAO), Branscomb and Auerswald (2002) estimate that between $5 billion (2 percent) and $36 billion (14 percent) of overall national R&D spending in 1998 was devoted to early-stage technology development. The relatively small share of total national R&D spending devoted to early-stage technology development supports the view that there is a "funding gap" where the amount of funding currently available is less than what is socially optimal or desirable. As discussed earlier, there is good theoretical and empirical reason to support the policy view that a higher level of national R&D is well justified.

Further, Branscomb and Auerswald find that private equity "angel" investors, corporations, and the federal government are the main sources of funding for early-stage technology development (see Figure 2). Of particular interest is the finding that the federal government, and not organized venture capital, is a major funding source for early-stage technology development. Approximately 20 to 25 percent of early-stage technology development is funded by the federal government, with the ATP as one of the principal federal programs focused in this critical area.

The ATP partners with small firms and startup firms, as well as larger firms, in supporting early-stage technology development. As seen in Figure 2, the other main funders of early-stage technology development are angel investors who fund startup firms led by entrepreneurs, and industry corporations that fund ongoing R&D efforts in their core competencies. This shows the importance for ATP

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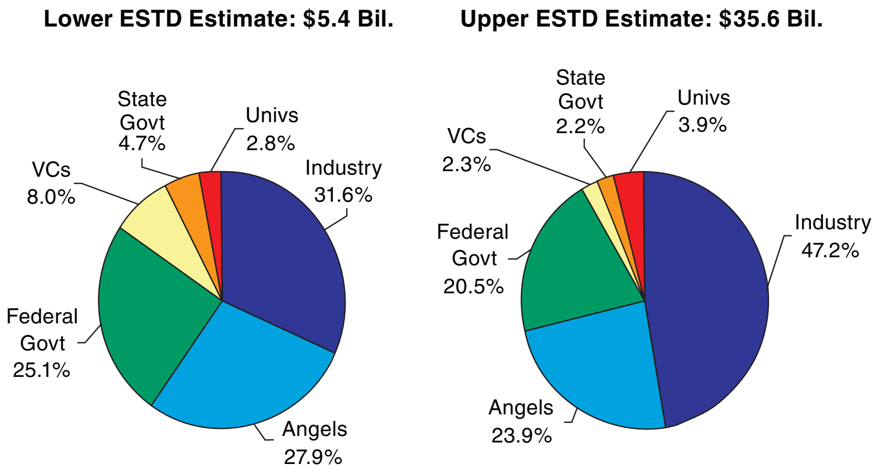

FIGURE 2 Estimated distribution of sources of funding for early-stage technology development (ESTD) and estimated funding based on narrow (lower estimate) and broad (upper estimate) definition criteria.
SOURCE: Lewis Branscomb and Philip Auerswald, *Between Invention and Innovation: An Analysis of Early-Stage Technology Development*, NIST GCR 02-841, Gaithersburg, MD: National Institute of Standards and Technology, 2002.

partners with both small startup firms and more established firms, and also highlights how ATP can partner with angel investors and corporate funding sources in accelerating and supporting the development of early-stage technologies.

For small startup firms, the ATP award provides critical funding support as well as benefits that extend beyond funding. The ATP has been very active in supporting small firms and entrepreneurial startup firms. Almost two-thirds of ATP awardees are small companies with fewer than 500 employees. Of these small firms, about 25 percent are very small firms with fewer than 10 employees, and another approximately 40 percent have from 10 to 20 employees. An ATP award provides external validation of the firm's technology, and increases the visibility of the company, both of which help the company attract additional funding from other sources. Survey data on ATP-awarded companies indicate that the ATP award does help attract additional funding to the company's technology (Feldman and Kelley 2001; ATP 2003a and 2005b).

Approximately 30 to 47 percent of early-stage technology development is funded by corporations (see Figure 2). Among corporations, the fraction of R&D that is dedicated to early-stage technology development varies both among firms and within industries. One estimate is that overall corporate spending on early-stage technology development is $13.2 billion, or about 9 percent of

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total corporate R&D. Of this $13.2 billion, early-stage technology investment in the computer software industry is $0.1 billion or 0.75 percent, whereas for the biopharmaceutical industry the average rate is 13 percent (ranging from 0 to 30 percent in the biopharmaceutical companies interviewed). A key driver appears to be the life-cycle position of the industry and individual company. More mature industries, such as the automotive sector, tend to invest a smaller percentage of R&D in earlier stages than do industries at an earlier stage of evolution, such as the biotech industry. Policies to encourage early-stage technology development may be most effective when directed to encouraging corporations to undertake higher risk research in new business areas outside their core. Monsanto's move into genetics in the 1980s is an example of a company making a temporary movement backwards out of product development and into a strategy emphasizing basic and early-stage technology development research (Branscomb and Auerswald 2002; Auerswald et al. 2005).

III. THE ADVANCED TECHNOLOGY PROGRAM— EVIDENCE THAT THEORY AND PRACTICE WORK

Evaluation works best when it is closely mapped to a program's mission. ATP's legislative mandate is to increase the prosperity of the United States by funding the development of high-risk technologies through a public-private partnership. ATP's goals are to add to the nation's scientific and technical knowledge base, to foster accelerated technology development and commercialization, to promote collaborative R&D, to refine manufacturing processes, to ensure small business participation, to increase the competitiveness of U.S. firms, and to generate broad economic and social benefits (Feller and Ruegg 2003).

ATP award recipients deliver benefits directly and indirectly. Direct benefits are achieved when technology development and commercialization is accelerated, which leads to private returns and market spillovers. Indirect benefits are delivered through publications, conference presentations, patents, and other ways in which knowledge is disseminated. From program purpose and design to final outputs, outcomes, and impacts, ATP's evaluation program measures these direct and indirect benefits.

The National Research Council has praised ATP's evaluation program, stating that "The ATP assessment program has produced one of the most rigorous and intensive efforts of any U.S. technology program . . . the quality, quantity, and analytical range of [their] studies are impressive" (National Research Council 2001).

Evaluation has been an integral part of program operations from the outset. To learn about the program's impact, program officials set aside a small amount of ATP's initial budget in 1990 to fund rudimentary evaluation activities. Since then, the budget for program evaluation has grown significantly, as has interest in evaluation. With a professional staff of economists, statisticians, information specialists, social scientists, business liaison specialists, and administrative support,

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the ATP's EAO is charged with carrying out ATP's evaluation activities. EAO aims to measure the economic impact of ATP's funding of high-risk, enabling technologies and also to increase understanding of underlying relationships between technological change and economic phenomena. EAO also provides business and economic expertise for ATP selection boards and locates expert business reviewers to review proposals.

ATP's evaluation program goals are to meet external requests for ATP program results, to use evaluation as a management tool to meet program goals and to improve program effectiveness, to understand ATP's contribution to the U.S. innovation system, and to develop innovative methodologies to measure the impact of public R&D investment. EAO tracks progress throughout the life of funded projects and for several years after the ATP funding ends. Evaluation work consists of conducting surveys, compiling data, producing statistical analyses, undertaking economic and policy research studies, and commissioning studies by consultants and research economists.

ATP's Evaluation Best Practices

ATP's experience in funding early-stage technologies and evaluating the impact of its awarded projects has resulted in many best practices. These best practices may prove useful to similar government programs in the early stages of their operations or to government programs that must meet external performance reporting requirements (Chang, Shipp, and Wisniewksi 2005).

Committing to Performance Evaluation

One of the most important best practices is to establish the practice of evaluation and to sustain those activities despite budgetary pressures. ATP allocates funding for a staff dedicated to evaluation activities—the EAO—and for carrying out evaluation activities using internal and external resources. It is important for public research and development programs to treat evaluation as a core activity and to pursue evaluation within a framework that measures the program against its stated objectives. Having a dedicated staff with appropriate backgrounds, capabilities, and experience is essential; having a dedicated budget for evaluation activities is critical.

Using a Multifaceted Approach to Evaluation

ATP's evaluation tools assess commercialization as well as knowledge creation and dissemination. These methods must accommodate the measuring of inputs, outputs, outcomes, and impacts over the life cycle of a project. Research and development takes place in the short to mid term, commercialization in the mid to longer term, and widespread diffusion of the technology over a longer time

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horizon. This time frame varies by technology area—shorter for information technology projects and much longer for biotech projects (Powell and Moris 2002). It also accounts for why multiple evaluation approaches are needed to capture the status of projects at various stages of their life cycle.

Commissioning External Studies by Experts

ATP contracts with experts to conduct economic analysis of individual projects, clusters of projects, or concepts underlying the economic principles of the program. ATP's EAO works with well-known researchers to shape, manage, and produce many of its reports. In the early years, EAO worked with economists affiliated with the National Bureau of Economic Research to help lay a strong foundation for evaluating the program. Zvi Griliches, Edwin Mansfield, Adam Jaffe, Bronwyn Hall, and others collaborated with ATP on important research to explore how to measure and track key economic concepts that apply to government support for the development of high-risk, enabling technologies carried out by the private sector. They studied concepts such as spillovers (knowledge, network, and market spillovers, see Jaffe 1997), return on investment (social, private, and public rates of return, see Mansfield 1996), and research productivity. By supplementing core in-house evaluation capability with expertise provided by outside contractors, ATP has pursued a balanced approach to evaluation and has welcomed new ideas and approaches.

Evaluating Unsuccessful Projects

Another best practice is evaluating unsuccessful projects along with successful ones. There is a great deal to learn from projects that failed to complete their goals or to deliver promised benefits. ATP has analyzed the reasons behind projects terminating early (ATP 2001, Appendix B). The knowledge generated by examining the reasons why projects fail can enhance project selection and project management.

Almost 10 percent of projects terminate early. A project can end early or not start for participant-initiated reasons, such as a change in goals, financial distress, lack of technical progress, or the inability of a joint venture project to reach an agreement on rights to intellectual property. A project can also end for ATP-initiated reasons, such as the project's failure to meet ATP project selection criteria or its shift away from the pursuit of high-risk research. In a very few cases, early success was the cause for early termination.

Strategically Presenting Results

Results have more effect if they are presented so that a nontechnical person can understand the science and commercialization. Results are presented in mul-

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tiple ways—a brief abstract enabling someone to quickly grasp the key findings, an executive summary for someone who wants an overview of key highlights, and the full report. Quantitative findings are presented in tabular form, with graphics, and with accompanying qualitative analyses. Many findings are released in fact sheets and made available on ATP's Web site. ATP has also published three special topic brochures that highlight projects in the health care, energy, and manufacturing sectors (ATP 2003b, 2003c, 2005).

Another way that results and data are summarized is in the form of a statistical abstract, an idea borrowed from the U.S. Census Bureau's annual *Statistical Abstract*. ATP's biennial statistical abstract was first released in September 2004, in a report called *Measuring ATP Impact, 2004 Report on Economic Progress*. The report describes ATP, using findings and data from recent reports and statistics. It also provides summaries of recent studies and ten detailed statistical tables that provide data on number and distributions by types of awards, technology areas, geographic regions, university participation, number of patents, commercialization, and post-award attraction of external funding.

Developing Innovative Methods to Evaluate ATP's Effectiveness

Evaluation of emerging technologies is a relatively new field. While traditional economic and social science methods can be employed to assess program success, the existing tools are often insufficient to describe the nuances and input of public-private investments. It is appropriate to modify existing tools, develop exciting new tools, or combine existing methods in ways never before explored.

For example, one of the more difficult concepts to measure is social return resulting from an ATP project. Social return includes private returns to the participating company in the project, and public returns, including knowledge, network, and market spillover benefits to that company's customers or to other firms, and a variety of indirect benefits to other companies and their customers as a result of the diffusion of knowledge created from the project (see Jaffe 1997 and Chang, Shipp, and Wang 2002 for a historical description of this issue).

Despite the difficulties in measuring social return, ATP has pursued a greater understanding of this concept by collaborating with consultants, professional economists, and academicians. Together, they carry out retrospective and prospective benefit-cost studies of a range of technologies and projects to test and stretch various methodological approaches. These studies include case studies of projects that developed photonics technology for use in petroleum refining, building controls, emergency medicine, and industrial materials (Pelsoci 2005), flow-control machining technology (Ehlen 1999), and technologies that reduced the dimensional variation of U.S. motor vehicles (Polenske et al. 2004).

In measuring spillovers, for example, they have used various approaches and means of illustration. To capture knowledge spillovers for the status reports

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of completed projects—a portfolio-wide, mini case study tool—they developed patent trees that illustrate multi-tiered citations of patents that were issued for ATP-funded technologies. In addition, a study was commissioned to examine knowledge spillovers using social network analysis. This emerging method uses fuzzy logic and systems analysis to examine knowledge spillovers from research and development projects within networks of participating organizations (see the discussion in Ruegg and Feller 2003, pp. 271-275 and Fogarty et al. 2006).

To study market spillovers, they explored the use of the U.S. Department of Commerce's Bureau of Economic Analysis input-output tables. Specifically, the first 50 completed ATP projects were mapped to their make-and-use industries to trace where the new technologies began and where they have since ended up (Popkin 2003). They are also exploring other emerging methods to measure spillovers and the impact of ATP funding, including coding potential commercial applications identified by ATP project participants using NAICs (North American Industry Classification) codes to identify make-and-use industries that illuminate the spillover path (Nail and Brown, forthcoming).

Systematically Collecting Data

The cornerstone of ATP's evaluation program is its comprehensive survey and data collection system. Survey collection efforts are structured to align with overall evaluation goals, which in turn are crafted to optimize the performance of ATP. As part of an ongoing survey and database assessment effort, we have identified six broad-based goals that form the conceptual basis of our surveys: (1) opportunities for national economic benefits, (2) acceleration of R&D, (3) increased investment in high-risk, long-term technology, (4) stimulation of collaboration, (5) progress in commercialization of technology, and (6) longer-run changes in firm behavior that result from participating in an ATP project. These goals define how ATP projects affect the economy and society.

ATP surveys can be viewed as a microcosm of our overall evaluation program at ATP. The survey system is a multifaceted effort that is designed to meet multiple (but complementary) program goals while balancing efficiency in operation with excellence in results. This is achieved by identifying and leveraging both internal and external resources and harnessing the benefits of collaboration with survey experts (a tactic learned through our evaluation of ATP), and by relying on continual self-assessment and feedback. We do not lose sight of our goal to measure against mission, in the short, medium, and long term.

Baseline information is collected on the initial survey, and follow-up questions in each area are included at the appropriate anniversary, closeout, or post-project surveys. The surveys collect data on diffusion of knowledge (patents, publications, presentations, and other information about intellectual property); measures of social and environmental effects (spillovers); acceleration in terms of reduced time to achieve technical progress and time-to-market; collaboration

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arrangements with universities, other firms, and other organizations; national economic benefits (business growth, development of business relationships and networks); the diversity of commercial applications arising from the technology that ATP has funded; and commercialization progress and expectations of revenues from commercialization of the technology, licensing, and cost-savings.

Finally, ATP surveys capture commercialization progress, results, and expectations, or specific aspects of it, although ATP does not fund the commercialization phase of projects. Our mission at ATP is not simply to fund high-risk technologies, but to fund high-risk technologies that have a strong potential to enhance economic growth. Economic growth can only be achieved when the technology enters the marketplace. To measure this impact, information is collected from firms on current and expected economic value achieved through revenues from commercial applications of the technology, licensing, and cost savings.

Examples of ATP's Studies

As noted above, ATP uses a multifaceted approach to evaluation. To reflect the richness and diversity of the studies, several examples, including highlights of their findings, are presented below. These examples include policy studies, status reports of completed ATP-funded projects, selected survey results, and benefit-cost studies. These examples are provided to show the depth and breadth of our assessment work.

Project and Portfolio Assessment

Status reports are descriptive mini case studies for each completed ATP project written several years after ATP funding ends. Status reports address how well the project performed against ATP's mission objectives to create and disseminate knowledge via acceleration, collaboration, commercialization, and benefits to the economy beyond the firm or firms developing the ATP technologies.

A performance rating for each project (zero to four stars) is computed using a uniform set of data.[5] The aggregation of stars provides a portfolio view of ATP performance. For example, aggregating the performance ratings for the first 150 ATP projects shows the distribution shown in Table 1.

The largest group of projects, 28 percent, fell into the two- and three-star categories. The three-star projects show strong progress. Combining these with the 13 percent rated outstanding shows an impressive 41 percent of projects performing at a high level. The two-star projects show moderate progress but are not particularly robust overall. Thirty percent of the projects scored one star or less, which is not surprising, given that ATP projects are high-risk R&D and not all

[5]For examples of ATP studies and a description of the methodology used to determine the performance rating, access the NIST Web site at <*http://www.atp.nist.gov/eao/ir05-7174/chapt5.htm*>.

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TABLE 1 Distribution of Performance Ratings for First 150 ATP Projects

Percent of Projects	Performance Rating
17	0 stars
13	1 star
28	2 stars
28	3 stars
13	4 stars

projects are expected to succeed. Projects may fail for technical reasons, business reasons, or a combination of both.

Each status report also includes a patent tree for each patent filed during ATP project or after the project ends to show the citation of the patent in subsequent patents. Patent trees are updated annually to demonstrate that knowledge spillovers continue several years after the ATP project ends.

A study of the first 150 completed ATP projects shows that 203 new products or processes resulted from 91 of these projects, and employment changes for three out of five of the small companies were quite large. Forty-nine companies at least doubled in size, and 22 companies grew by more than 500 percent.

Answering the Counterfactual Question: What Happens Without ATP?

The Survey of ATP Applicants was conducted for awardees in the 1998, 2000, and 2002 competitions and is planned again for applicants from the 2004 competition. This survey was administered to all applicants in the previous competition year to compare the company and project characteristics of awardee and nonawardee companies soon after awards are announced. It addresses the counterfactual question: What happens when a project does not receive ATP funding? The survey results found that 39 percent of those projects were not pursued, and 44 were pursued on a smaller scale. Of those pursued on a smaller scale, more than four out of five reported that their project scope was reduced to below 40 percent of the proposed ATP project.

Evidence from the Survey of ATP Applicants shows that ATP is successful in directing funding to projects that have higher technical risk and longer time horizons than projects proposed by nonawardees (ATP 2003a). A measure of technical risk is the probability that a project will not achieve its technical goals.

- Among ATP awardees, the average estimate for the probability of not fully achieving technical goals is 45 percent, compared to nonawardees' estimated probability of 31 percent.
- More than half (54 percent) of ATP awardees expect a time horizon of four years or more on their proposed ATP projects, compared to one-third of nonawardees.

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Proposed ATP projects for both awardees and nonawardees are higher risk and have a longer time horizon than do typical R&D projects. ATP *awardees* report a greater contrast between their proposed and typical R&D projects, compared to nonawardees.

A key finding is that ATP awardees attract additional funding after submitting their ATP proposal. This phenomenon is referred to as the halo effect. For example, three out of four awardees report increased internal funding, whereas one out of four nonawardees reports increased funding from internal company sources. ATP awardees are also more likely to receive funding from external sources. One out of three awardees reports increased funding, and only one out of five nonawardees report increased funding from external sources (Feldman and Kelley 2001; ATP 2003a and 2005b).

Measuring Acceleration Effects

The Business Reporting System (BRS) allows an examination of ATP awardees from a longitudinal perspective and from a cross-sectional perspective. Responses to the BRS surveys indicate that ATP funding accelerated R&D in nine out of ten organizations. Of those organizations that indicated that they were ahead in their R&D cycle:

- Thirteen percent indicate they are ahead by one year.
- Fifty-three percent indicate that they are ahead by one to three years.
- Seven percent indicate that they are ahead by more than three years.

ATP participants report that the acceleration of R&D reduces the time it will take to bring products to market or to implement new production processes. Reduction in time-to-market by two years or more is anticipated for about three out of five planned commercial applications.[6]

Measuring Outcomes—Benefit-Cost Studies

Benefit-cost studies are one of the primary ways to measure outcomes quantitatively. Outcomes are difficult to measure because one must make assumptions about the impact of the new technology and acceptance by buyers. These studies examine one project or a cluster of projects in the same technology area to assess both retrospective (realized benefits) as well as future benefits. A qualitative analysis is also included in the studies.

One example of a benefit-cost study is Low-Cost Manufacturing Technology for Amorphous Silicon Detectors, a joint venture project funded by ATP in 1995

[6]Based on BRS survey data from 673 organizations in 347 ATP projects funded from 1993 to 1998, for projects with one or more years of ATP funding.

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(Pelsoci 2003). Digital mammography and radiography systems are innovative technology solutions to the diagnostic and productivity limitations of conventional x-ray systems. The new process, which was implemented in 2004, is expected to reduce fabrication costs by approximately 25 percent without compromising performance. On the basis of 33 million mammography and 68 million chest x-rays per year, prospective benefits are $125 to $193 for every $1 that ATP has spent. Societal benefits include avoidance of unnecessary medical procedures as a result of lower false-positive rates, improved breast cancer detection, reduced patient exposure to radiation, and reduced examination time.

Behavioral Additionality

Behavioral additionality is defined as the difference in firm behavior that persists over time and results from a government intervention.[7] The assumption is that government financing of business R&D changes firm behavior in a desirable direction. Behavioral additionality has generally been ignored by econometric studies of the effects of R&D support that focus on input additionality, where estimates are made of additional R&D expenditure, or output additionality, whereby firm performance is compared between recipients and nonrecipients of public support.

A one-time survey of joint ventures incorporated questions that asked about changes in firm behavior that resulted from having an ATP award. Many of the new questions are now incorporated into the ongoing BRS surveys.

Results from the Joint Venture Survey show that the formation of ATP joint venture projects and the rigor of the agreement fostered trust and cooperation among partners. Respondents reported that goodwill and trust were high among joint venture partners. A regression analysis showed ATP involvement to be an explanatory factor, along with effective governance procedures and the size of the joint venture (that is, the number of partners). Findings from another ATP survey, the Post-Project Survey, show persistent collaborative links, with 46 percent continuing to work with their partners on non-ATP technology and 14 percent with their subcontractors. More than half (55 percent) continued in R&D because of their positive ATP experience (Shipp et al. 2005). Participating in the Organisation for Economic Co-operation and Development (OECD) workshops on behavior additionality has provided ATP with new insights and approaches to our work and is especially timely as we are in the midst of improving our surveys. Including new questions that relate to behavior additionality will enhance and inform our future work.

[7]ATP is participating in an OECD working group that met in Manchester, England, in May 2004 and Vienna, Austria, in January 2005. The purpose of the working group is to present results and discuss studies conducted in several countries to measure the effect of government financing of business R&D on the long-run behavior and strategy of recipient firms in performing R&D (OECD 2005).

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Analysis of Regional Innovation Patterns

ATP has three projects under way to investigate regional innovation patterns. The first examines patent hot spots to identify geographic areas where there is intensive R&D in a specific technology area. Hot-Spot Analysis provides a filter on recent patents by focusing on the 20 percent of recent patents that are likely to have impact in the future. Using recent patents with no filtering mechanism is problematic because there were more than 300,000 patents issued in the past two years, and most of them may have little value. The project's ultimate goal is to identify those patents that are more closely associated with high-risk, early-stage technology. Use of this method is mentioned in the legislation for the National Innovation Act of 2005 to identify areas for regional economic development.

A second project is examining regional patterns graphically—for example, identifying and plotting fiber optic installation as one measure of high-tech activity. The third project is the development of a database that collects data on economic activity by area and compares it to the U.S. average or other specified areas. This is a new area of research under way, and preliminary results are intriguing.

IV. THE ADVANCED TECHNOLOGY PROGRAM—CONCLUSIONS

The ATP's mission is to support U.S. companies in pursuing early-stage, high-risk research to develop new technologies that have great potential for producing broad-based national economic benefit. ATP funds industry-led research and development projects that have high technical risk and inventiveness and promising potential for broad economic impact. Since 1990, the ATP has been a significant government player in supporting the development of emerging technologies in the United States. The rationale for programs such as the ATP rests on theory and evidence that the social benefits of R&D are greater than the private returns. A hallmark of the ATP is its multifaceted and integrated evaluation program that uses economic and statistical analysis to develop estimates of impacts of ATP funding on project timing and success. Through the use of systematic evaluation, our surveys, studies, and reports show that ATP is indeed meeting its mission to accelerate the development of high-risk, enabling technologies.

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Government Programs to Encourage Innovation by Startups & SMEs: The Role of Innovation Awards

Charles W. Wessner[1]
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Policymakers in the United States and Japan share the recognition that innovation remains the key to international competitiveness in the twenty-first century. Policymakers in both countries increasingly recognize that equity-financed small firms are an effective means of capitalizing on new ideas and bringing them to the market. Small firms, however, face a variety of obstacles as they seek to bring new products and processes to the market.[2] In this context, public policies that reduce the structural and financial hurdles facing such innovative small firms can play a useful role in enhancing a nation's innovative capacity. In the United States, innovation awards such as the Small Business Innovation Research program and the Advanced Technology Program, have proven effective in helping small innovative firms overcome these hurdles while also enhancing networking among U.S. universities, large firms, and small innovative companies.

Success in innovation has helped the United States and Japan become the world's leading economies. Remaining innovative requires, as Dr. Mary Good

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[2]Zoltan J. Acs and David B. Audretsch, *Innovation and Small Firms,* Cambridge, MA: The MIT Press, 1990.

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notes, "a *strategy* that provides resources to talented people in an atmosphere that promotes creativity—focused on outcomes ranging from new products to customer satisfaction to new scientific insights to improved social programs—to create wealth and/or improve the human condition."[3] In this information age, continuing economic leadership requires that nations adapt such a strategy to the new realities of globalized research, development, and manufacturing. As we see below, while the innovation systems in United States and Japan reflect major strengths, they also face new challenges in remaining competitive.

U.S. ASSETS AND CHALLENGES IN INNOVATION

Competitive advantages enjoyed by the United States include a large and integrated domestic market, and an economic and institutional infrastructure able to quickly redeploy resources to their most efficient use. These are buttressed by a strong higher education infrastructure, deep and flexible capital and labor markets, and strong S&T institutions. Flexible managerial and organizational structures and a willingness to adopt innovative management practices and products are distinguishing features of the U.S. economy. A major asset is an entrepreneurial culture that accepts failure as a byproduct of new entrepreneurial initiatives and a willingness of investors to provide second opportunities to experienced, if initially unsuccessful, managers. This cultural and business perspective on failure of a startup is buttressed by bankruptcy laws that limit the liability entrepreneurs face when new ventures fail. The combination of these features generates an adaptive and rapidly changing innovation ecosystem that creates many successful small companies and enables some to grow into new large firms.

Some of these competitive advantages are the result of substantial and sustained public investments in education and research and development (R&D), many of which date to policies adopted in the cold war period. Although overall economic prospects in the United States today remain healthy, business leaders, senior academics, and experienced policymakers believe that the country is now facing major challenges to its technological leadership. Many point, for example, to inadequacies in the education system, especially at the secondary level where U.S. students score below their peers abroad in science and mathematics. These concerns have spawned recent studies that highlight troubling trends in publications, foreign-student retention, high-technology exports, and the production of information technology products. It is also true that fewer U.S. students are pursuing science careers and that the United States may be losing some of its attraction as a destination for the best students from around the world.[4]

[3]Mary Good, Presentation at the National Academies conference on "Accelerating Innovation," Washington, D.C., October 19, 2005.

[4]See, for example, recent reports by—the President's Council of Advisors on Science and Technology, "Sustaining the Nation's Innovation Ecosystems," January 2004; Council on Competitiveness,

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The role of foreign students in the U.S. innovation system is generating growing concern. Although the United States remains the major destination for students from around the world to pursue advanced training and high-skill employment, these individuals are increasingly offered new opportunities at home and elsewhere. A recent study by the National Academies found that as countries such as China and India develop their own public and private research infrastructures and as multinational companies outsource more of their R&D abroad, there are more opportunities for talented scientists and engineers to pursue world class research in their own countries.[5] Post-9/11 reductions in visas for foreign students may have accelerated this dispersal by making it more difficult for many scholars to stay and work in the United States, a trend deplored in the reports noted above.[6]

In part, the falloff in U.S. students pursuing careers in science and engineering may be an unanticipated byproduct of a falloff in R&D funding levels following the end of the cold war as federal agencies adjusted to new mission priorities. The falloff in R&D funding, documented by the Board on Science, Technology, and Economic Policy of the National Academies, shows that funding for physics, chemistry, and engineering suffered significant cutbacks.[7] (See Figure 1.) These reductions in funding have arguably prompted fewer students to pursue science and engineering degrees.[8] In any case, the lag effects of these reductions will take years to be fully manifest.

Responding to this and other concerns about the nation's innovation capacity, the U.S. Congress recently requested the National Academies to assess the nation's competitive situation and identify concrete steps to ensure its economic leadership. The resulting National Academies report, *Rising Above the Gathering Storm* notes that weakening federal commitments to science and technology place the future growth and prosperity of the United States in jeopardy:

> Although many people assume that the United States will always be a world leader in science and technology, this may not continue to be the case, inasmuch as great minds exist throughout the world. We fear the abruptness with which a

Innovate America: Thriving in a World of Challenge and Change, Washington, D.C.: Council on Competitiveness, 2005; and National Academy of Sciences/National Academy of Engineering/Institute of Medicine, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future,* Washington, D.C.: The National Academies Press, 2007.

[5]National Research Council, *Policy Implications of International Graduate Students and Postdoctoral Scholars in the United States,* Washington, D.C.: The National Academies Press, 2005.

[6]See, for example, National Academy of Sciences/National Academy of Engineering/Institute of Medicine, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future,* op. cit.

[7]National Research Council, *Trends in Federal Support of Research and Graduate Education*, Stephen A. Merrill, ed., Washington, D.C.: National Academy Press, 2001.

[8]Ibid.

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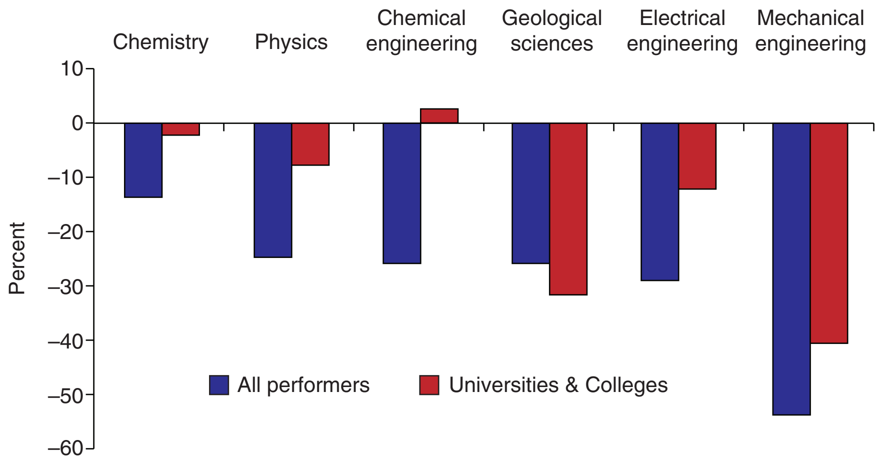

FIGURE 1 Changes in federal research obligations for all performers and university/college performers, FY1993-FY1999 (constant 1999 dollars).
SOURCE: National Research Council, *Trends in Federal Support of Research and Graduate Education*, Stephen A. Merrill, ed., Washington, D.C.: National Academy Press, 2001.

> lead in science and technology can be lost—and the difficulty of recovering a lead one lost, if indeed it can be regained at all.[9]

To overcome this growing vulnerability, the report calls for (among other measures) expanding the U.S. talent pool by providing greater incentives for science and mathematics teachers. The report also calls for increasing federal investments in long-term basic research by 10 percent per annum over the next seven years. In addition, it recommends a variety of steps to make the United States a more attractive place for foreign students to study and perform research, including actions to increase the number of visas that permit U.S.-trained foreign students to remain and work in the United States after their studies are completed.[10]

SOME STRENGTHS AND CHALLENGES IN INNOVATION FACING JAPAN

Like the United States, Japan also faces a competitive challenge from China and other Asian countries. Yet, despite reports about the sclerotic state of the Japanese economy, its relatively closed innovation system, and its aging popula-

[9]National Research Council, *Rising Above the Gathering Strom: Energizing and Employing America for a Brighter Economic Future*, op. cit.
[10]Ibid, page ES-2.

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TABLE 1 Turning Japanese: Top U.S. Patent Award Recipients, 2004

	Number of Patents	2003 Rank
IBM	3,248	1
Matsushita Electric	1,934	4
Canon	1,805	2
Hewlett-Packard	1,775	5
Micron Technology	1,760	6
Samsung Electronics	1,604	9
Intel	1,601	7
Hitachi	1,514	3
Toshiba	1,310	13
Sony	1,305	10

SOURCE: U.S. Patent and Trademark Office, as reported in *The Economist*, "Competing through Innovation," December 17, 2005.

tion, Japan remains one of the world's technology powerhouses. A distinguishing feature of the Japanese economy is the large proportion of R&D carried out in the laboratories of large companies, a system that is by definition more proprietary and therefore less open than university-based systems.

The Japanese approach is enormously productive. As Table 1 shows, Japanese companies are world leaders in patents, representing five of the top ten U.S. patent award recipients.

Most of these patents, moreover, pertain to advanced technologies such as telecommunications and electronics. Japan is also a leader in integrated manufacturing, producing some of the world's best machine tools, automobiles, and high-end electronics.[11] Japan is also making substantial investments and progress in areas such as aerospace and solar technologies. Solar panels for residential use have seen regular price declines resulting from economies of scale and incremental improvements in efficiency, a proven Japanese approach to bringing new technologies to the market.[12]

Despite these considerable strengths, concern remains that Japan's "innovative genius is more suited to constant improvements in integrated manufacturing than to blue-sky inventions."[13] The worry is that even if Japan remains competitive in the present, it may not have the necessary agility to adapt rapidly to future trends. Whereas traditional Japanese strengths in corporate innovation have rested within the traditional Keiretsu structure, this tight integration among suppliers, manufacturers, distributors, and retailers can make it very difficult for innovative

[11] *The Economist*, "Competing Through Innovation," December 17, 2005.

[12] Ibid.

[13] *The Financial Times*, "World Leader in Patents Focuses on Incremental Innovations," October 12, 2005.

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new firms to break into established markets.[14] An additional challenge is that institutional links between universities and industry have traditionally been weak in Japan, making it difficult for new ideas born outside corporate laboratories to find sponsorship.[15]

The good news, however, is that Japanese policymakers, leading analysts, and others have recognized the need to strengthen this element of the innovation system. A variety of measures to improve Japan's innovation potential were adopted over the past decade. For example, Japan's 1995 S&T Basic Law encourages university-industry partnerships.[16] Recent legislation has also encouraged more public investment in universities as well the creation of new graduate programs that avoid the hierarchical limitations of traditional universities.[17] Spurred by this new policy environment, Japanese and foreign venture capitalists are seeking in greater numbers to provide funding for new, entrepreneurial firms.[18] The number of university-based startups is showing substantial progress as well.[19]

Increasingly, the importance of greater openness is also recognized as important for Japan's future innovative potential. For example, in a recent presentation, the OECD's Director for Science, Technology, and Industry, Nobua Tanaka, drew attention to the fact that a more open economy has positive consequences for national innovative capacity.[20] He noted that international collaboration in science and technology, which entails encouraging foreign students to study at domestic universities, welcoming foreign professors, and encouraging more foreign direct investment, can contribute to an atmosphere of greater openness within public research organizations, universities, and businesses, spurring creativity, innovation, and growth. To support this point, Tanaka cites recent research by the OECD that finds that openness has significant positive impacts on the economy, notably that the marginal return on foreign R&D is three time higher than that generated by business R&D and more than twice as high as that from public R&D.[21]

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[14] Henry S. Rowen and A. Maria Toyoda, "From Kiretsu to Start-ups: Japan's Push for High-Tech Entrepreneurship," Asia-Pacific Research Center Working Paper, Stanford, CA, 2002.

[15] *The Economist*, "Competing Through Innovation," op. cit.

[16] Access the English text of the 1995 S&T Basic Law at <*http://www.mext.go.jp/english/kagaku/scienc04.htm*>.

[17] Yamada Reiko, "University Reform in the Post-massification Era in Japan: Analysis of Government Education Policy for the 21st Century," *Higher Education Policy* 14(4):277-291, 2001.

[18] *The Economist*, "Competing Through Innovation," op. cit.

[19] *The Economist* reports that between 2000 and 2003 the number of startups created to commercialize discoveries at Japanese universities rose from 315 to 800. Ibid.

[20] Presentation by Mr. Nobua Tanaka, Director, DSTI/OECD at the International Forum on Technology Foresight and National Innovation Strategies, Seoul, Republic of Korea, November 4, 2005.

[21] Recent OECD research finds that 1 percent more in business R&D generates 0.13 percent in productivity gains and 1 percent more in public R&D generates 0.17 percent in productivity gains, while 1 percent more in foreign R&D generates 0.45 percent gain in productivity growth. See Dominique Guellec, and Bruno van Pottelsberghe de la Potterie, "R&D and Productivity Growth: Panel Data Analysis of 16 OECD Countries," Organisation for Economic Co-operation and Development, DSTI Working Papers 2001/314, June 2001.

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Such a policy of openness to foreign researchers and investment has served the United States well. Despite oft-cited (and often justified) fears about intellectual theft and national security vulnerabilities related to sensitive research topics, the United States has on balance benefited from its relatively open innovation system.[22]

With the postwar internationalization of its university research system, the United States has welcomed many of the best students in the world, many of whom stayed and contributed to the U.S. economy following graduation. Even students who returned home after completing their degrees in the United States have in many cases proved to be a source of future research collaboration, business relationships, and political support as well as a significant source of innovation and growth in their home countries. The international exchange has also been of benefit to many U.S. students, exposing them to foreign perspectives and practices and thus preparing them to function more effectively in the increasingly integrated world of science and technology.[23]

This value of openness is increasingly appreciated in Japan. Recognizing that the nation's traditional industry-based research laboratories are prone to be closed (given that private firms have an incentive to protect proprietary information that is the basis of their competitive advantage), Japanese policies have increasingly encouraged more university-based research and small business research. They have also increased the emphasis on the transfer mechanisms needed to help usher non-corporate innovation to the marketplace.[24]

SMALL INNOVATIVE BUSINESS IS A KEY SOURCE OF INNOVATION

In seeking to broaden Japan's innovation base, Japanese policymakers seem to have recognized that equity-financed small firms are an effective mechanism for capitalizing on new ideas and bringing them to the market.[25] In the United States, small firms are also a leading source of employment growth, generating 60-80 percent of net new jobs annually over the past decade. These small businesses also employ nearly 40 percent of the U.S. science and engineering workforce.[26] Scientists and engineers working in small businesses produce 14 times

[22]The Corson and Allen Reports of National Academy of Sciences studies found open research laboratories to be in U.S. national interest, despite these threats. National Research Council, *Scientific Communication and National Security,*" Washington, D.C.: National Academy Press, 1982; National Research Council, *Balancing the National Interest: U.S. National Security Export Controls and Global Economic Competition*, Washington, D.C.: National Academy Press, 1987.

[23]Eugene B. Skolnikoff, "Knowledge Without Borders? Internationalization of the Research Universities," *Daedalus* 122(4), 1993.

[24]Yamada Reiko, "University Reform in the Post-massification Era in Japan: Analysis of Government Education Policy for the 21st Century," op. cit.

[25]Zoltan J. Acs and David B. Audretsch, *Innovation and Small Firms,* op. cit.

[26]U.S. Small Business Administration, Office of Advocacy, "Small Business by the Numbers," Washington, D.C.: U.S. Small Business Administration, June 2004.

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more patents than do their counterparts in large firms and these patents tend to be of higher quality and are twice as likely to be cited.[27]

In the United States, firms like Microsoft, Intel, AMD, FedEx, Qualcomm, and Adobe, all of which grew rapidly in scale from small beginnings, have transformed how people everywhere work, transact, and communicate. This record supports the encouragement of new equity-based high-technology firms so that some may develop into larger, more successful firms that create the technological base for future competitiveness.

. . . YET SMALL BUSINESS WILL FACE MAJOR CHALLENGES ON THE ROAD TO COMMERCIAL SUCCESS

Even so, commonly held myths in the United States about the innovation process pose major obstacles to developing and even maintaining policies that encourage small firms with valuable new ideas to persevere. Many U.S. policymakers have a belief in the primacy of the market and a reluctance to recognize its limitations. For example, a common U.S. myth, at least among Washington policymakers, is that "if it's a good idea, the market will fund it." In reality, there is no such thing as "The Market." Unlike the market model found in introductory economics texts, real world markets always operate within specific rules and conventions that lend unique characteristics to particular markets, and nearly all markets suffer from seriously imperfect information. Indeed, the problem of imperfect capital markets is particularly challenging for fledgling entrepreneurs. The knowledge that an entrepreneur has about his or her product is normally not fully appreciated by potential customers—a phenomenon that economists call *asymmetric information*. This asymmetry can make it hard for small firms to obtain funding for new ideas because, as Michael Spence (a recent Nobel Prize winner) points out, new ideas are inherently hard to understand.[28]

Market entry is thus a challenge for new entrepreneurs, especially those with new ideas for a potentially disruptive product. These entrepreneurs are also likely to be unfamiliar with government regulations and procurement procedures, and academic researchers may be unacquainted with commercial accounting and business practices. Many small firms are therefore at a disadvantage vis-à-vis incumbents in the defense-procurement process and face especially high challenges with regard to finance.[29]

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[27]Ibid.

[28]The Nobel Committee cited Spence's contribution in highlighting the importance of market signals in the presence of information asymmetries. For his seminal paper on this topic, see Michael Spence, *Market Signaling: Informational Transfer in Hiring and Related Processes*, Cambridge: MA: Harvard University Press, 1974.

[29]With regard to the challenges small firms face in obtaining funding, see Lewis M. Branscomb and Philip A. Auerswald, *Taking Technical Risks: How Innovators, Executives, and Investors Manage High-Tech Risks*, Boston, MA: The MIT Press, 2001. See also Josh Lerner, "Public Venture Capital,"

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Innovators in large firms also face a similar problem, where multiple options, established hurdle rates, and technological and market uncertainties militate against even promising technologies. As Dr. Bruce Griffing, the laboratory manager responsible for developing mammography diagnostic technology for General Electric, has noted, "there is a valley of death for new technologies, even in the largest companies." [30]

Another hurdle for entrepreneurs is the "leakage" of new knowledge that escapes the boundaries of firms and intellectual property protection. The creator of new knowledge can seldom fully capture the economic value of that knowledge for his or her own firm. This spillover can inhibit investment in promising technologies for large as well as small firms, but it is especially important for small firms focused on a particularly promising product or process.[31]

The challenge of incomplete and insufficient information for investors and the problem for entrepreneurs of moving quickly enough to capture a sufficient return on "leaky" investments pose substantial obstacles for new firms seeking private capital. The difficulty of attracting investors to support an imperfectly understood, still-undeveloped innovation is especially daunting. Indeed, the term "Valley of Death" has come to describe the period of transition when a developing technology is deemed promising but is too new to validate its commercial potential and thereby attract the capital necessary for its development.[32] This simple image of the valley of death captures two important points. The first is that although there are substantial national R&D investments in the United States, Japan, and elsewhere, the path to transitioning these investments in research to create valuable products is not self-evident, given the informational and financial constraints noted above. A related point is that technological value does not lead inevitably to commercialization. Many good ideas perish on the way to the market. The challenge for policymakers is to help firms create additional market-relevant information by supporting the development of promising ideas through this difficult early phase.

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in National Research Council, *The Small Business Innovation Program: Challenges and Opportunities,* Charles W. Wessner, ed., Washington, D.C.: National Academy Press, 1999. On the challenges facing small businesses in defense procurement, see remarks by Kenneth Flamm in National Research Council, *SBIR: Program Diversity and Assessment Challenges*, Charles W. Wessner, ed., Washington, D.C.: The National Academies Press, 2004, Pp. 11, 64, and 65.

[30]Bruce Griffing, "Between Invention and Innovation, Mapping the Funding for Early Stage Technologies," Presentation at the Carnegie Conference Center, Washington, D.C., January 25, 2001.

[31]Edwin Mansfield, "How Fast Does New Industrial Technology Leak Out?" *Journal of Industrial Economics* 34(2):217-22, 1996.

[32]See the schematic of the Valley of Death in the paper by Stephanie Shipp and Marc Stanley, "Government's Evolving Role in Supporting Corporate R&D in the United States: Theory, Practice and Results in the Advanced Technology Program," in this volume. For a discussion of the Valley of Death, see Vernon J. Ehlers, *Unlocking Our Future: Toward a New National Science Policy: A Report to Congress by the House Committee on Science,* Washington, D.C.: U.S. Government Printing Office, 1998, Accessed at <*http://www.access.gpo.gov/congress/house/science/cp105-b/science105b.pdf*>.

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Notwithstanding the reality of these early-stage financing hurdles, many believe that the U.S. venture capital markets are so broad and deep that entrepreneurs can readily access the capital needed to cross the valley of death. In actual fact, venture capitalists not only have limited information on new firms but are also prone to herding tendencies, as witnessed in the recent dot.com boom and bust.[33] Venture capitalists are also, quite naturally, risk averse. Their primary goal, after all, is not to develop the nation's economy but to earn significant returns for their investors.[34] Accordingly, most funds tend to focus on later stages of technology development because there is more information at this stage in the process about the commercial prospects of the innovation (and hence less risk to their investment.) The result is that the U.S. venture capital market, although large, is not focused on early-stage firms: In 2004, startups in the United States received only \$346 million or 1.65 percent of the \$20.9 billion of available venture capital.

What's more, the amount of venture capital made available varies enormously with the vigor of the stock market, the normal outlet for initial public offerings, which are the primary means by which venture capitalists recoup their fund's investments. The collapse of venture capital investment beginning in the second quarter of 2000, for example, followed the dramatic stock market declines of March 2000.[35] Venture funding fell from an unsustainable \$94.6 billion in 2000 to \$18.9 billion in 2003. Since then, there has been a modest up-tick in funding commitments, with \$20.9 billion in funding in 2004, and a similar amount expected in 2005. First-round funding for new companies remains limited as venture firms continue to invest further downstream, where risks are more manageable.

FILLING THE FUNDING GAP

The limitations of the market for venture capital require that small innovative firms seek funding from a variety of sources.[36] In addition to pursuing business angels and venture capital firms, early stage technology firms also seek development funding from industry, federal and state governments, and universities. Indeed, the diversity of these sources for early-stage funding represents one of the strengths of the U.S. system. There are longstanding state programs such as the Ben Franklin program in Pennsylvania and more recent innovation efforts such as TEDCO in Maryland. Both provide early-stage loans on a limited scale.

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[33]See Tom Jacobs, "Biotech Follows Dot.com Boom and Bust," *Nature* 20(10):973, October, 2002.

[34]The goal of venture capitalists is to make money for our fund investors—not to develop the economy." Personal communication with David Morgenthaler, founder Morgenthaler Ventures and past President of the National Venture Capital Association.

[35]William L. Megginson, "Towards a Global Model of Venture Capital?" *Journal of Applied and Corporate Finance* 16(1), 2004.

[36]Lewis M. Branscomb and Philip E. Auerswald, *Between Invention and Innovation: An Analysis of Funding for Early-Stage Technology Development,* Gaithersburg, MD: NIST GCR 02–841, November 2002.

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Surprisingly, among these funding sources, the role of the federal government is significant for its size and importance. Research by Branscomb and Auerswald estimates that the federal government provides 20-25 percent of all funds for early-stage technology development—a substantial role by any measure and one often surprising to Americans in its dimensions.[37] This federal contribution is rendered more significant in that competitive government awards address segments of the innovation cycle that private institutional investors often (quite rightly) find too risky.

The availability of early-stage financing and its interaction with other elements of the U.S. innovation process are the focus of growing analytical efforts.[38] As we examine below, the Small Business Innovation Research Program (SBIR) is the largest example of the government's public-private partnership efforts to draw on the inventiveness of small, high-technology firms though competitive innovation awards. The potential of SBIR in this regard underscores the need to understand how it strengthens the nation's innovation capacity.

THE SMALL BUSINESS INNOVATION RESEARCH PROGRAM (SBIR)

The SBIR program, created in 1982 through the Small Business Innovation Development Act, designed to stimulate technological innovation among small private-sector businesses while providing the government new, cost-effective, technical and scientific solutions to challenging mission problems. SBIR was also designed to encourage a role for small businesses in federal R&D and facilitate the development of innovative technologies in the private sector, helping to stimulate the U.S. economy.[39]

[37]It is important to remember that these are estimates. The authors stress the "limitations inherent in the data and the magnitude of the extrapolations . . ." and urge that the findings be interpreted with caution. They note further that while the funding range presented for each category is large, these approximate estimates, nonetheless, provide "valuable insight into the overall scale and composition of early-stage technology development funding patterns and allow at least a preliminary comparison of the relative level of federal, state, and private investments." For further discussion of the approach and its limitations, see Lewis M. Branscomb and Philip E. Auerswald *Between Invention and Innovation: An Analysis of Funding for Early-Stage Technology Development,* op. cit., pp. 20-24.

[38]The growth and subsequent contribution of venture capital have begun to attract the serious study needed to illuminate the dynamics of high-technology firm evolution. See for example, the work of Jeffrey Sohl and colleagues and the University of New Hampshire's Center for Venture Research, described at <*http://www.unh.edu/cvr*>.

[39]The SBIR legislation drew from a growing body of evidence, starting in the late 1970s and accelerating in the 1980s, which indicated that small businesses were assuming an increasingly important role in both innovation and job creation. This evidence gained new credibility with the empirical analysis by Zoltan Acs and David Audretsch of the U.S. Small Business Innovation Data Base, which confirmed the increased importance of small firms in generating technological innovations and their growing contribution to the U.S. economy. See Zoltan Acs and David Audretsch, *Innovation and Small Firms*, op. cit.

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The SBIR concept has several significant advantages:

- The program is focused on helping small companies bring their ingenuity to focus on government and societal needs in domains as diverse as health, security, the environment, energy efficiency, and alternative energy sources.
- The needs are articulated by government agencies, and the proposals are initiated by individual companies, often new to government R&D programs.
- A two-phase filter is employed with fewer than 15 percent of applicants being accepted in the first phase and approximately half in the second phase.
- The program has no budget line, requires no new funds, and is therefore both politically viable and relatively impervious to the whims of the budget process.
- The program is decentralized across the government. Program ownership rests with many agencies quite different in size and with dramatically different missions. The program is not the responsibility of a single "innovation agency."

Since its establishment in 1982, the SBIR program has grown to some $2 billion per year and includes eleven federal agencies that are currently required to set aside 2.5 percent of their extramural R&D budget exclusively for SBIR contracts for small companies (fewer than 500 employees).[40] Each year these agencies identify various scientific and technical problems to which might be able to provide innovative solutions. These topics are published as individual agency "solicitations," which are now normally made available through Web postings. A small business can identify an appropriate topic it wants to pursue from these solicitations and offer a proposal for an SBIR grant. The required format for submitting a proposal is different for each agency. The proposals are reviewed and evaluated on a competitive basis by technical experts, sometimes drawn from the federal laboratories or research centers. Since 1992 more emphasis has been given to commercialization potential. Each agency then selects the best proposals. Given the different agency missions, the instruments vary, with the Department of Defense and the National Aeronautics and Space Administration awarding contracts and agencies such the National Institutes of Health and the National Science Foundation awarding grants to the most highly qualified small businesses with the most innovative solutions.

Program Structure

As conceived in the 1982 Act, SBIR's grant-making process is structured in three phases:

[40]These include the Department of Defense, the Department of Health and Human Services, the National Aeronautics and Space Administration, the Department of Energy, the National Science Foundation, the Department of Agriculture, the Department of Commerce, the Department of Education, the Department of Transportation, the Environmental Protection Agency, and the Department of Homeland Security.

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- Phase I grants essentially fund a feasibility study in which award winners undertake a limited amount of research aimed at establishing an idea's scientific and commercial promise. The 1992 legislation prescribed Phase I grants as high as $100,000.[41]
- Phase II grants are larger—typically about $750,000—and fund more extensive R&D to develop the scientific and technical merit and the feasibility of research ideas. [42]
- Phase III. This phase does not involve SBIR funds but is the stage at which grant recipients should be obtaining additional funds either from a procurement program at the agency that made the award, from private investors, or from the capital markets. The objective of this phase is to move the technology from the prototype stage and into the marketplace.

Phase III of the program is often fraught with difficulty for new firms. In practice, agencies have developed different approaches to facilitating this transition to commercial viability; not least of which are additional SBIR awards. While some firms with more experience with the program have become skilled in obtaining additional SBIR awards, a wide variety of firms interact with the program. Nearly a third of the recipients of SBIR awards are new to the program each year. As noted, other firms have received multiple awards—sometimes many awards—over a sustained period. Normally this reflects agency satisfaction with the quality of the research and/or product being provided. It is important to keep in mind that not all proposals call for commercialization, and not all successful SBIR products can be commercialized.[43]

Motivation among firms varies. Previous National Research Council research has shown that different firms have quite different objectives in applying to the program. Some seek to demonstrate the potential of promising research. Others seek to fulfill agency research requirements on a cost-effective basis. Still others seek a certification of quality (and the investments that can come from such recognition) as they push science-based products toward commercialization.[44]

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[41]With the agreement of the Small Business Administration, which plays an oversight role for the program, this amount can be higher in certain circumstances; e.g., drug development at NIH, and is often lower with smaller SBIR programs, e.g., the Environmental Protection Agency or the Department of Agriculture.

[42]NSF, for example, makes Phase II awards at the $500,000 level. In its Phase II-B plus program, NSF provides up to an additional $250,000 in matching funding for firms that attract private funding—providing an incentive for firms to actively commercialize their product.

[43]For example, a logarithm developed under a NASA award to improve air traffic flow within the United States is dependent on adoption by a risk-averse Federal Aviation Administration.

[44]See Reid Cramer, "Patterns of Firm Participation in the Small Business Innovation Research Program in Southwestern and Mountain States," in National Research Council, *The Small Business Innovation Research Program: An Assessment of the Department of Defense Fast Track Initiative*, Charles W. Wessner, ed., Washington, D.C.: National Academy Press, 2000.

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Features that make SBIR grants attractive from the firm's perspective, aside from the funding itself, include the fact that there is no dilution of ownership or repayment required. Importantly, grant recipients retain rights to intellectual property developed using the SBIR award, with no royalties owed to the government. The government retains royalty-free use for a period, but this is very rarely exercised. Selection to receive SBIR grants also tends to confer a certification effect, a signal to private investors of the technical and commercial promise of the technology.[45]

From the perspective of the government, the SBIR program helps officials draw on private sector ingenuity to achieve their respective agency missions.[46] By providing a bridge between small companies and the federal agencies, especially for procurement, SBIR serves as a catalyst for the development of new ideas and new technologies to meet federal missions in health, transport, the environment, and defense. In the case of defense procurement, the program offers a valuable bypass to the heavily encumbered defense procurement process with its "mil-spec" requirements that often impede the adoption of new performance-enhancing technologies. In short, if effectively managed and above all integrated closely with current mission requirements, SBIR can be a win-win opportunity for both the entrepreneur and the government agency, with further benefits to society from the efficiencies and innovations that the program can introduce.

SBIR AND THE UNIVERSITY CONNECTION

SBIR also provides a bridge between universities and the marketplace. An important percentage of SBIR awards involve university researchers either as firm founders or as participants in the research, in the latter case as principal investigators or subcontractors. This substantial university involvement is somewhat ironic. When the SBIR program was created in the early 1980s, universities strongly objected to the program, seeing it as a source of competition for federal R&D funds. In the course of the decade of the 1990s, this perception of the program significantly evolved. In the commercialization-sensitive environment created by the Bayh-Dole Act, SBIR awards were increasingly seen by researchers and the university leadership as a source of early-stage financial support for university researchers with promising ideas. The catalytic role of SBIR awards is described in Figure 2.

The role of SBIR in encouraging professors to found companies based on their research appears to be growing in importance.[47] Importantly, the avail-

[45]This certification effect was initially identified by Josh Lerner, "Public Venture Capital," in National Research Council, *The Small Business Innovation Program: Challenges and Opportunities*, op. cit.

[46]See National Research Council, *SBIR: Program Diversity and Assessment Challenges,* op. cit.

[47]This remains to be empirically determined, although there is substantial anecdotal evidence supporting this trend. For an illustrative case, see David Audretsch et al., "Does the Small Business

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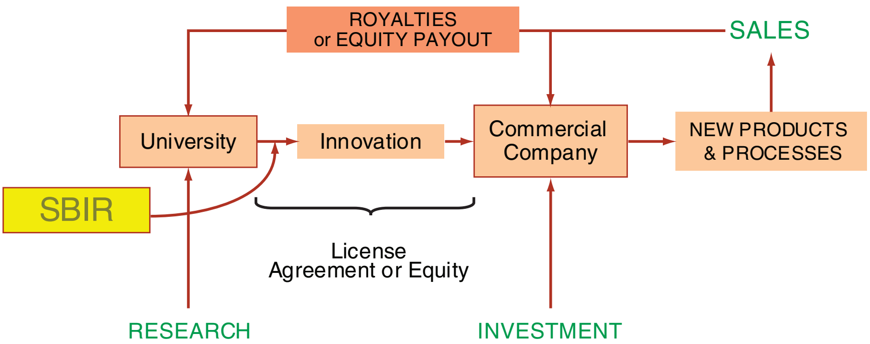

FIGURE 2 How ideas are commercialized: Transferring university technology to firms.
SOURCE: Adapted from Christina Gabriel, Carnegie Mellon University.

ability of the awards and the fact that a professor can apply for an SBIR award without quitting his or her university post or actually having a firm, encourages applications from academics who could not otherwise tolerate the risk involved in commercializing their own technologies. Initial National Academy of Sciences research has shown that SBIR awards directly cause the creation of new firms, with positive benefits in employment and growth for the local economy.[48]

Contrary to what one might expect, the awards generally do not seem to detract from the teaching role of the university professor. On the contrary, the real-life application of research with the attendant recognition in academic, technical, and financial terms can serve as a source of inspiration for students to pursue the real-world applications of their studies to societal needs in health, the environment, or national security. Similarly, well-constructed agreements can provide access to otherwise cost-prohibitive technological resources, thus enhancing the relevance of the students' educational experience.[49] University innovation along with early-stage funding by the government have spurred the growth of many successful technology companies, promoting a positive symbiotic relationship between the university and the regional economy.[50]

Innovation Research Program Foster Entrepreneurial Behavior? Evidence from Indiana," in National Research Council, *The Small Business Innovation Research Program: An Assessment of the Department of Defense Fast Track Initiative*, op. cit.

[48]National Research Council, *The Small Business Innovation Research Program: An Assessment of the Department of Defense Fast Track Initiative,* op cit., p. 35.

[49]Cooperation with private companies is not without risk and requires careful management; yet even controversial agreements like the 1998 Berkeley agreement with Novartis seemed to have provided significant benefits to the university with no loss to academic freedom. See Gordon C. Rausser, Letter to the Editor, *Atlantic Monthly* May 19, 2000. Accessed at <*http://www.cnr.berkeley.edu/pdf/dean_rausser/Atl_ltr_edt_5_2000.pdf*>.

[50]Jennifer A. Henderson and John J. Smith, "Academia, Industry, and the Bayh-Dole Act: An Implied Duty to Commercialize," White Paper, Center for the Integration of Medicine and Innovative Technol-

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SBIR AND ATP

Along with the SBIR Program, the Advanced Technology Program (ATP) is a key example of programs designed to help bring high-risk, enabling, and innovative civilian technologies to market.[51] As described in the paper in this volume by Shipp and Stanley, ATP's mission is to provide funds for the development of generic technologies that are often too risky for individual firms but, if successful, can offer high payoffs for society as a whole.

The ATP and SBIR programs complement each other. The larger award sums offered by ATP, its focus on next-stage commercialization, as well as the synergies it creates between small and large firms make ATP, in effect, an SBIR Phase III—helping to commercialize successful prototypes funded by the SBIR program.

Together, the SBIR and ATP innovation award programs illustrate the best practice principles behind successful partnerships. Their awards are limited in time and limited in amount, and they require industry to take ownership through risk and cost sharing. They also foster collaboration among small companies, large companies, and (increasingly) universities. The dissemination of enabling technologies made possible by these programs makes both small and big firms more competitive, helps accomplish government missions faster and at lower costs, and improves the nations' productivity, enabling all citizens to enjoy the fruits of technological advances and economic growth.

CONCLUSIONS: LEARNING FROM EACH OTHER

Learning from each others' experience is a pathway for mutual progress. Given the cultural norms in Japan, SBIR-type awards would perhaps work best with existing firms but could also be used to encourage cooperation between small firms and universities.[52] An ATP-type program could also have a broader application, bringing large Japanese firms together with universities and small companies. For these programs to be effective, some of the management principles successful in the United States could be applicable in the Japanese context as well.

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ogy, Harvard University, October 2002. It is important to reemphasize that not all universities have a commercialization culture, and among those that do, not all have a successful commercialization process. For a discussion of some of the reasons for this variation, see Donald Siegel, David Waldman, and Albert Link, "Toward a Model of the Effective Transfer of Scientific Knowledge from Academicians to Practitioners: Qualitative Evidence from the Commercialization of University Technologies," *Journal of Engineering and Technology Management* 21(1-2):115-142, 2004.

[51]See paper by Stephanie Shipp and Marc Stanley, "Government's Evolving Role in Supporting Corporate R&D in the United States: Theory, Practice and Results in the Advanced Technology Program," in this volume. ATP ceased to exist in 2007. Its successor is the Technology Innovation Program.

[52]One example of a cultural norm found in Japan is *Haji* or "shame culture," which stands in contrast to Western "guilt culture." See Takie Sugiyama Lebra, "The Social Mechanism of Guilt and Shame: The Japanese Case," *Anthropological Quarterly* 44(4):241-255, 1971.

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While our national innovation systems differ in scale and flexibility, both Japan and the United States face similar challenges in innovation. We have to address these new challenges by becoming more innovative and productive, and we have to justify R&D expenditures by creating new jobs and new wealth. To do this, our countries have to reform existing institutions and create new ones. Rather than merely announce the need for change, we have to craft new mechanisms that shift incentives in a positive way.

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Programs to Stimulate Startups and Entrepreneurship in Japan: Experiences and Lessons

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1. THE DECLINE OF STARTUP RATE AND THE CHANGE IN POLICIES TO STIMULATE STARTUP IN JAPAN

During Japan's high-growth era that lasted through the 1970s, startup firms maintained a high entry rate. However, based on some statistic data, the entry rate fell in the 1970s-1980s, indicating the stagnant entrepreneurship activity in Japan. Concerned that this decline in new business activity might weaken the nation's economy, the government began in 2000 to institute policy measures designed to stimulate formation of new companies.

This chapter provides a preliminary assessment of how these policies have affected startups and small and medium enterprises (SMEs).

The Japanese government first became aware of the reversal of the rate of entry and exit in 1989, which was reported in the "White Paper on Small and Medium Enterprises in Japan." Although the paper warned that the slowdown in startup formation could lead to economic stagnation, it took a long time for this recognition to lead to actual policy changes. It was only after the revision of the Small and Medium Enterprise Basic Law in 1999 that the Japanese government began to address the entrepreneurial challenge. The reason for this 10-year interval between the recognition and the action is, in my view, due to the irreconcilability of the policies needed to promote startup activity with the existing SME policies. Until the 1990s, the Small and Medium Enterprise Basic Law (hereafter referred

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to as the "Old Law") enacted in 1963 guided the policies for small and medium enterprises in Japan. The Old Law intended to correct the "dual structure" in which small and medium companies trailed behind their large counterparts in wage and labor productivity. If SMEs could not match the performance of large companies, it was not desirable to encourage the creation of more SMEs.[1] However, the situation changed in the 1990s when the government recognized that in England and the United States startup companies had provided a valuable stimulus to the economy since the 1980s. Therefore, in 1999 the Japanese government revised considerably the Small and Medium Enterprise Basic Law. This "New Law" aimed to promote diverse and vigorous growth of independent SMEs.[2] After this turning point, government took a series of steps to promote startups.[3] The Japanese government's 2001 "Startup-Doubling Plan" has as its target a doubling of startups from 180,000 in 2001 to 360,000 by the year 2006.

2. THE MAIN POLICIES TO PROMOTE ENTREPRENEURSHIP ACTIVITY IN JAPAN

The primary policies to support startup companies are (1) removal of the minimum capital requirement for the establishment of limited liability companies, (2) provision of education and information for entrepreneurs through the National Startup and Venture Forum, and (3) a new startup loan program through the National Life Finance Corporation, which requires no collateral, guarantors, or personal guarantees, and the expansion of the upper limit of "free property" based on the New Bankruptcy Law.[4]

Removal of Minimum Capital Regulation

Removal of the minimum capital requirement for limited liability companies was conditionally executed in February 2004 by way of revision of the Law for

[1]In 1989 when the reversal of the rate of entry and the exit rate based on number of enterprises was discovered, the author was working for the Small and Medium Enterprise Agency (SME Agency) as a deputy director. A discussion was held for determining policy stance toward this phenomenon. In the discussion, the dominant opinion was that policies that drove small businesses to excessive competition were not desirable.

[2]The New Law intends to support highly motivated SMEs in order to revitalize the Japanese economy, in contrast with the Old Law the objective of which was to support existing SMEs to correct social and economic distortion. By definition, New Law and Old Law could be said to have contrasting images of SME policy—that is, one as a part of industry policy and the other as a part of social policy.

[3]The "White Paper on Small and Medium Enterprise in Japan" is composed of annual analysis of SMEs and of policies to be taken in the next fiscal year. The first occasion that the "White Paper" focused on policy measures for startup was the parts which described SME policies in fiscal year 1999, the year the Small and Medium Enterprise Basic Law was amended.

[4]Entered effect on January 1, 2005.

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Facilitating the Creation of New Business. This measure was adopted because the minimum capital requirement for limited liability companies was often a constraint for startups, which typically have only a small amount of funding. Before the introduction of this policy, minimum capital requirement for joint-stock corporations was ¥10 million[5] under the Commercial Law regulations. This new policy seems to be successful. Between February 1, 2004, and January 21, 2006, there were 24,639 confirmed applications with 20,211 notification completions. The corresponding numbers of the firms with ¥1 capital (the "¥1 company") are 1,172 and 927 respectively.

Based on the success of this policy, the Japanese government enacted the Corporate Law in 2005 to remove the minimum capital requirement for establishing firms in general, which is consistent with the U.S. joint-stock corporation policy.

Provision of Education and Information to Entrepreneurs

According to the Global Entrepreneurship Monitor[6] research program, of its 46 subject countries, Japan is second to the lowest in entrepreneurship activity. In addition, according to the *Employment Status Survey* of the Ministry of Public Management, Home Affairs, Post and Telecommunications, there were 1.24 million would-be entrepreneurs in Japan in 1997, which means that for every 50 employed people only one would-be entrepreneur was found.[7] Moreover, the survey also reports that only half of this class of would-be entrepreneurs is *actually* preparing to become self-employed.

Japanese leaders realized that an important first step would be to provide education and information about entrepreneurship to stimulate interest. In 1999, the Japan Productivity Center for Socio-Economic Development established the National Startup and Venture Forum, a nonprofit nongovernmental organization to provide services to attract and help entrepreneurs. Among its activities was the establishment of the Japan Venture Award to honor successful entrepreneurs and their sponsors that could serve as role models for the next generation of startups. It also created the Startup and Venture Evening Forum, which stages small symposia that focus on specific challenges facing entrepreneurs.[8]

Other organizations have joined forces on policies to promote the startup of new business. For example, the Japan Chamber of Commerce and Industry and

[5]For limited private companies, minimum capital requirement is ¥3 million.

[6]The Global Entrepreneurship Monitor (GEM) research program is an annual assessment of the national level of entrepreneurial activity. GEM is initiated in 1999 with ten countries, expanded to 21 in the year 2000, 46 in 2006, the largest research program in the world on this topic, conducted by Babson College in the United States.

[7]In 1997, the number of employed in Japan stood at about 60 million.

[8]The Activities of the National Startup and Venture Forum were taken over in 2007 by the Organization for Small & Medium Enterprises and Regional Innovation, Japan (SMRJ).

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Local Chamber of Commerce and Industry help potential entrepreneurs to complete concrete business strategies by holding "Startup Classes."

Startup Loan Program

Research in the United States and Europe has revealed that startup firms suffer from liquidity constraint (Evans and Jovanovic 1989; Holtz-Eakin, Joulfian, and Rosen 1994; Lindh and Ohlsson 1996). Funding is also the largest problem for the startups in Japan. *Survey of the Environment for Startups* (SES) found that 49 percent of firms reported a "Procuring funds for entry." "Procuring high-quality employees" and "Finding customers" were cited by 32 percent and 25 percent respectively. Problems of "Acquiring the specialized knowledge and skills for necessary skills" were cited by 20 percent, and problems of "Acquiring business knowledge (in finance, law)" and "Deciding site location" were cited by 18 percent and 17 percent respectively (Figure 1).

Given this circumstance, firm size at the time of startup is constrained by the amount of the entrepreneur's holding assets. If government-affiliated financial institutions were willing to lend more money, entrepreneurs would prefer to begin with a larger-size firm. An empirical study using Japanese data confirms that entrepreneurs who used the National Life Finance Corporation as a source of funding were able to enlarge startup firm size even if other conditions were controlled (Yasuda 2005).

Based on this policy rationale, the government initiated a financial program especially for startups in December 2001. In this "New Startup Loan Program," the National Life Finance Corporation lends up to ¥10 million for startups without requirement for collateral, guarantors, or personal guarantees. This scheme is widely used by startups, and between fiscal years 2002 and 2006 the number of cases from 2,975 to 7,942.

Other Policies Closely Linked to Startup

In addition, some policies that were taken in the first half of 2000s were closely linked to fostering the startup environment. One of these measures is expansion of the upper amount limit of "free property," i.e., property exempt from seizure under the Bankruptcy Law. The Legislative Council revised the Bankruptcy Law to expand the limit of free property from ¥210,000 to ¥990,000. This makes restarting easier for entrepreneurs who failed the first time around and lowers the risk of startup.[9]

[9]Fan and White (2002) pointed out that bankruptcy exemption level has positive effect on the probability of households owing business and of starting a business.

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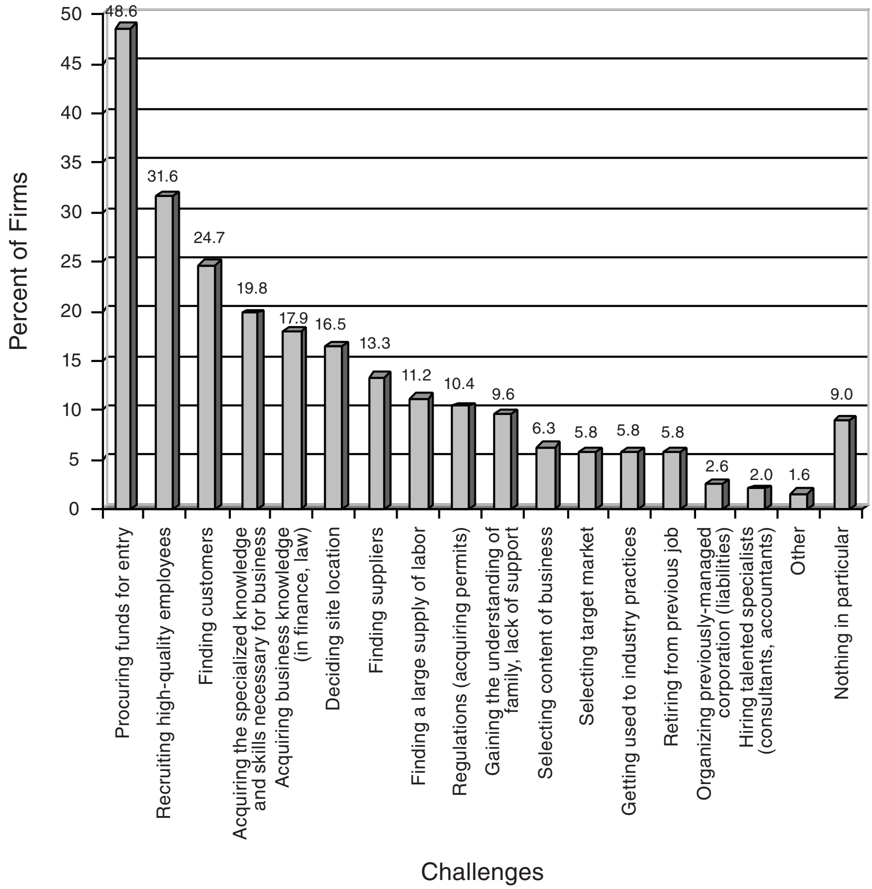

FIGURE 1 Challenges during preparation for startup/entry: A high proportion feels challenged by procuring funds for entry.
NOTE: Due to multiple responses, the total exceeds 100 percent.
SOURCE: Applied Research Institute, Inc., *Survey of the Environment for Startups*, November 2006.

3. PRELIMINARY ANALYSIS OF THE BUSINESS AWARENESS OF STARTUP SUPPORTING POLICY

3.1 Business Awareness of Startup Supporting Policy

If Japanese policies to promote entrepreneurship are to succeed, government officials must identify and understand latent and potential entrepreneurs, design information campaigns that will ensure that these people are aware of the new policy incentives, and monitor how the policies influence the target audience.

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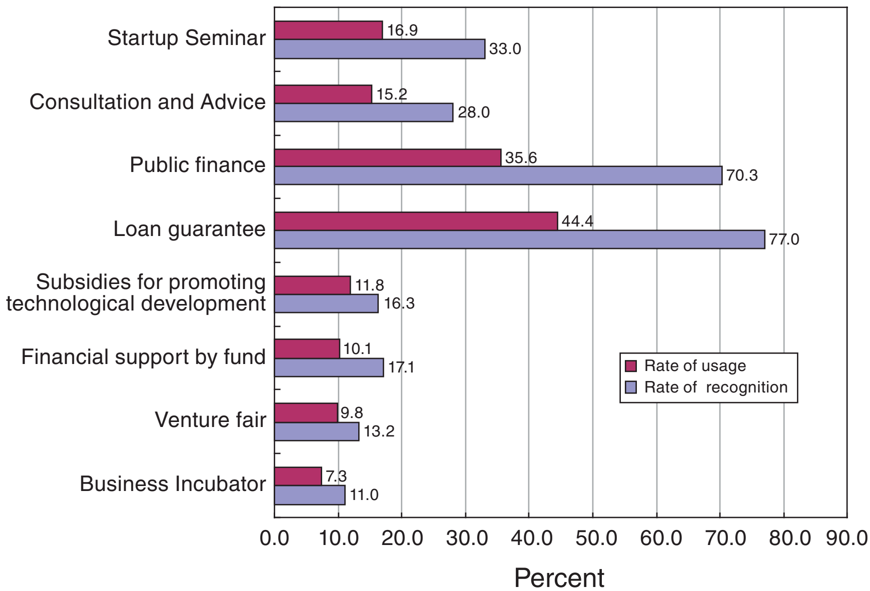

FIGURE 2 The rate of recognition and usage of startup-related policy by new startups. SOURCE: Japan Small Business Research Institute, *Survey of the Environment for Start-ups,* Tokyo: Japan Small Business Research Institute, 2002.

We therefore investigated the degree of recognition in Japan of SME policies that are aimed at new business entrants.[10] First, we show the results of responses to the questions of whether entrepreneurs at time of startup were aware of each startup-related policy carried out by national and regional governments and agencies (Figure 2). As shown here, although policies concerning startup finance are rather well known by entrepreneurs, other policies are less known to them. At the same time, a highly positive relationship can be observed between the degree of recognition and the degree of use of policy measures.

3.2 Model for Estimation

Next, we move to the question of which entrepreneurs acquire information on policies useful for startups and which do not. We used the Probit model of regression analysis to decipher which entrepreneurs and what types of firms were aware of various policies at time of startup. We asked about the following policies:

[10]Many of the policies reviewed in this section are not included in the "Startup-Doubling Plan," but ones adaptable for startups within the policies established for existing SMEs.

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- Startup seminar—"Startup Classes" and "Seminars for Promoting Startup" by Japan Chamber of Commerce and Industry and Local Chamber of Commerce and Industry.
- Consultation and advice—Inquiry counter for business counsel and advice for SMEs and business ventures.
- Public finance—Loan by National Life Finance Corporation, Japan Finance Corporation for Small and Medium Enterprise and Shokochukin Bank (The Central Cooperative Bank for Commerce and Industry), etc.
- Loan guarantee scheme by loan guarantee association established by each prefectures and the nation.
- Subsidies for promoting technological development by the central government ("Japanese SBIR").[11]
- Financial support by venture fund organized by local government and Small Business Investment & Consultation Co.
- Venture Fair—Exhibition for business venturing by Organization for Small & Medium Enterprises and Regional Innovation.
- Business Incubator—Business workplace for business venturing; established by Organization for Small & Medium Enterprises and Regional Innovation, etc.

The attributes of entrepreneurs that we considered were:

- Entrepreneur age at the time of startup.
- Gender.
- Education: a university gratitude or higher, or not.
- Related work experience.
- Business management experience.
- Startup type dummies: spin-off,[12] franchise, independent, family business and the others. (The benchmark is "the others.")
- Personal income level just before startup.

We also considered the following firm attributes:

- Number of workers at the time of startup.
- Legal form at the time of startup: limited liability or not.
- Sector: manufacturing, transportation, communication, retail, wholesale, restaurant, service.

[11]In Japan, the program like SBIR in the United States was introduced in 1999 by the Law for Facilitating the Creation of New Business.

[12]In this survey, spin-off type is defined as the startup which is established related to and under the control of the former employer after retirement from an existing enterprise.

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3.3 Dataset and Basic Statistics

In this section, we show the contents of the dataset used. Our dataset is from *Survey of the Environment for Startups*. This survey was conducted by the Japan Small Business Research Institute from October-December, 2002. The objects of survey were 10,000 firms that started business during 1995-1999 extracted randomly from the database of Tokyo Shoko Research, Ltd, (TSR). The survey was conducted by mail (response rate 11.4 percent), and the main questionnaire item was an archival record of entrepreneur, basic data of startup firm, usage of policy, etc. The number of observations with information on explanatory variable is 894.

Annexes A and B show the basic statistics of these variables. (Major features such as age distribution, sectoral composition, etc., could be discussed).

4. ESTIMATION RESULTS (BASIC ATTRIBUTES OF ENTREPRENEUR AND RECOGNITION OF STARTUP PROMOTION POLICY)

The results of the estimations are depicted in Table 1. From these estimations, we could identify the following three findings on awareness of policies supporting startups by entrepreneurs.

1. Entrepreneurs with business management experience tend to have more information on startup-support policies at the time of startup.
2. Entrepreneurs with related work experience have more information on financial-support policies for startups.
3. Older entrepreneurs are often not aware of financial-support policies.
4. “Family business development-type” entrepreneurs tend to be less aware of financial support policies.

Based on these findings, the following interpretations can be made. The first finding can be explained by the notion that many entrepreneurs with business management experience are "serial" entrepreneurs already possessing startup experience. The second finding shows that entrepreneurs with related work experience have an advantage in acquiring information on financial support policy by way of their previous work; however, they do not know about expanded policies for promoting startups because many of them have no experience at the startup stage. Underlying the third and forth findings is the fact that older and "family business development-type" entrepreneurs are under less liquidity constraint. They do not need to make an effort to search useful policies for starting up.

5. FURTHER CONSIDERATION OF THE OBSERVATIONS AND LESSONS FROM JAPAN

In the previous section, we noted that entrepreneurs with business management experience, many of whom are considered to be “serial” entrepreneurs, could

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more easily acquire information on startup-support policies. One reason for this is that organizations responsible for providing this information are connected to the Small and Medium Enterprise Agency with which these serial entrepreneurs are likely to be familiar. These include:

1. Government-affiliated agencies such as Organization for Small & Medium Enterprises and Regional Innovation, JAPAN, Small Business Investment & Consultation Co. Ltd. etc.
2. Chamber of Commerce and Industry, Society of Commerce and Industry.
3. Government-affiliated financial institutions such as National Life Finance Corporation, The Central Cooperative Bank for Commerce and Industry and Japan Finance Corporation for Small and Medium Enterprises, etc.

Indeed, these organizations are well known among existing SMEs, but they could be completely unfamiliar to the first-time startup firm. Managers of these new companies might feel hesitant to visit the organizations that work with the locally renowned SMEs.

The crucial point is that "small business policy" and "entrepreneur support policy (startup supporting policy)" is different things (Lundstörm and Stevenson 2001). In the context of Japan, as mentioned in the first section, small business policy which is based on the Old Law is one thing, and startup supporting policy based on the New Law is another, and it could even be said that the two are conflicting. If the two policies have quite different target firms, the outreach strategy should also be different for each.

The consideration of startup policies up to now poses a new challenge as to how to reach new business entrants. Government must develop new communication channels. For example, the network of gas stations or post offices might make an effective new route. The public bank system might be useful. Moreover, and above all, it is necessary to reevaluate lessons passed to entrepreneurs from mentors, most of whom have startup experience.

6. CONCLUSION

In this part of this volume, we have reviewed the history and current status of policies for supporting startups. Three main pillars of startup support policies and other measures concerning startup promotion were described. From these descriptions, we can also see that in the past 10 years the mindset of Japanese government has significantly changed from the view that a high level of business entrants brings about excessive competition among SMEs to the view that entrepreneurial activities are indispensable for vitalizing the national economy.

However, in order for new policies to work well, it is essential for new entrepreneurs to be aware of them. That is, effective outreach is the first essential step for a successful policy. Survey results that those firms that are already part of the

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TABLE 1 Estimation Results

	Startup Seminar	Consultation and Advice	Public Finance	Loan Guarantee	Subsidies for Promoting Technological Development	Financial Support by Fund	Venture Fair	Business Incubator
Entrepreneur Age at Startup	0.008	0.003	−0.012**	−0.014***	0.011	−0.003	−0.001	0.005
	(0.006)	(0.006)	(0.005)	(0.005)	(0.007)	(0.006)	(0.007)	(0.007)
Female Dummy	0.156	−0.008	0.023	0.265	−0.712	−0.417	−0.020	−0.235
	(0.274)	(0.289)	(0.267)	(0.274)	(0.537)	(0.391)	(0.351)	(0.415)
High Education Dummy	−0.047	−0.012	−0.010	−0.066	−0.114	−0.156	−0.112	0.200
	(0.096)	(0.099)	(0.090)	(0.091)	(0.119)	(0.113)	(0.120)	(0.133)
Related Work Experience Dummy	0.078	0.104	0.188*	0.208*	−0.022	0.111	−0.039	−0.036
	(0.121)	(0.124)	(0.111)	(0.111)	(0.146)	(0.143)	(0.144)	(0.154)
Business Management Dummy	0.135	0.185*	0.507***	0.451***	0.249**	0.262**	0.178	0.346***
	(0.104)	(0.106)	(0.099)	(0.100)	(0.125)	(0.119)	(0.129)	(0.135)
Spin-off Type	−0.209	−0.207	−0.289	−0.561***	−0.157	−0.593***	−0.271	−0.435*
	(0.192)	(0.200)	(0.185)	(0.191)	(0.237)	(0.219)	(0.229)	(0.240)
Franchising Type	0.088	−0.222	−0.161	0.012	−0.166	−0.645	−0.004	−0.838
	(0.291)	(0.329)	(0.287)	(0.295)	(0.426)	(0.425)	(0.352)	(0.530)
Independence Type	−0.224	−0.080	−0.039	−0.188	0.015	−0.332*	−0.244	−0.436**
	(0.165)	(0.172)	(0.160)	(0.167)	(0.203)	(0.181)	(0.195)	(0.199)

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Family Business Development Type		–0.391 (0.248)	–0.149 (0.253)	**–0.881*** (0.237)**	**–0.419* (0.234)**	–0.528 (0.347)	–0.453 (0.288)	–0.503 (0.318)	–0.460 (0.308)
Personal Income Level Just Before Startup	**¥2.5 million or less**	0.030 (0.218)	0.185 (0.221)	0.125 (0.204)	–0.096 (0.203)	0.412 (0.256)	0.334 (0.241)	0.256 (0.262)	**0.588** (0.272)**
	¥2.5-5 million	0.017 (0.136)	0.158 (0.139)	0.072 (0.126)	–0.128 (0.127)	–0.175 (0.188)	–0.266 (0.179)	0.081 (0.178)	**0.330* (0.191)**
	¥10-15 million	–0.028 (0.125)	0.041 (0.128)	0.090 (0.116)	0.035 (0.118)	0.088 (0.148)	0.115 (0.142)	0.203 (0.156)	**0.335** (0.168)**
	¥15 million or more	–0.148 (0.179)	–0.032 (0.182)	–0.075 (0.166)	–0.239 (0.166)	0.065 (0.205)	0.215 (0.194)	0.359 (0.202)	**0.481** (0.217)**
Limited Liability		0.152 (0.146)	0.126 (0.151)	0.050 (0.133)	0.194 (0.133)	0.098 (0.189)	0.272 (0.187)	–0.049 (0.176)	0.157 (0.204)
Natural Legalism of Employment at Startup		–0.052 (0.057)	0.035 (0.058)	0.010 (0.052)	**0.182*** (0.053)**	–0.049 (0.070)	0.036 (0.065)	–0.023 (0.070)	**–0.164** (0.079)**
Constant		**–0.916*** (0.346)**	**–1.082*** (0.354)**	0.162 (0.323)	0.211 (0.330)	–1.700 (0.429)	**–1.003** (0.404)**	**–1.001** (0.421)**	**–1.470*** (0.461)**
LR chi^2		28.01	20.22	**72.13*** **	**70.13*** **	**51.28*** **	**46.65*** **	18.90	**38.73** **
Number of Observation		894	894	894	894	894	894	894	894

NOTE: ***=1 percent significant level, **=5 percent significant level, * =10 percent significant level; Figures in parentheses indicate standard error; Coefficients for industry dummies are omitted.

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SME network have little trouble learning about new policies to assist startups. But first-time entrepreneurs are not part of the SME network and are not receiving the necessary information. Government must develop separate communication channels to reach these new entrepreneurs, who in many ways dwell in a different world from the SMEs. For startup-promotion policies to achieve all their goals, they must be effective in reaching the latent and potential entrepreneurs.

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ANNEX A Basic Statistics for Entrepreneur Attributes

	30 years old or less	31-40 years old	41-50 years old	51-60 years old	over 60 years old
Age of entrepreneur at time of startup	5.8%	22.0%	37.8%	29.6%	4.6%
Female	2.9%				
High education	57.4%				
Related work experience	79.6%				
Business work experience	32.2%				
Startup type	Spin-off type	Franchise type	Independence type	Family business development type	Others
	15.8%	3.2%	65.9%	6.4%	8.7%
Personal income level just before startup	¥2.5 million or less	¥2.5-5 million	¥5-10 million	¥10-15 million	¥15 million or more
	5.6%	17.6%	43.3%	24.3%	9.3%

ANNEX B Basic Statistics for Firm Attributes

Number of workers at the of startup	5 workers or less	6-20	21-35	36-50	51-65	66-80	81-95	96-110	111 or more
	53.0%	37.1%	5.4%	1.3%	1.3%	0.4%	0.4%	0.1%	0.8%
Sector of startup firm	manufacturing	transportation	communication	wholesale	retail	restaurant	service		
	20.0%	2.2%	1.3%	27.3%	15.4%	1.5%	32.2%		
Legal form at startup	limited liability	unlimited liability							
	85.9%	14.1%							

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Economic Impacts of International R&D Coordination: SEMATECH and the International Technology Roadmap

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The 1990s were an important and dynamic period in the evolution of the global semiconductor industry. During this decade, three major forces transformed the face of the industry. First, there was a marked acceleration in the rate of technological change in the sector starting in the middle of the decade. Second, a new U.S. R&D strategy emerged. Third, a global dispersion of the production infrastructure for the industry that had begun in the mid-1960s increasingly extended into R&D. This paper describes how these three developments were linked, how changing institutional arrangements used to organize semiconductor R&D shaped technological change, and the economic impacts of innovation in this industry.

THE PACE OF TECHNOLOGICAL CHANGE

The acceleration of technological change in semiconductors in the late 1990s is now well appreciated. Table 1 shows that an increased pace of technological progress was evident throughout the industry, but that two sectors—memory and microprocessors—forged ahead at a significantly faster speed.

Microprocessors are of particular interest for many reasons. First, they had the highest rate of improvement in price performance for any class of semiconductor product in the 1990s and afterward. (See Table 1.)

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TABLE 1 Rates of Decline in Quality-Adjusted Price for Semiconductors, 1991-1999

	Compound Annual Decline Rates (%)		
	CAGR 91-95	CAGR 95-99	CAGR 91-99
MOS MPU	–40.36	–61.89	–52.3
MOS Memory	–8.02	–47.87	–30.8
of which, DRAM	–7.76	–53.46	–34.5
MOS MPR	–3.89	–23.01	–14.0
Other MOS Logic	–6.76	–19.13	–13.2
Thyristors & Rectifiers	–0.84	–12.94	–7.1
MOS MCU	0.36	–13.87	–7.0
Power Transistors	–0.78	–10.27	–5.6
Small Signal Transistors	0.26	–10.50	–5.3
Optoelectronics	3.25	–10.04	–3.6
Diode & All Other Discrete	4.28	–9.03	–2.6
Digital Bipolar	5.37	–4.01	0.6

SOURCE: Author's calculation based on data in Aizcorbe, Flamm, and Khurshid (2004).

Second, microprocessors are the largest single semiconductor input, in terms of value, in personal computers[1] and are the technological core of all computers, big and small. Technological improvements in the semiconductors alone have been estimated to account for 40 percent to 60 percent of price-performance improvement in personal computers (PCs) in the late 1990s.[2] Quality-adjusted improvement in computer prices, in turn, is credited with a major role in the rapid improvement in U.S. productivity growth in the late 1990s.[3]

Finally, microprocessors have increasingly become the dominant product in semiconductor production facilities located in the United States, as semiconductor manufacturing, in turn, became the largest U.S. manufacturing industry (measured

[1]J. L. Hennessy and D. A. Patterson, *Computer Architecture: A Quantitative Approach*, 3rd Edition, San Francisco, CA: Morgan Kaufmann Publishers, Inc., 2002, p. 21, estimate that the microprocessor accounted for 22 percent of the component costs of a thousand dollar PC in 2001. The next most significant semiconductor input was the memory (DRAM), which accounted for 5 percent of component costs.

[2]See A. Aizcorbe, K. Flamm, and A. Kurshid, "The Role of Semiconductor Inputs in IT Hardware Price Decline: Computers vs. Communications," Federal Reserve Finance and Economics Discussion Paper 2002-37, Washington, D.C.: The Federal Reserve Board of Governors, Washington, August 2002; revised 2004, forthcoming in E. Berndt, ed., *Hard to Measure Goods and Services—Essays in Honor of Zvi Griliches*, Chicago, IL: National Bureau of Economic Research.

[3]See D. Jorgenson and K. Stiroh, "Raising the Speed Limit: U.S. Economic Growth in the Information Age," *Brookings Papers on Economic Activity*, G. Perry and W. C. Brainard, eds., Washington, D.C.: Brookings Institution Press, 2000; D. Jorgenson, "Information Technology and the U.S. Economy," *American Economic Review* 91(1), March 2001.

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by value added) in the 1990s. In 2004, microprocessors accounted for in excess of 46 percent of all U.S. semiconductor shipments, compared to 29 percent in 1995.[4] To an ever-increasing extent, the future of U.S. semiconductor manufacturing has become synonymous with the technological health of microprocessors.

A NEW RESEARCH STRATEGY[5]

The roots of a newly aggressive U.S. technology policy in semiconductors in the 1990s reach back to the late 1970s, another period of radical industrial change in a global semiconductor industry previously dominated by U.S. producers. In that epoch, Japan had launched a series of government-industry semiconductor R&D consortia—the so-called very large-scale integration (VLSI) projects. These efforts were perceived by most observers to have greatly advanced the technological and manufacturing competence of Japanese semiconductor producers.

In 1987, the U.S. Defense Science Board issued a report noting a rapid deterioration in the relative position of U.S. semiconductor manufacturers, characterizing this as a national security issue. Responding, the U.S. government decided to have the Defense Department pay half of the cost of a joint industry consortium—dubbed SEMATECH (for *se*miconductor *ma*nufacturing *tech*nology) and budgeted at $200 million annually.

The objective of improving U.S. semiconductor manufacturing technology may have been fairly clear, but the means by which SEMATECH was to do it sparked considerable debate. In its first few years of existence, SEMATECH's organizational focus shifted about and was not always wholly effective. One constant was that it was restricted to U.S. companies; Japanese producer NEC, which had a U.S. production plant, was turned away when it sought to join in 1988.

SEMATECH refocused its structure and research direction in 1992, when William Spencer joined SEMATECH, replacing its founding CEO, Robert Noyce. Even in earlier years, there had been an increasing emphasis at SEMATECH on projects aimed at improving the equipment and materials that U.S. semiconductor makers procured from suppliers. Under Spencer, SEMATECH carried out an internal reorganization and explicitly defined a new long-range strategy (SEMATECH II), focusing on reduction of the elapsed time between introductions

[4]Per the Bureau of Census, *Current Industrial Reports*, for those years. In 2004, by way of contrast, the next most important product category, DRAMs, accounted for about 11 percent of U.S. semiconductor shipments.

[5]My interpretation of SEMATECH's history draws on L. Browning and J. Shetler, *SEMATECH: Saving the U.S. Semiconductor Industry*, College Station, TX: Texas A&M University Press, 2000; W. J. Spencer, L. Wilson, and R. Doering, "The Semiconductor Technology Roadmap," *Future Fab International* 18, 2004, and K. Flamm and Q. Wang, "SEMATECH Revisited: Assessing Consortium Impacts on Semiconductor Industry R&D," in National Research Council, *Securing the Future: Regional and National Programs to Support the Semiconductor Industry*, Charles W. Wessner, ed., Washington, D.C.: The National Academies Press, 2003.

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of new technology "nodes" into manufacturing plants by SEMATECH members from 3 years between nodes, to 2 years.

A crucial element in this strategy was the institutionalization and acceptance within the U.S. semiconductor industry of a so-called roadmap process, a systematic attempt by all major players in both the U.S. integrated circuit industry and its materials and equipment suppliers to jointly work out the details of the complex array of likely new technologies required for manufacturing next-generation chips, coordinate the required timing for their introduction, and intensify R&D efforts on the pieces of technology that were likely to be "showstoppers" and required further work if the overall schedule was to succeed.

The National Advisory Council on Semiconductors (NACS), set up by the federal government at the same time as SEMATECH, took the first step down the roadmap road by convening a "Microtech 2000" workshop in 1992. A report was also published in 1992 detailing the goals for semiconductor manufacturing technology produced by participants at this workshop. SEMATECH continued to provide technological leadership for the roadmap process. The first official "National Technology Roadmap for Semiconductors," issued in 1994, still had new technology nodes being introduced at the historical pace of approximately three-year intervals. But the effort to step up the pace succeeded: The 250-nanometer technology node came online a year earlier than predicted by the time the 1994 Roadmap came out. The 1997 National Technology Roadmap called for maintaining the two-year intervals rather than returning to the historical three-year pattern for the next technology node (180 nanometers) and those to follow.

This acceleration in the rate of manufacturing technology improvement within what had become a globalized semiconductor industry clearly was assisted by factors beyond the walls of the U.S. SEMATECH consortium. Intensifying competitive pressures were felt around the world, and quickening the pace of new technology deployment was a logical economic response. However, the open discussion of industry-wide R&D needs and explicit coordination of R&D efforts across companies through an industry-wide program was a significant new development.

The industry-wide embrace of an accelerated, two-year rhythm for technology introductions coincided with a major structural change within SEMATECH. The consortium decided in 1995 to join with foreign producers in an international partnership to quicken deployment of materials and equipment designed for use with 300mm (12-inch) silicon wafers (I300I). U.S. government funding for SEMATECH was terminated by mutual consent in 1996. A new International SEMATECH was formed in 1998 to house the increasing number of projects involving foreign chip producers. Finally, in 1999, the original SEMATECH reorganized itself as International SEMATECH. Today, the share of world semiconductor output accounted for by SEMATECH members greatly exceeds the share held when the original U.S.-only consortium formed in late 1980s.

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SEMATECH's reorganization as an international entity implicitly recognized that technological capability, and the best manufacturing technology, resided in a geographically dispersed network of global equipment and materials suppliers. The internationalization of SEMATECH, another Spencer initiative, was actively encouraged by U.S. policymakers, particularly at the Department of Defense.[6] By all accounts, the prior recovery and stabilization of the health of the U.S. semiconductor industry played a critical role in building the political support for this decision by all parties.

SEMATECH's activities today have little resemblance to the classical vision of an industrial research laboratory. As an organization, it is mainly concerned with coordination and standards, bringing materials and equipment suppliers together with its members to work on technology projects largely executed outside its walls, serving as executive agent for the industry roadmap, and uniting a broad array of firms to organize industry standards for tools, software, and metrics for manufacturing.

SEMATECH was viewed as a major success in Japan. The SEMATECH model (ironically, a U.S. reaction to the Japanese VLSI consortia of the 1970s) became the inspiration for a new generation of Japanese semiconductor R&D consortia in the mid-1990s. Japan's semiconductor industry formed its own R&D consortium, SELETE, with a single non-Japanese member—Korean producer Samsung. As the new century dawned, two transnational R&D organizations coexisted within the international semiconductor industry—SELETE, headquartered in Japan, and International SEMATECH, with headquarters in the United States. The 1997 roadmap became the last "national" technology roadmap, replaced by "International Technology Roadmaps" sponsored and coordinated through these two global R&D consortia and semiconductor industry associations in the United States, Europe, Japan, Korea, and Taiwan.

In September 2004, SEMATECH once again transformed itself, dropping the term "international" from its name. SEMATECH public communications spun this as a "branding" issue, perhaps indicating that in today's thoroughly globalized semiconductor industry the very word "international" has become redundant.

SEMATECH continues to have many international members, including, most recently, Korean giant Samsung. SEMATECH also spun off a subset of its R&D activities into the International Semiconductor Manufacturing Initiative (ISMI) in 2004. Members of ISMI gain access to a variety of semiconductor manufacturing technology projects but are walled off from access to the "highest tech" (e.g., lithography) R&D, which remain within the main SEMATECH organization. All nine "full" SEMATECH members (AMD, Freescale, Hewlett-Packard, IBM, Infineon, Intel, Philips, Samsung, Texas Instruments) also get membership in ISMI. But six ISMI-only members (TSMC, Panasonic/Matsushita Electric, Spansion, NEC, Renesas) do not get access to the full SEMATECH information

[6]Where the author was one of the officials playing a significant role in devising the new policy.

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set. In 2005 Panasonic became the first Japanese firm to join ISMI, and it has since been followed by NEC and Renesas.

To summarize, SEMATECH transformed itself from a national (U.S.) R&D consortium, designed to strengthen the competitive fortunes of U.S.-based semiconductor firms, to a fully international consortium. Although it no longer receives an annual subsidy from the federal government (though U.S. government agencies have been invited to help fund specific projects of interest to them), it now receives significant subsidies from the states (Texas and New York) in which it has facilities located.

Perhaps the most enduring impact of the internationalization of SEMATECH was the globalization of the international roadmap it now leads. The creation of the International Technology Roadmap for Semiconductors (ITRS) is a unique phenomenon. In no other global high technology industry do all major producers, worldwide, come together to coordinate, in detail, the direction and pace of introduction of new manufacturing technologies. That the ITRS is global recognizes that the leading edge firms in semiconductors are true multinationals, scattered about the globe.

The continuing support by this global community for the roadmap reflects a common belief that close coordination among specialized suppliers of manufacturing equipment and materials and with the users has indeed served to accelerate innovation in the industry. Two-year nodes have continued to be introduced on a regular basis. Indeed, given the high fixed costs of R&D and investment in new manufacturing technology, there have been repeated calls to slow down the pace of introduction of the new nodes from the breakneck two-year cycle to improve profitability (see Figure 1). To date, these calls have gone unanswered; once on the technology bullet train, it is difficult for any firm to slow down its introduction of new technology as long as there is a decent probability that its rivals will continue to maintain the accelerated pace and beat it to market with newer and higher-performance manufacturing technology.

Interestingly, the close coordination of the introduction of new technology across firms might normally be expected to be the sort of thing that government antitrust authorities might view skeptically. However, a U.S. law passed in the 1980s carved out a specific exception by granting limited antitrust immunity for registered R&D consortia such as SEMATECH. Under this sheltering umbrella, and because the United States tends to be a leader in international antitrust enforcement, the SEMATECH-guided national technology roadmap, and its successor, the ITRS, have flourished.

THE INTERNATIONALIZATION OF R&D

The shift in the late 1990s to an international focus did *not* mirror a trend in U.S.-based semiconductor producers toward performing more of their R&D in other countries. Two sources of data—the Commerce Department's survey

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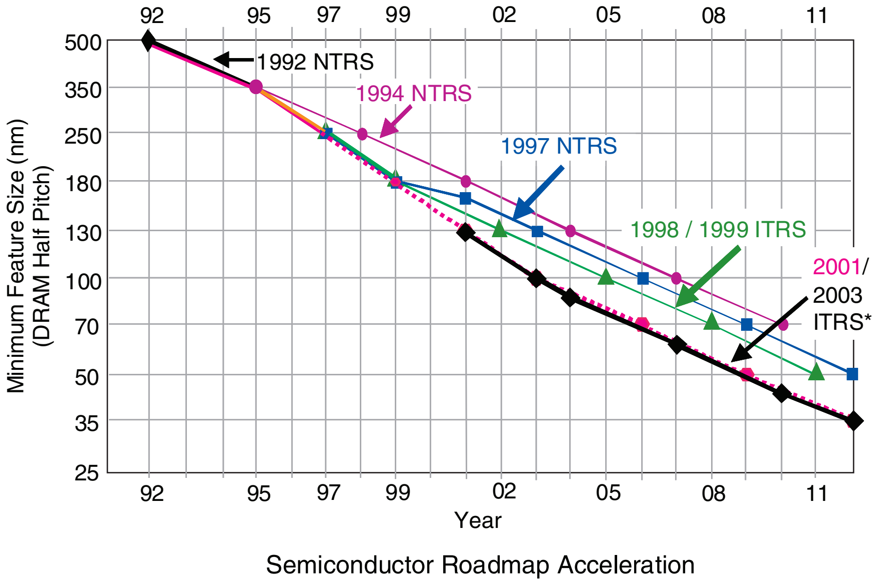

FIGURE 1 Relation of ITRS to 2-year cycle.
NOTE: The 2003 ITRS timing is unchanged from the 2001 ITRS.
SOURCE: Spencer, W. J., L. Wilson, and R. Doering. 2004. "The Semiconductor Technology Roadmap." *Future Fab International* 18.

of the R&D performed by U.S. multinationals and their majority-owned foreign affiliates (Figure 2), and the National Science Foundation's survey of U.S. industrial R&D performed by domestic companies and their foreign subsidiaries (Figure 3)—show that the ratio of R&D performed overseas by subsidiaries to R&D performed domestically by their parents actually declined in the electronic component industry (which is dominated by semiconductors) in the late 1990s.

Most recently, however, there *has* been an apparent shift toward a true internationalization of R&D performed by U.S. semiconductor makers. Figure 4 (majority-owned foreign affiliate R&D relative to parent R&D) and Figure 5 (subsidiary R&D relative to U.S. domestic company) both show a recent trend toward a significant increase in the role of U.S. companies' overseas R&D in semiconductors after the millennium.

What are we to make of this? One credible explanation is that throughout the late 1990s, U.S. companies occupied a position at the technological frontier in virtually all areas of semiconductor manufacture. There was little incentive to build overseas labs and listening posts. R&D cooperation through the roadmap process created an alternative information and coordination mechanism that

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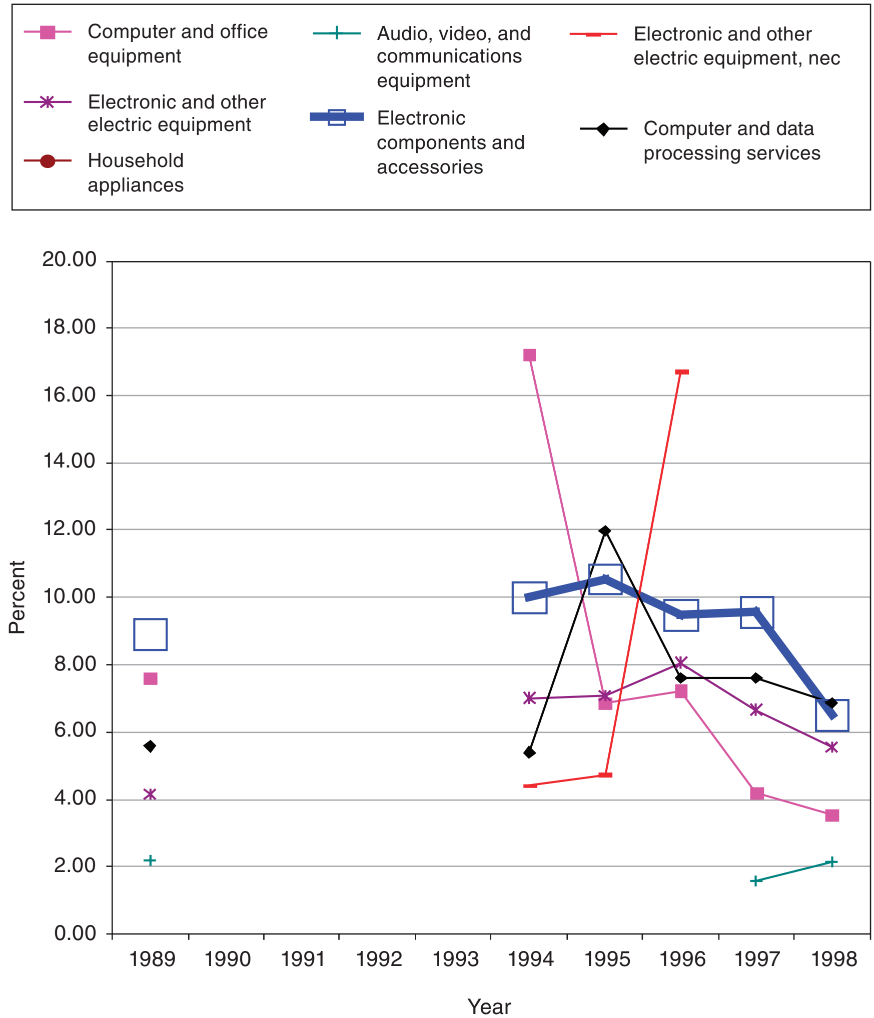

FIGURE 2 Majority-owned foreign affiliate R&D as percent parent R&D.
SOURCE: Bureau of Economic Analysis.

provided a way of cooperating with foreign materials and equipment suppliers in those areas where "best of breed" manufacturing technology did not reside in the United States.

Since the turn of the century, however, it has been increasingly evident that a steadily increasing share of manufacturing and technology development is being undertaken outside the United States by increasingly competent and techno-

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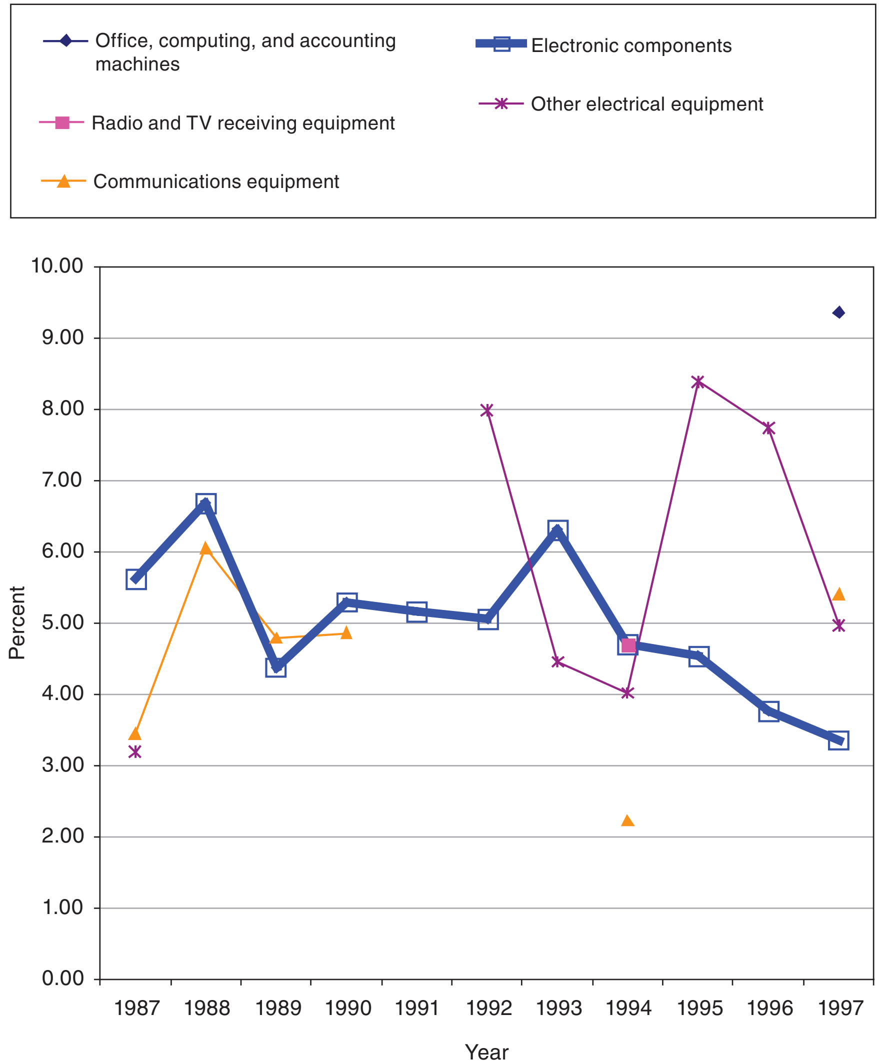

FIGURE 3 Subsidiary R&D as a percent of U.S. domestic company R&D.
SOURCE: National Science Foundation.

logically progressive foreign producers. Indeed, many U.S. firms now have joint technology development activities with these foreign firms. A rational response to improving competence outside the United States is to gain access to these overseas developments by establishing offshore R&D activities that afford some access to foreign technology.

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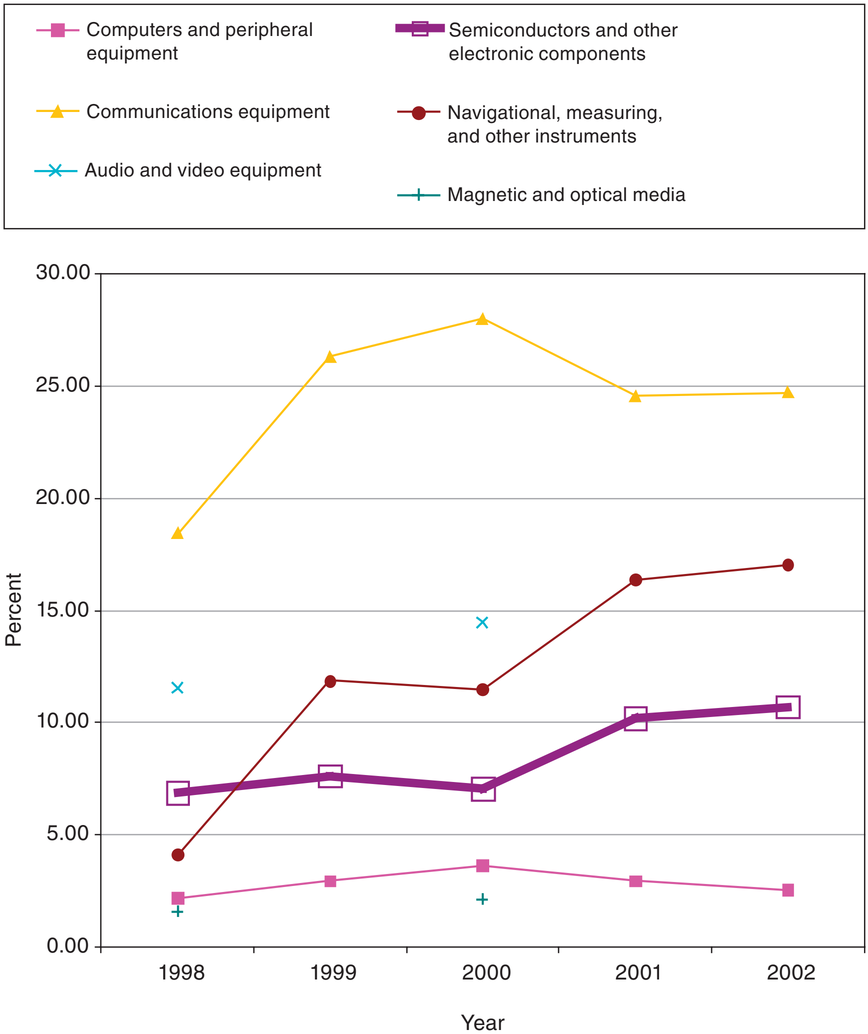

FIGURE 4 Majority-owned foreign affiliate R&D as a percent of parent R&D.

NEW MODELS OF INTERNATIONAL R&D COOPERATION

Although SEMATECH (itself inspired by the Japanese VLSI technology consortia of the 1970s) was the pioneer in first creating an international cooperation mechanism (the roadmap) and later in transforming itself from a national technology initiative into an international consortium, it is no longer the only player in this space. Today, there are alternative models for truly international

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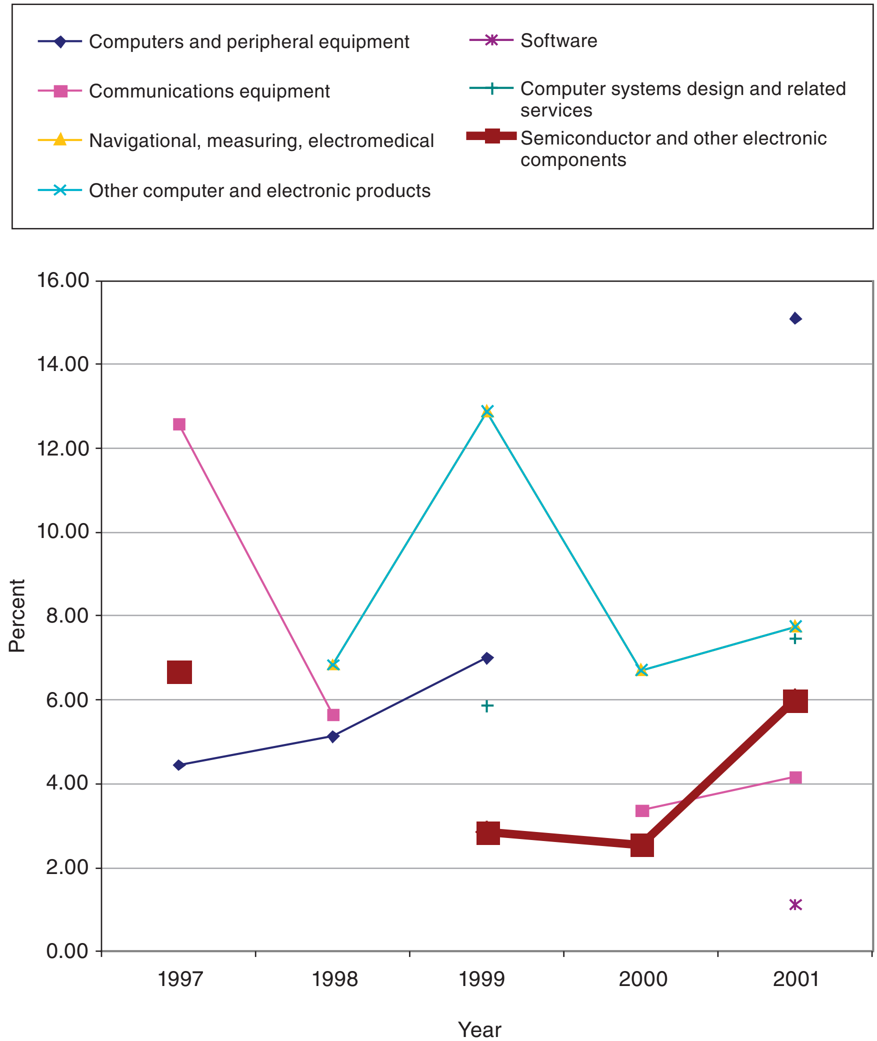

FIGURE 5 Subsidiary R&D as a percent of U.S. domestic company R&D.

consortia that have brought new energy and dynamism to the globalization of semiconductor R&D.

One model is a national or regional government-subsidized center or lab, in which a number of international semiconductor producers participate in a broad research program. One such example is the "Crolles 2" research consortium, in which Philips, STM, and Freescale participate. The government subsidy is

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provided by the French nuclear agency, the EU, and regional authorities.[7] Like SEMATECH, the Crolles 2 participants all fund a common research agenda.

Another, substantially larger effort built around a central R&D lab is IMEC in Leuven, Belgium, subsidized mainly by the Flanders regional government in Belgium, but also with some EC funding.[8] Unlike SEMATECH, IMEC historically has had university research tightly coupled with private participants on the premises of its facility. Also unlike the original SEMATECH model, IMEC allows private participants to pick and choose from individual projects to fund and participate in. Much of what IMEC does is contract research undertaken for individual participants; in 2000-2001, this accounted for about 70 percent of IMEC's budget.[9] Nonetheless, IMEC's 2005 budget was about $280 million,[10] roughly double SEMATECH's budget.

Yet another new model of international semiconductor R&D cooperation relies on a private company to provide the organizational framework. IBM has what might be characterized as a "hub and spoke" arrangement with a variety of global semiconductor producers, including Toshiba, Sony, Samsung, Infineon, Chartered, and AMD. IBM's own facilities in New York serve as the common R&D location, and foreign participants send engineers and technical personnel to IBM to participate in technology development, and share in the results. IBM also receives government subsidies from the state of New York for some of the inputs to this activity.[11]

One interesting common thread that runs through all of these new international R&D arrangements is that the bulk of the funding no longer is coming from national governments. Instead, regional governments and funding entities—whether states, provinces, or larger regions—are funding global technology development in the hopes of creating technology spillovers that stimulate the growth of new industrial "clusters" in the home region. This is true for Texas and New

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[7]See for example, Peter Clarke, "LETI, Crolles alliance open $350-million 32-nm research fab," *EE Times*, April 24, 2004, Acessed at <*http://www.eetimes.com/showArticle.jhtml?articleID=18902684*>.

[8]Interestingly, IMEC was actually established by the Flanders regional government back in 1984, before SEMATECH was started. IMEC's budget remained under 50 million Euros through the mid-1990s, in contrast to SEMATECH's initial $200 million budget. However, IMEC budget al.most quintupled over the decade from 1996 to 2006, while SEMATECH's total budget shrank. Presentation of Anton De Proft, IMEC, at Symposium on "Synergies in regional and national policies in the global economy," Leuven, Belgium, September 2006.

[9]Gail Purvis, "Moving into the Real World," *Electronic Business* July 1, 2002.

[10]Presentation of Anton De Proft, IMEC, at the National Academies Symposium on "Synergies in Regional and National Policies in the Global Economy," Leuven, Belgium, September 2006.

[11]For discussions of these relationships, see, "IBM & AMD aim alliance at the 22nm frontier," *Semiconductor Fabtech* November 1, 2005; "IBM, Sony, Toshiba take technology alliance beyond 32nm," *Semiconductor Fabtech* December 1, 2006; "IBM and partners ready 45nm low power process," *Semiconductor Fabtech* August 30, 2006; "Governor Pataki Announces Historic Investments by IBM Global High-Tech Leaders In Nanoelectronics Manufacturing And Development," January 6, 2005,Accessed at <*http://www.nanotechwire.com/news.asp?nid=1453*>; Peter Clarke, Mark LaPedus and Mike Santarini, "IBM-led Consortium to Build Fab in N.Y.," *EE Times* January 5, 2005.

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York funding for SEMATECH, New York funding for IBM facilities used with its research partners, Flemish funding for IMEC, and French national and regional funding for Crolles 2.

IMEC and Flanders is an extreme case of this phenomenon. Although Flanders founded IMEC in 1984 to jumpstart a Belgian semiconductor manufacturing industry, there is still not a single major semiconductor device or equipment manufacturing plant located anywhere in Belgium. The historical record in creating a Belgian semiconductor cluster does not seem particularly strong from a U.S. perspective. From 1984 through 2002, for example, there were 20 spin-offs from IMEC, only a few of which seem directly related to semiconductor device, materials, and equipment manufacturing, and none of which has gone on to become a major industry player.[12] Nonetheless, Flanders is pouring tens of millions of Euros into the development of technology used by semiconductor manufacturers.

Semiconductor manufacturing firms from around the globe are essentially co-funding the development of their technology in Belgium, but none appear to have actually located a major semiconductor design or manufacturing facility making use of this technology in Belgium. Although it is certainly true that a skilled and trained technical workforce is growing in Flanders, to date this has not created a broader and wider manufacturing cluster that extends much beyond the R&D services being performed for the benefit of foreign multinationals that do some design in Flanders but all of their manufacturing elsewhere. The IMEC model may ultimately prove a useful economic development strategy, but so far it has not fulfilled its initial objectives.

Yet IMEC has experienced enormous growth over the past 5-10 years, and it may well be that the local industrial spillovers from this burgeoning activity are still to come. There is every sign that global semiconductor producers perceive IMEC to be a very successful R&D enterprise, even if its downstream industrial success remains to be proven. SEMATECH, for example, has recently started (with a subsidy from Texas) a research consortium with the University of Texas at Austin (the Advanced Materials Research Consortium), much as IMEC built its activities around relationships with university researchers in Leuven and elsewhere in Belgium. Historically, success has bred imitation, and by this metric, IMEC certainly appears to be a successful R&D consortium.

THE IMPACT OF R&D COORDINATION ON THE SEMICONDUCTOR INDUSTRY: THE CASE OF MICROPROCESSORS

To recap the analysis above, the 1990s saw the convergence of three distinct trends—the evolution of SEMATECH and a drive to create a roadmap to guide the development of semiconductor manufacturing technology in the United States, a

[12]Gail Purvis, "Moving into the Real World," op. cit. Some of these spin-offs appear to provide research and design services to the IMEC consortium.

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globalization of semiconductor R&D and the internationalization of the U.S.-led semiconductor roadmap process, and an acceleration in the rate of technological progress in semiconductor manufacturing. How closely were these phenomena linked?

Studies by economists measuring semiconductor prices show accelerating declines in quality-adjusted semiconductor prices in the late 1990s for virtually all types of semiconductors after the move to a two-year cycle in 1995.[13] Faster semiconductor prices declines, in turn, had large effects on price declines for computer and communications equipment, which in turn had a major impact on aggregate economic growth and productivity improvement in recent years.[14]

A simple model of semiconductor manufacturing costs can be used to predict how an acceleration of the cycle between new technology nodes from 3 years to 2 years will effect manufacturing costs for a semiconductor component with given functionality.[15] Using a model of this sort, we can decompose improvements in semiconductor price-performance into two broad sources of change—declines in price for given quality (or functionality) flowing from lower manufacturing costs associated with new technology and qualitatively improved capabilities and functionality (performance) provided by chips. We can estimate the first element as the contribution of lower-cost manufacturing to quality-adjusted chip price, and measure the second as a residual after deducting off the first element from some measure of total quality-adjusted price declines for semiconductors.

Although this framework attempts to distinguish between "pure" manufacturing cost improvement and all other sources of innovation in chips (which we label "design innovation"), we need to recognize that design innovations are often stimulated by the availability of lower-priced semiconductor functionality. Also, improved manufacturing technology may create quality improvement as an incidental by-product of the manufacturing process and thus have an impact beyond simply reducing the cost of given functionality on a chip. For example, smaller feature sizes on a chip, which lower the manufacturing cost for some given set of transistors, may also mean potentially faster logic gates or clock speeds, simply because electrons have to travel shorter distances between transistors. By the same token, architectural innovations may be required in order to fully exploit the faster potential clock speeds. Thus, while we can partition sources of quality-adjusted

[13]See Table 1.

[14]See D. Jorgenson and K. Stiroh, "Raising the Speed Limit: U.S. Economic Growth in the Information Age," op. cit.; Jorgenson, "Information Technology and the U.S. Economy," op. cit.

[15]See K. Flamm, "Microelectronics Innovation: Understanding Moore's Law and Semiconductor Price Trends," *International Journal of Technology, Policy, and Management* 3(2), 2003; K. Flamm, "The New Economy in Historical Perspective: Evolution of Digital Technology," in *New Economy Handbook*, St. Louis, MO: Academic Press, 2003; K. Flamm, "Moore's Law and the Economics of Semiconductor Price Trends," in National Research Council, *Productivity and Cyclicality in Semiconductors: Trends, Implications, and Questions*, D. W. Jorgenson and C. W. Wessner, ed., Washington, D.C.: The National Academies Press, 2004.

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price declines in semiconductor parts to a contribution of lower manufacturing costs for given functionality and a contribution of all other sources of chip improvement ("design innovation"), we need to recognize that these two factors are not in fact independent and that two are synergistic. Lower-cost transistors on a chip may also be faster transistors and stimulate new designs, while new designs are needed to take full advantage of vastly cheaper transistors.

I have elsewhere looked at the relative contributions of cheaper functionality flowing from manufacturing innovation and design innovation in the semiconductor chip with the highest rate of decline in the late 1990s—the microprocessor.[16] My estimate is that roughly half of the decline in quality-adjusted price over this period came from lower manufacturing costs for the transistors in a given chip design, with the other half of quality-adjusted price improvement coming from other sources, including architectural and design innovation.[17]

Within the half of quality-adjusted price decline attributable to introduction of new technology nodes, perhaps one-sixth to one-third of the improvement is attributable to acceleration in the introduction of new nodes from 3 years to 2 years. While this is significant, it underestimates the total impact of improvement in manufacturing technology, since as argued above, it neglects incidental quality improvements associated with smaller feature sizes not captured in price per transistor.

Furthermore, the indications are that the relative importance of manufacturing technology improvement in microprocessors has greatly increased in the past several years. This is because microprocessors hit a "brick wall" associated with power and heat dissipation in 2003-2004, reducing the rate at which processor speeds have since increased over time.

Rather than adding qualitatively new capabilities and features to microprocessor architectures, the current emphasis is on replicating and linking multiple microprocessors (multiple "cores") on a single chip, as the primary direction for continuing utilization of the cheaper transistors flowing from manufacturing innovation. From a software perspective, using multiple cores on a single task is inherently more difficult and demanding, than speeding up the rate at which a single processor operates. Indeed, the difficulties of writing software that easily coordinates multiple processors on a single problem form the critical bottleneck for current research on design of supercomputers.[18] One would therefore expect

[16] See K. Flamm, "Suggested Changes to NEP Findings and Recommendations," Presentation to the National Research Council Board on Science, Technology, and Economic Policy, October 2005; K. Flamm, "The Economics of Innovation in Microprocessors," draft, December 2006.

[17] Increased competition in the microprocessor industry and any possible effect on price-cost margins would also be included in this "residual". For a discussion arguing that changes in margins may have played a significant role, see A. Aizcorbe, S. Oliner, and D. Sichel, "Shifting Trends in Semiconductor Prices and the Pace of Technological Progress," Federal Reserve Board Finance and Economics Discussion Series Working Paper No. 2006-44, September 2006.

[18] See Natonal Research Council, *Getting Up to Speed: The Future of Supercomputing*, Washington, D.C.: The National Academies Press, 2004.

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the problem of writing software for multiple core microprocessors to increasingly dominate the perceived benefits of higher numbers of cores on processors, and for economic measures of decline in the quality-adjusted price of microprocessors to slow as these problems increasingly dominate the utilization of the cheaper transistors supplied by continuing manufacturing innovation in microprocessors. Ironically, perhaps, scalable solutions to the problem of harnessing the power of multiple processors on a single task, which now pace cutting edge research on supercomputers, will now become a major issue for microprocessors.

After a sharp reduction in the rate at which prices were declining over 2003-2005, the rate of decline in quality-adjusted microprocessor prices rebounded and is currently declining at a rate where most of the price decline can be attributed to cost-improvement associated with the introduction of new technology nodes. Thus, in microprocessors, the poster child for rapid improvement in semiconductor price performance over the past decade, the role of the shift from a 3-year to 2-year technology node cycle played a significant but not predominant role in accelerating innovation in the late 1990s and early 2000s. Currently, however, manufacturing innovation is relatively more important than in the 1990s, accounting for the vast bulk of continuing decline in quality-adjusted microprocessor prices. Thus, it seems reasonable to propose that the relative economic importance of manufacturing innovation in semiconductors more generally and, therefore, of R&D coordination through institutional mechanisms like the ISTR and the current crop of global R&D consortia has increased substantially.

CONCLUSION

The 2-year cycle for the introduction of new technology nodes remains a feature of recent roadmaps, which continue to call for a reversion to the slower-paced 3-year cycle in later years. Calls for a slower cycle have mainly gone unanswered.

Before there was a roadmap, semiconductor companies organized their technology planning around something approximating Gordon Moore's prediction of a doubling of transistors per integrated circuit every 18 months. As it continued to hold approximately true, companies organized technical plans around the Moore's Law timetable. This was not because that schedule necessarily maximized their profit but because they believed that all their competitors would be introducing new products and technology on the Moore's Law schedule, and that they too had to stick to the plan to stay competitive.

This changed in the 1990s, when the U.S. SEMATECH consortium sponsored the roadmap coordination mechanism in pursuing its goal of technology acceleration. By explicitly coordinating an increasingly complex array of decentralized pieces of technology, requiring simultaneous improvement to create a new generation of manufacturing systems, the roadmap appears to have succeeded in altering the tempo of innovation. This effort was extended and internationalized, and today

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it is a unique and important institutional feature of the industrial organization of the global semiconductor industry.

Indeed, the industry's unsuccessful (to date) efforts to get off the "technology treadmill" and return to an older, slower pace of technological change in roadmaps for the end of this decade may indicate that the acceleration impulse, once launched, cannot easily be damped. An individual company gains no competitive advantage if it slows innovation and is matched by the rest of the industry, whereas it may lose greatly if the rest of the industry continues at the original, faster pace.

The speedup in manufacturing innovation, we have seen, was felt across the breadth of the semiconductor industry. Even in microprocessors, where rates of price decline greatly outpaced most other products, the acceleration of node introduction played a significant, if not predominant, role in the late 1990s and early 2000s. Currently, the introduction of new technology nodes seems to have become the primary driver of quality-adjusted price declines in microprocessors.

Economists are largely accustomed to thinking of the speed of technological change as something that is exogenous, dropping in gracefully from outside their models. One moral of the history of SEMATECH and the technology roadmap is that the pace of technological change may have an internal policy component as important as its external scientific foundations. Particularly where many complex items of technology secured from a broad variety of sources must be coordinated in a fairly precise manner in order to create economically viable new technology platforms, vague and diffuse factors like expectations and even political coalitions may play an important role.

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Semiconductor Consortia in Japan: Experiences and Lessons for the Future

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AN ARMADA OF PROJECTS

When the Japanese semiconductor industry suffered a slump in the 1990s, policymakers looked to the past for ideas about how to revive it. Having been very pleased with the results of the Very Large-Scale Integrated Circuit (VLSI) project in facilitating the rise of Japanese semiconductor industries in the 1980s (Morris 1990), Japan launched an armada of projects that mirrored this strategy, including the Semiconductor Leading Edge Technologies, Inc. (Selete),[1] Association of Super-Advanced Electronics Technologies (ASET),[2] Semiconductor Technology Academic Research Center (STARC),[3] Millennium Research for Advanced Information Technology (MIRAI),[4] Highly Agile Line Concept Advancement (HALCA),[5] Advanced SoC Platform Corporation (ASPLA)[6] (ERI-JSPMI 2002), Extreme Ultraviolet Lithography System Development Association (EUVA),[7]

[1]<*http://www.selete.co.jp/*>.
[2]<*http://www.aset.or.jp/*>.
[3]<*http://www.starc.jp/index-j.html*>.
[4]<*http://www.miraipj.jp/ja/*>.
[5]<*http://www.nedo.go.jp/iinkai/kenkyuu/bunkakai/16h/jigo/3/1/5-2.pdf*>.
[6]ASPLA's homepage has already closed.
[7]<*http://www.euva.or.jp/index.html*>.

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System in Package Consortium (SiP),[8] Consortium for Advanced Semiconductor Materials and Related Technologies (CASMAT),[9] Low Energy Electron Beam Proximity Projection Technology Consortium (LEEPL),[10] VLSI Design Education Center (VDEC),[11] and New Intelligence for IC Differentiation (DIIN).[12] Among the consortia, VDEC at the University of Tokyo and DIIN at Tohuku University, both initiated by the Ministry of Education, Culture, Sports, Science, and Technology, have somewhat different founding purposes than other industry-centric consortia.

Some of the cooperative development projects of the industry-centric consortia have already been completed, including. Phase 1 and 2 of the ASET project and the HALCA project. Semiconductor technology development of Phase 1 of the ASET project was completed four years ago with the goal of "the development of photolithographic elemental technologies for 130nm-70nm and beyond and the development of basic elemental technologies of semiconductor processes." It is now time to review the results.

In Phase 1 of the ASET project, a series of experiments called "Super Advanced Technology" were carried out as contracted research. A total of eight semiconductor-related projects were implemented as the part of the series. There were three electron beam (EB) related projects: One was the "development of high speed EB direct writing equipment." Two were X-ray lithography-related projects, one of which was the "development of proximity X-ray lithography." Three other projects were the "development of ArF lithography," "plasma physics and diagnostics," and "development of surface cleaning and simulation."

These projects yielded impressive results, including 1,288 technical disclosures, 246 patent applications, and 101 registered patents. As an example of the content, the in "plasma physics and diagnostics" produced basic technology development in correlating process evaluation indicators such as selectivity and process distribution to equipment parameters such as process pressure and plasma electron density.

Though the results of the research were satisfactory, the projects received little appreciation. Why did Phase 1 of the ASET project, intended to be the second Ultra LSI Lab, fail to achieve a similar level of appreciation? Based on the following circumstances, we will see the expected role and behavior of consortia.

BACKGROUND CIRCUMSTANCES OF CONSORTIA ESTABLISHMENT

The research and development (R&D) targets of the existing consortia can be classified into three categories: investigation of individual process technology

[8]*<http://www.sip-c.com/news/pdf/ISMP2005.pdf>.*

[9]*<http://www.casmat.or.jp/>.*

[10]LEEPLE's homepage has already closed.

[11]*<http://www.vdec.u-tokyo.ac.jp/>.*

[12]*<http://www.soi.wide.ad.jp/class/20030000/slides/01/9.html>.*

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and material (MIRAI, EUVA, SiP, CASMAT and LEEPLE); development of semiconductor devices (MIRAI, Selete, and ASPLA); and development of device design support technologies (STARC). All of these activities are, in a sense, efforts to improve the efficiency of R&D performed by distinct organizations within major IDMs. Such work may be the development of elemental technologies and material technology by a research group, the development of devices by a device development group through the integration of elemental technologies, and the efficiency improvement of the design by a design technology development group within a firm.

The most significant change that current consortia such as Phase 1 of ASET or Selete before it became ASUKA have experienced is that of the member constituency. Though most of the results of Phase 1 of the ASET project were assumed to be fed back to the improvement of semiconductor manufacturing equipment, the equipment manufacturers were not directly involved in the promotion of research work. Based on the perception that such organization hampered the implementation of the project results, current projects such as EUVA, SiP, CASMAT, and LEEPLE (but not MIRAI) that affect process technologies and materials are organized by equipment and material manufacturers as well as device manufacturers. Among them, SiP and CASMAT are organized only by equipment and material manufacturers.

Three consortia that address device development (MIRAI, Selete, ASPLA) aimed to reduce R&D costs by sharing the development cost that had increased with technological advancement. The consortia also aimed at offsetting the reduction in R&D personnel within IDMs that had started in the late 1990s. These requirements have been the consistent missions of the consortium related to the Japanese semiconductor since the establishment of ASET and Selete of 1996 as can be seen in the following statement on ASPLA's homepage.

> To maintain the competitiveness of Japanese semiconductor companies in the world market, it is necessary to improve the development efficiency by sharing the huge development cost among the members and by standardizing the technical area where sharing was possible in the SoC design and process and to concentrate the resources on the forte. This achieves the effective use of the resource, the reduction of development time and cost, and the diversification of the design property and the process that can be mutually used. In addition to this, the optimum technology transfer to the member companies becomes possible by finishing up the result of development in the platform as an organized technology. Moreover, it is expected that the technologies become de facto standard in the world by globalizing the access to the ASPLA technology.

In this paper, the problems of consortia related to the Japanese semiconductor industry are discussed by focusing on the three consortia concerned with development of semiconductor devices because, both the decline of the Japanese semiconductor industry and the inefficiency of the consortia seem to be caused by the

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failure in learning the equipment and material technologies that contribute to the semiconductor industry through semiconductor devices.

MIRAI, SELETE, AND ASPLA

The establishment objectives of MIRAI and Selete are recorded as follows respectively.

MIRAI:

> If alternatives are not found for materials used in semiconductor Large-Scale Integrated Circuits (LSI), the industry will face a major barrier in raising LSI performance, no matter how many advances are made in fabrication technologies. For example, with materials in use today, thickness reduction will create the problem of increased electricity "leakage" through insulating films, which will increase power consumption. In addition, LSI data-processing signal delay caused by wiring is becoming a major issue facing the industry, raising the demand for the development of new materials that insulate circuit wirings from one another. Further breakthroughs are also being called for in the fields of fine patterning technologies for semiconductors, transistor structures and measuring technologies with extreme resolution.
>
> With an eye to clearing such technological barriers, the seven-year MIRAI project (consisting of a three-year first phase and four-year second phase) comprises R&D in new insulating materials, which will be indispensable for semiconductors of the future, and development of the processing technologies necessary for their practical realization. As a result of these activities, the project will develop and demonstrate the feasibility of semiconductor technologies to markedly improve such basic performance features as the power consumption and data processing speed of LSIs in the 45nm and future technological generations.

SELETE:

> Since its establishment of February, 1996, Selete becomes ninth year in this 2004. We are promoting the "ASUKA Project" that is the 5 years project with Semiconductor Technology Academic Research Center (STARC). We advance the joint development of the device and the processing technology for 65nm technological node, and are advancing the early development of the semiconductor high technology by the following themes.

Thus, MIRAI, Selete, and ASPLA target the implementation of semiconductor devices; each has a target technology level classified according to the technology node size, such as MIRAI on 45nm, Selete on 90-65nm, and ASPLA on 90nm. Then, as development tasks to which the three consortia relate mutually, the specific research themes are set, such as "research on elemental

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technologies of High-k gate insulating materials, measurement, and analysis" (MIRAI), "research on transistors with new High-k material as gate insulator" (Selete), and "development and improvement of standard processes for 90nm node generation, and management of manufacturing line to verify invested asset and SoC" (ASPLA). MIRAI targets the verification of the applicability of elemental technologies to devices. Selete targets the completion of process modules and ASPLA targets the completion of actual device processes. The design concept for the three projects is that MIRAI investigates materials, Selete introduces them into process modules applicable to mass production, and ASPLA builds experimental devices with them.

Concerning the development of device that uses high dielectric substance material, for instance, the role of MIRAI is a material choice, development of a leading edge process, and that of Selete is the development of the next generation transistor that uses the High-k material. This is confirmed by the following Selete engineers' comment:

> Our processes are not leading edge. The level of the development of top major companies is more advanced than ours. Therefore, the process developed here would not be used by them. However, there is no guarantee that their development will succeed without any problem. If their development fails, our processes will become the substitutions. In addition, the companies in the secondary tier will use our processes.[13]
> .

However, the differences of the core members of each consortium made it difficult to enable smooth information exchange among MIRAI, Selete, and ASPLA. Though MIRAI and Selete were located in the same building, it was only through open seminars or society meetings that researchers learned of their counterparts' accomplishments. There was almost no collaboration between the two organizations. This lack of information exchange caused a problem, for example, when MIRAI and Selete independently ran similar research on High-k. Another Selete engineer commented:

> The content of our research and the content of the research of MIRAI have consequentially become almost the same. This is because the device structure depends on the material and an appropriate material is selected according to the device structure.[14]

That is, the development of high-performance transistors is impossible without adequate selection of High-k materials. In reality, evaluation of High-k

[13]The researcher of technology, chief researcher of High-k unit process group of Selete. Interview by author, Selete in Tsukuba, July 17, 2003.

[14]The researcher of electrical properties of transisters, group leader of transistor module group of Selete. Interview by author, Selete in Tsukuba, July 16, 2003.

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material and transistor development should go in parallel. As long as information is not shared between MIRAI and Selete and as long as development themes are separated between MIRAI and Selete, it is inevitable that the two organizations will run similar research projects.

HIGH LEVEL OF KNOWLEDGE INTEGRATION AND COMPLEXITY

Semiconductor devices have the characteristic that the extent of knowledge integrated into them has continuously increased with their functional advance (Fujimura, 2000). In the era up to 16KDRAM in terms of DRAM integration level, we saw little interaction between elemental technologies, only the combination of elemental technologies such as oxidation, etching, and aluminum deposition. Manufacturing equipment was simple and mostly manually operated. Then, in the 64KDRAM era, new process technologies such as RIE, sputtering, and ion implantation emerged, and the equipment became complex.[15] A better understanding of the equipment as well as the process phenomena became a requirement to build manufacturing processes. Also, there has been an increase in the number of processes (process modules) for which it is necessary to examine the interactions with adjacent processes, such as film deposition after pre-treatment and aluminum etching followed by ashing.

In the 1M to 4MDRAM era, process establishment became essential for the areas that define device characteristics (functional modules). To solve the stress migration problems, for example, better knowledge of film quality and of the deposition process of underlying inter-metal insulating films or of covering film on aluminum was required to complete the process, in addition to the existing knowledge of aluminum deposition and aluminum etching processes. In the 16M to 64MDRAM era and later, new materials such as copper (Cu) and Low-k came into the limelight. New materials helped to produce new devices like FeRAM and MRAM. We now need to understand material physics as well as process technologies to define device structures. For the design of all transistor equipments and for the choice of High-k material today, High-k materials are selected based on transistor electrical characteristics with the material, and the transistor structure depends on the selected High-k material. Device manufacturers, equip-

[15]The VLSI project efficiently contributed to the rapid evolution of Japanese chip makers by supplying these new technologies. Equipment for micro-lithography (stepper, electron-beam lithography, and X-ray lithography), in particular, was the key to strengthen the competitiveness of Japanese chip makers. In the era, most attractive emerging market was that of DRAM whose productivity strongly depended on the capability of the lithography process. However, the targeted pattern size was the minimum one micron meter, and 2-3 micron meter practically. Thus, minimum size of lithography pattern was decided almost by the performance of lithography equipment. In other words, it was enough for the members of the VLSI project to concentrate on the development of the equipment. They did not have to consider the interaction among several unit processes. This is the largest difference between the VLSI project and consortia in these days (Chuma 2006).

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ment manufacturers, and material manufacturers cannot each create competitive products without the knowledge of all technology segments.

The copper interconnection process is one of the typical cases that illustrate the interdependence among materials, equipment, and device characteristics. Copper (Cu) is the contaminant that destroys electrical properties of the transistor, so that it is the material that should not be used for integrated circuits. However, the electric resistance of aluminum has become so high for tiny ULSI devices, copper has unavoidably been introduced to semiconductor device manufacturing. Similarly, low-dielectric (low-k) materials have come to be used as the insulator between wiring layers to improve electrical properties of semiconductor devices. Because the dry etching of copper is very difficult, the pattern formation of copper by conventional patterning method using photolithography and dry etching is impossible. Thus, the patterning method called "Damascene" came to be used instead of the dry etching.

The Damascene method of completing the wiring process consists of the following steps: digging up the ditch of the wiring pattern on the insulator; pouring copper to the ditch; and removing the copper overflow from the ditch by CMP treatment of mechanical grinding with a pad like a file. Thus, the insulating material and the low-dielectric substance material that forms the ditch are ground at the same time with copper in CMP. Although copper and the low-dielectric material have different stiffness and fragility, they have to be polished with same speed to form the wiring with enough accuracy. If not, the process afterwards can be hindered by copper protruding beyond the ditch or by buried copper denting.

Thus, the accuracy of the grinding equipment, the physical properties of the low-dielectric substance material, and the device properties relating to the wiring have to be considered when CMP is performed. Creating an accurate copper interconnection using CMP therefore requires the sharing of information among the equipment vendors, the material supplier, and the device manufacturer.

Japanese semiconductor device manufacturers believe that NEC is one year behind Micron Technologies and Motorola of the United States and two years behind Samsung of South Korea late in starting the development of CMP (Chuma and Hashimoto 2007). CMP will also be indispensable to forming the wiring for the semiconductor device in the future. Therefore, the delay in the adoption of this process can have serious competitive consequences. To make up the delay of the Cu wiring technology and to strive for the technological advantage, Japan decided that consortia should focus on R&D in the Cu wiring process, particularly CMP and the low-k materials, and Cu wiring is listed as the R&D theme of MIRAI and Selete. The problem was the need to establish one more consortium—CASMAT—that assumed the Cu wiring technology to be a development theme.

Japanese semiconductor materials manufacturers are playing a major role in the world market and will try to continue to offer high quality and advanced semiconductor materials. But they are now facing the challenge of overcoming the methodology limit of the individual material research to improve the perfor-

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mance of the comprehensive set materials under the changing circumstances of rapid progress of nanoscale devices and complex processes. Against this backdrop, it becomes more and more important to have close cooperation between different manufacturers of semiconductor devices, semiconductor materials, and semiconductor equipment in order to promote the concurrent development of processes and materials.

The Consortium for Advanced Semiconductor Materials and Related Technologies (CASMAT) was founded by a group of major Japanese manufacturers of semiconductor materials in March 2003 to help meet this challenge. Its mission is explained on its homepage.

> CASMAT is equipped with integrated wafer back-end process by state-of-the-art process equipment which is compatible with 65nm node lithography and 300mm wafer process technology. . . . The entire process modules are accompanied with various evaluation equipments in order to feed the results back to the material developments.

The stated research task is the

> Development of tools that can assist in the comprehensive evaluation of not only the electrical characteristics of semiconductor devices but also their impact on reliability, which we call "integrated component development aid tools," in addition to the mutual influence between materials, and the same between materials and processes.

Selete is organized only by device manufacturers, and there is no room for the equipment and material manufacturers to participate in its management. However, MIRAI is open to equipment and material manufacturers as well, and eleven equipment and material manufacturers, including Tokyo Electron, ULVAC, and Mitsui Chemicals, have actually joined the consortium. It is no wonder that some companies join both MIRAI and CASMAT. It may actually be rather reasonable to do so since the two consortia have different technology node targets. However, none of the ten equipment or manufacturing companies that are CASMAT members has joined MIRAI.

Though the author is not familiar with the political issues concerning company qualifications to join the consortia, it can be said that the situation must be serious enough. For some reason material manufacturers felt a need to found CASMAT though we already had MIRAI and Selete for the same technology purposes. Whatever the reason is, it means that MIRAI and Selete do not have enough capability to absorb the wisdom of material manufacturers and reflect it in their R&D for improving device performance.

The golden age of the Japanese semiconductor industry from the 1980s into the early 1990s was mainly sustained by DRAM. As DRAM was a commodity product with a common worldwide specification, it was hard to differentiate by

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device features and product competitiveness. Reliability and pricing were the sole qualities used in making purchase decisions. In other words, the industry was highly dependent technically on process equipment and/or material. This is why Japanese device manufacturers chose to enclose their technologies by manufacturing the equipment and the materials internally or having them made by related (or subsidiary) companies. Major integrated device makers (IDM) acquired advanced knowledge about all areas of devices, equipment, and material, and then directed the equipment and material manufacturers to give them what they needed. This situation led them to secure better and higher quality equipment and material than was available to U.S. device manufacturers, and their more reliable DRAMs gave them a strong competitive advantage.

Since the late 1990s, however, it has become difficult for device manufacturers to maintain their technological edge in all areas of equipment and material as the technologies advanced, and the enclosure collapsed. When the enclosure collapsed and the advantage in equipment and materials was lost, Japanese device manufacturers could not compete against Korean and Taiwanese device manufacturers who excelled in productivity. Many of the Japanese manufacturers were forced to exit the DRAM business. They tried to strengthen their design capability to differentiate device features, but because U.S. companies were already differentiating device features, Japanese companies could not gain a competitive advantage in these aspects. They could gain a market share only in the digital consumer device market by capitalizing on the strength of digital consumer products made by Japanese manufacturers.

Consortia were established to turn the tide. ASUKA's predecessor, Phase-1 of Selete, had a mission to evaluate 300mm-compliant equipment. However, it failed to give equipment manufacturers enough feedback information on equipment evaluation results from processing modules they considered necessary for technology development. It could not get cooperation from equipment manufacturers. It dragged the master-servant relationship of the 1980s into the 1990s, so that the consortium did not expect much from the equipment manufacturer and made them produce what was required for their devices. Though some improvement was made in consortia afterward, the device manufacturers still have not yet been able to find an effective strategy to establish cooperation across the industry sectors, and the equipment manufacturers have not escaped their dependencies on device manufacturer leadership. The master-servant relationship still lingers.

Global market share of the Japanese device manufacturers is roughly 27 percent, and the share of the Japanese equipment manufacturers is roughly 30 percent. In contrast, the global market share of the Japanese material manufacturers is about 70 percent, which means material manufactures have the highest competitive power relatively. Under normal circumstances, it should be one of the advantages for domestic device and equipment manufacturers against overseas companies to have strong material manufacturers close at hand. However, it is very much regrettable that they have been unable to have those material manufacturers

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participate in Selete or MIRAI, where equipment and material knowledge were expected to be integrated onto devices, and to have left material manufacturers no choice other than to establish their own unique consortium. The Japanese device manufacturers are no longer in a position to educate equipment and material manufacturers but to get support from them.

TOWARD THE INTEGRATION OF VARIOUS TYPES OF KNOWLEDGE

Given that Japanese device, equipment, and material manufacturers could not build an efficient information exchange system, it is not surprising that the device manufacturers did not understand the qualitative changes of the technologies required for the devices. Some ascribe the decline of the Japanese semiconductor industry in the 1990s to equipment and material manufacturers, saying that the advantage in device manufacturing technology was lost because equipment and material manufacturers had exported products that had been refined, using the knowledge and experiences of the device manufacturers.

This is a typical example of the ignorance of technology change. The reason that equipment and material manufacturers sell their products globally is that it is impossible to invest enough in development to fully support the increase of device complexities if their sales are limited to the domestic market. The loss of competitiveness of the device manufacturers should be ascribed to their inability to build a new symbiotic relationship with equipment and material manufacturers suitable for technology advancement.

Even now, device manufacturers have strong concerns about the outflow of expertise through equipment and material manufacturers. It is not easy to maintain confidentiality and exchange information. Consortia should act as a meeting place where each device, equipment, and material manufacturer can improve their unique differentiating technologies through the exchange of these technologies while keeping their secrets.

As was mentioned earlier, there are three consortia today with the mission to bring forth the real devices: MIRAI, Selete, and ASPLA. They were organized so that the functions inherent to IDM were spun off for the purpose of cost reduction. The essence of semiconductor device development is to create a device by consolidating individual process technology. All the device manufacturing companies, including foundries, do such work. In other words, this is the source of differentiation, and achieving 100 percent commonality is only a dream in a free competition society.

In MIRAI, however, companies feel less resistance to information exchange since MIRAI handles next-next generation technologies and beyond, with enough lead time for implementation. Selete or ASPLA, on the other hand, handle next-generation and current-generation technologies, respectively. Therefore, most of the device manufacturers, though participating in Selete and/or ASPLA, run their

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own development projects of next-generation processes independently and in parallel. A comment such as "Really necessary and important technology will not be developed by Selete or ASPLA" reflects the attitude that is necessary to refrain from sharing knowledge with each other since the work there might affect their own competitiveness. Those consortia will duplicate their investment for development rather than reduce development cost and consolidate knowledge.

A definition of consortia functions should be based on a thorough consideration of where the arena is, the definition of the technical area where companies share information, and where they compete with each other.

THE CASE OF IMEC IN BELGIUM[16]

IMEC in Belgium is a successful case in these respects. IMEC does not run R&D on unique processing module technologies except cleaning. Accordingly, they do not develop process equipment, nor do their components include module components such as process chambers. But they do process evaluation and equipment evaluation by functional module unit. They do research on next generation CMOS transistors using the technology, but they do not develop specific devices (e.g., memories and MPUs). But they do research on design technologies. They do not develop specific equipment such as routers using semiconductors, but they do research on wireless communications. IMEC does not do research on or develop the devices, process equipment, and specific equipment, since there are companies who manufacture these products as their main business. They are equipment manufacturers, device manufacturers, and set manufacturers. In other words, the research topics of IMEC are all on industry boundaries, and it works as the bridges that link different sectors.

The member companies of the IMEC can join IMEC's research projects, get the information, and execute their own unique research projects in the IMEC at the same time. Assume, for example, equipment manufacturer A has developed process equipment that offers advanced processing capability. In the IMEC system, company A can have its private laboratory within the IMEC that excludes other companies, and A can evaluate the equipment with device characteristics by applying the new device as an experiment to CMOS process. At that time, all of the processes, except the one on company A's equipment, are applied by IMEC personnel to company A's experimental wafers. So, it is only company A researchers and IMEC personnel who actually see company A's experimental wafer, and processing of the wafer by the new equipment is carried out by company A's personnel only. That is, company A can use the pilot line of IMEC to evaluate its equipment while keeping its information confidential. The company can use the results to promote the equipment to device manufacturers. If the device manufacturer is a member of IMEC at the time, it will understand the features of

[16] *<http://www2.imec.be/>*.

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IMEC CMOS and can accept the evaluation result of company A's equipment. From a device manufacturer's viewpoint, this means that the equipment manufacturer obtains the evaluation results of reliable devices, and it saves the device manufacturers from doing the evaluation work from scratch by themselves. That is, they can quickly absorb the equipment and material manufacturer's wisdom. Similarly, device manufacturers can secure their own lab area in IMEC and develop their unique devices by using the IMEC pilot line.

At IMEC, device, equipment, and material manufacturers can exchange their information while protecting their own differentiating technology secrets through adequate theme selection and organization management. There is no need for device manufacturers to enclose equipment and material manufacturers to assimilate knowledge from them. Instead, they can quickly get the results of development by equipment and material manufacturers.

CONCLUSION

With increase in the transistor density on a chip, the minimizing pattern size has become smaller and interaction between unit processes has become more complex. To obtain the smaller pattern size with minimizing the undesirable influences of the process interaction, after the era of 1MDRAM, deep understanding of the physical-chemical phenomena in each unit process and the physical-chemical properties of materials has come to be needed. In other words, to develop an effective new process, and to select an appropriate new material, researchers came to have to consider the interactions. In the Japanese consortia newly started, however, it is so difficult for researchers of consortia to get the necessary information for solving the interaction problems because of sectionalized organization. If Japanese chip suppliers want to keep development capability of unit processes with minimum research cost, they need to focus the key process to standardize other processes among the consortia members. A consortium should be established to develop the technologies that agree all members' making them to the standard among members. Before starting the new consortium, members have to characterize the technology.

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Issues in and Possible Reforms of the U.S. Patent System

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PREFATORY NOTE

This paper was written for the symposium in January 2006, when many were optimistic that a patent reform bill would soon pass in Congress and be signed into law. Because of the delay between the symposium and the publication of the report, the description that it contains of the current state of legislation in this area is inevitably out of date. However, because the paper is documentation of what was said at the symposium, I have left it as it stands, while adding a postscript that updates the situation to mid-2008.

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1. OVERVIEW

During the first half of this decade, the chorus of critics of the current operation of the U.S. patent system has increased in size, and even included the occasional member of the popular press. The outcry has culminated in a series of reports by governmental and public interest organizations recommending a number of reforms to the system.[2] Based for the most part on the recommendations in these reports, a bill (H. R. 2795) was recently introduced in the U.S. Congress that would introduce a number of far-reaching changes to the system. Hearings related to the proposed changes in the bill have been held in the Senate and the House, and in the various subcommittees it has been substantially revised, in response to critiques by stakeholders in the system. At the present time it is not clear when and whether and in what form legislation will issue, but that something will come out of the process seems almost certain.

My presentation today discusses the economic rationale for the patent system, briefly reviews the changes to the U. S. patent (and innovation) system that have led to the current situation, and summarizes the arguments behind the calls for reform. It then discusses in more detail the issues that are under consideration for legislation and the current prospects for that legislation.

2. PATENTS AND INNOVATION

For an economist, the central patent policy question is whether the patent system, which entails costs and benefits, increases innovative activity on net.[3] In testimony before the Federal Trade Commission/Department of Justice (FTC/DOJ) hearings on Competition and Intellectual Property Law in the Knowledge-Based Economy, I offered a simple chart as a framework for thinking about costs and benefits of patents (Table 1).

This chart is intended to suggest that in addition to the familiar arguments that patents increase innovation via incentive effects and diffusion and decrease competition because they create temporary monopolies, there are offsetting effects in both cases that have become more apparent in recent years.[4] These offsetting

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[2]In particular, see Federal Trade Commission, *To Promote Innovation: The Proper Balance of Patent and Competition Law Policy*, October 2003; National Research Council, *A Patent System for the 21st Century*, Washington, D.C.: The National Academies Press, 2004; and the Reply to the National Academies Report by the American Intellectual Property Law Association, 2004.

[3]A secondary question might be whether the patent system increases innovative activity so much that it rises above the social optimum. Most scholars and policy makers seem to agree that this is an unlikely possibility.

[4]This is not to say that these effects have gone completely unrecognized in the past. Consider the following quotation from a sugar manufacturer in Great Britain during the 19th century: "In the manufacture with which I am connected—the sugar trade—there are somewhere like 300 or 400 patents. Now, how are we to know all these 400 patents? How are we to manage continually, in the natural process of making improvements in manufacture, to know which of these patents we are

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TABLE 1 The Patent System Viewed by a Two-Handed Economist

Effects on:	Benefit	Cost
Innovation	creates an incentive for R&D; promotes the diffusion of ideas	impedes the combination of new ideas & inventions; raises transaction costs
Competition	facilitates entry of new small firms with limited assets; allows trading of inventive knowledge, markets for technology	creates short-term monopolies, which may become long-term in network industries

effects are the tendency of patents to increase the costs of subsequent innovators, especially when these innovators need to combine inventions from many sources, as well as the fact that patents may help competition by facilitating the vertical disintegration of knowledge-intensive industries and helping new entrants.

As the chart illustrates, the body of economic theory that lies behind it yields an inconclusive answer to the question of whether patents encourage innovation generally. We therefore turn to the empirical evidence on this question, which comes in several flavors: survey evidence, cross-country studies, and studies within individual patent systems. The conclusions from the empirical studies that I have surveyed in the past are several in number. The first is that introducing or strengthening a patent system (lengthening the term, broadening subject matter coverage, etc.) unambiguously results in an increase in patenting and in the strategic uses of patents (Lerner 2002; Baldwin et al. 2000; Hall and Ziedonis 2001).

Second, it is much less clear that these changes result in an increase in innovative activity, although they may redirect such activity toward things that are patentable and/or are not subject to being kept secret within the firm (Moser 2001; Lerner 2002; Baldwin et al. 2000). Third, if there is an increase in innovation due to patents, it is likely to be centered in the pharmaceutical and biotechnology areas, and possibly specialty chemicals (Levin et al. 1987; Cohen et al. 2001; Arora et al. 2001).

Fourth and finally, the existence and strength of the patent system DOES affect the organization of industry, by allowing trade in knowledge, which facilitates the vertical disintegration of knowledge-based industries and the entry of new firms that possess only intangible assets (Hall and Ziedonis 2001; Arora et al. 2003; Arora and Merges 2004).

at any time conflicting with? So far as I know, we are not violating any patent; but really, if we are to be exceedingly earnest in the question, probably we would require to have a highly paid clerk in London continually analysing the various patents; and every year, by the multiplication of patents, this difficulty is becoming more formidable." [R. A. Macfie, quoted in "Is the Granting of Patents for Inventions Conducive to the Interests of Trade?" *Transactions of the National Association for the Promotion of Social Science,* George W. Hastings, ed., 661, 665, 1865.]

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Thus, the bottom line from the empirical evidence is that the patent system provides clear incentives for innovation in only a few sectors, but that firms and industries do respond to its presence, both by making use of the system and by sometimes tailoring their innovative strategies to its presence. As Edith Penrose said some time ago when speaking to the same question, "If national patent laws did not exist, it would be difficult to make a conclusive case for introducing them; but the fact that they do exist shifts the burden of proof and it is equally difficult to make a really conclusive case for abolishing them."[5]

3. EVOLUTION OF THE U.S. PATENT SYSTEM SINCE 1980

As with (almost) all governmental institutions, the U.S. patent system has evolved and continues to evolve, in ways that are ultimately driven by forces related both to a perception of increased global competition, especially in knowledge-intensive sectors, and to technological change itself. The expansion of subject matter coverage, the strengthening of the enforcement system, and the encouragement of patenting by upstream actors can all be seen as driven by these forces.

Unfortunately (from the perspective of optimal policy), many of the changes in patent policy in the United States during the past two decades have been a result of court decisions, especially those of the Court of Appeals of the Federal Circuit (CAFC), and to a lesser extent by the Supreme Court. Addressed as they are to the features of individual cases, these decisions do not always consider the broader policy implications as they set precedents. As a result of a series of court decisions by these bodies, the subject matter eligible for patenting has been extended to new technologies (biotechnology), technologies previously not subject to patent protection (business methods, software), and to upstream scientific research tools, materials, and discoveries (*Madey v. Duke*, 2002). The rights of patent holders vis-à-vis alleged infringers have been strengthened by such decisions as *Polaroid v. Kodak* (1986/1991), which yielded a major damage award to Polaroid and shut down Kodak's instant camera business.

Of course in many ways these court decisions were the consequence of legislative changes in 1982, during which the CAFC was created, and the strengthening of the position of patent holders by a number of procedural changes in the courts. In a comparison of appeals cases from 1953 to 1978 and from 1982 to 1990, the share of District Court decisions finding validity and infringement that were upheld by the higher court increased from 62 percent to 90 percent. Decisions of invalidity and no infringement were reversed 12 percent of the time before the Federal Circuit's creation, and 18 percent afterward. Moreover, the rate of preliminary injunctions increased dramatically.[6]

[5]*The Economics of the International Patent System*, 1951.
[6]See Lerner (1995); Lanjouw and Lerner (1997); Allison and Lemley (1998); and Jaffe (2000).

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The early 1980s was also the period when the well-known Bayh-Dole Act become law, leading to the emergence of new players such as many universities and public research institutions, as well as an increase in activity at institutions that had already been patenting some of their research results.

The 1988 Process Patent Amendments Act enabled U.S. process patent holders to block the import of foreign products produced by methods infringing their patents as well as to hold domestic sellers or users of a product made by a patented process liable for infringement.

From the 1980s onward there was also a marked evolution in the attitude of the Justice Department's Antitrust Division and the Federal Trade Commission toward business conduct involving patents, resulting in a much more nuanced and pro-patent position (FTC 2003). In 1981 the division's deputy assistant attorney general abandoned a list of nine licensing practices that the department a decade earlier had characterized as automatically illegal. The 1988 Justice Department Antitrust Enforcement Guidelines for International Operations outlined the consumer benefits from intellectual property licensing and adopted a rule-of-reason approach to such issues. In 1995 the Justice Department and the Federal Trade Commission jointly issued Antitrust Guidelines for the Licensing of Intellectual Property, reiterating the 1988 principles and declaring that "the Agencies do not presume that intellectual property creates market power in the antitrust context" and intellectual property licensing is "generally pro-competitive."

Taken together, these changes all add up to a considerable strengthening of patent holder rights and broadening of the reach of the patent system. As I summarize in the next section, the response to these changes on the part of private firms has been dramatic.

4. EVOLUTION OF PATENT STRATEGY IN U.S. FIRMS SINCE 1980

The most obvious response to these changes in the patent system was the increase in patenting across many sectors, leading to a doubling of patent applications and grants during the 10-year period between 1992 and 2002. In Hall (2005), I showed that the time series of aggregate patent applications in the United States displayed a structural break in 1984, with the annual growth rate increasing from zero to over 6 percent. Such a growth rate will produce a doubling in twelve years. I also showed that most of the growth was due to increased patenting by firms in the information and communication technology (ICT) sectors, which is consistent with the view that much of it is for defensive reasons (Arora et al. 2001; Hall and Ziedonis 2001; Hicks et al. 2001). At the same time, the contribution of increased university and public research institution patenting to growth was relatively small. From a regional perspective, over half the growth was due to inventors in the United States, one third to those in Asia, and the small remainder to inventors in Europe. Thus the growth was driven by the behavior of the ICT sector in the United States and Asia.

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A number of other behavioral changes have accompanied this increase in patenting: slightly higher renewal rates, more frequent assertion of patents, a doubling of U.S. District Court patent suits from 1988 to 2001, and some evidence that the probability of a patent-related suit has increased recently (Bessen and Meurer 2005). The complexity of patents in terms of the number of claims and citations of prior art has grown, and patentees tend to invest more in the process of application and examination. In testimony before Congress, the current Director of the U.S. Patent and Trademark Office (USPTO), Jon Dudas, reported that more than 100,000 of the 355,000 patent applications filed in 2004 were continuations of applications that had been previously reviewed by an examiner. He also reports on the problem of "super-sized" applications submitted by a minority of applicants (7 percent of the applications account for 25 per cent of the claims examined; some are submitted on CD-ROMs with thousands of claims).

In addition, many critics have argued that the sheer volume of patent applications threatens to degrade the quality of issued patents or lengthen the backlog or both. On the backlog there is no doubt. In April 2005, Dudas reported that pendency in data-processing technologies stood at three years and growing, and that without intervention, the current backlog of applications awaiting first review could double from 500,000 to a million in the next 5 years.

Finding hard evidence of a decline in quality is more difficult, although a number of legal scholars and practitioners have been vocal on the subject, sometimes not for quotation. There are several reasons to believe that quality (especially the application of the nonobviousness criterion of patentability) has suffered as the number of applications has grown. First, the number of patent examiners has not kept pace with the increase in workload represented by the increased number and growing complexity of the applications. Second, there does seem to have been a dilution of the application of the nonobviousness standard in biotechnology (due to court decisions) and some limitations on applying it properly to business method patent applications, in part because of the absence of adequate written prior art documents.

Third, patent approval rates at the USPTO are higher than in some other major nations' patent offices (notably the European Patent Office), even before adjusting for the impact of the continuation process (which makes the ultimate grant rate for any given application higher). Finally, some changes in the treatment of genomic and business methods application were introduced (the second pair of eyes for business methods patents and the requirement of a specific application or use of a new gene sequence) that resulted in a slowing down of patent grants in those fields, suggesting that the previous bar may have been set too low.

During the FTC/DOJ hearings on the patent system and antitrust policy in 2002, a number of industry representatives expressed concerns about the difficulty of negotiating the patent thicket in their area and the risk of being "held up" ex post by a patent on a technology that was only a small component of their product. This complaint was heard largely from those in the complex-product industries

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(the ICT sector), such as Robert Barr, then Vice-President for Intellectual Property and Worldwide Patent Counsel at Cisco Corporation. He described two types of problems faced by firms in the sector: first, the large stockpiling of patents necessary as a defensive measure against others in the industry and, second, the threat posed by small entities that have nothing at risk themselves and may not even be producers. On the first, Barr says the following:

> My observation is that patents have not been a positive force in stimulating innovation at Cisco. . . . Everything we have done to create new products would have been done even if we could not obtain patents on the innovations and inventions contained in these products. . . . The only practical response to this problem of unintentional and sometimes unavoidable patent infringement is to file hundreds of patents each year ourselves, so that we can have something to bring to the table in cross-licensing negotiations. . . . The time and money we spend on patent filings, prosecution, and maintenance, litigation and licensing could be better spent on product development and research leading to more innovation.[7]

On the second problem (that of being attacked ex post by a small entity that does not face much risk of infringement itself):

> . . . stockpiling patents does not really solve the problem of unintentional patent infringement through independent development. If we are accused of infringement by a patent holder who does not make and sell products, or who sells in much smaller volume than we do, our patents do not have sufficient value to the other party to deter a lawsuit or reduce the amount of money demanded by the other company.

The first of the problems Barr describes is clearly a case of mutually assured destruction that leaves the firms in question no better off than if they were not accumulating massive numbers of patents for defensive purposes, and yet at the same time is a very costly strategy. Increasing the administrative costs of patents to firms or reforms within the industry itself to discourage this behavior would seem to be the obvious solution, since it would be in the interest of all firms involved to reduce spending on this activity. However, the second problem is more controversial: The small entities that assert patents in this way may have legitimate claims to ownership of some of the technology in a large firm's product. Some observers have even questioned how common this kind of patent assertion is.[8]

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[7]That this is not just the belief of one representative of one company is confirmed by the interview evidence obtained by Rosemarie Ziedonis and myself from several semiconductor firm representatives, as well as by our subsequent econometric work (Ziedonis and Hall 2001).

[8]For example, in well-publicized testimony, Nathan Myrhvold of Intellectual Ventures and former CTO of Microsoft has critiqued the idea that patent litigation is increasing or indeed is an important problem. Because Myrhvold has not yet released the study on which these claims are based, it is difficult to know how his numbers compare to those in several published studies, or indeed how they were obtained.

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Nevertheless, the ICT industry in general has been very concerned about these kinds of assertions and their consequences for the incentives to invest in complex technologies that might potentially incorporate a piece of technology that leads to a dispute that cannot be resolved by cross-licensing.

The final area where change in patenting practice and IP management has raised concern in policy circles is the increased patenting of "research tools" and its consequences. Walsh et al. (2003) interviewed some 70 players in the biotechnology research area and found that by and large intellectual property in biotechnology is being managed relatively successfully. Because of increasing patent assertion and the extension of patentability to life forms and gene sequences, the associated costs of research are somewhat higher and research can sometimes be slowed, but it is rarely blocked altogether. There are, however, occasional cases of restricted access to foundational discoveries and to some diagnostic genetic tests. A number of "working solutions" have evolved, including negotiated licenses and royalty payments. Patents are also circumvented by inventing around them, using substitute research tools, and locating research activity offshore. Institutional responses include the National Institutes of Health guidelines encouraging research grantees to facilitate access to patented research tools and the steps taken by several research organizations to place results in the public domain, where they become patent-defeating prior art.

5. THE PATENT REFORM BILL AND ITS CURRENT PROSPECTS

During the past year and partly in response to the National Academy of Sciences (NAS) and FTC reports as well as the position taken by the AIPLA, Congress has shown considerable interest in patent reform. Several hearings presided over by Senator Orrin Hatch (R-UT) have been held in the Senate, and in June 2005, Representative Lamar Smith (R-TX) introduced a Patent Reform Bill (H.R. 2795) in the House and held a subcommittee hearing on June 9, 2005. Based on testimony and the input received from various stakeholders, Smith published a substitute bill and held hearings on it in September 2005. A summary list of hearings held is shown in Table 2.

A number of interested groups have thrown their support behind the principle of patent reform, although they do not necessarily agree on all the individual items in the proposed bill. These groups are the American Intellectual Property Law Association (AIPLA), the Intellectual Property Owners Association (IPO), the IP Law section of the American Bar Association, the Biotechnology Industry Organization (BIO), and the Business Software Alliance (BSA). A coalition formed by 37 large patentholding firms (9 chemical, 16 pharmaceutical, and 12 in a number of other sectors), the AIPLA, and the IPO has presented a reform package that is similar to but not identical to the substitute H.R. 2795 bill published by Smith in September.

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TABLE 2 Summary of Hearings on Patent Reform, 109th U. S. Congress

Date	Committee	Topic
April 25, 2005	Senate Judiciary, Subcommittee on IP	The Patent System Today and Tomorrow
June 7, 2005	Senate Judiciary, Subcommittee on IP	Patent Law Reform: Injunctions and Damages
June 9, 2005	House Judiciary, Subcommittee on Courts, the Internet, and IP	H.R. 2795, the "Patent Act of 2005"
July 14, 2005	Senate Judiciary, Subcommittee on IP	Perspectives on Patents: Harmonization and Other Matters
September 15, 2005	Senate Judiciary, Subcommittee on IP	Amendment in the nature of a substitute to H.R. 2795, the "Patent Act of 2005"

The original H. R. 2795 bill contained the following provisions:

1. Changes the current "first to invent" standard to "first inventor to file" (§3). This is an important step in achieving international harmonization and was accompanied by a rewrite of the prior art rules that has caused some controversy in the legal profession but is a necessary part of harmonization. Accompanying this change was the preservation of a one-year grace period after publication, intended to benefit small inventors and university researchers. Also accompanying it was an extension of prior user rights to all U.S. manufacturers of all inventions to protect those who use trade secrecy instead of the patent system. These changes are in the revised bills.

2. Eliminates the subjective "best mode" requirement from §112 of the Patent Act, delineating objective criteria that an inventor must set forth in an application (§4). This change also represents a move toward harmonization. It remains in the revised bill.

3. Imposes a duty of candor and good faith on parties to contested cases before the patent office, eliminating inequitable conduct as a defense of patent unenforceability (§5), unless at least one claim in the patent has already been found invalid.

4. Reduces the scope of willful infringement by raising the standard of proof required and limits the amount of damages a patent holder can collect from an infringer (§6). The substitute bill of Smith and the coalition reform package both change the wording but still try to limit the situations where treble damages can be assessed to cases where notice of infringement has clearly been given by the patent holder.

5. Limits patentees' ability to obtain injunctions (§7). This has proved very controversial and has been removed from the substitute bill and coalition reform package.

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6. Authorizes the director of the patent office to regulate continuation applications (§8). Again, this is controversial and has been removed.

7. Establishes a new post-grant opposition system in the patent office (§9) with a 9-month window. A second window of 6 months at the time of litigation has since been removed, but of course reexamination could still be requested. The substitute bills contain changes intended to increase the take up of *inter partes* reexamination.

8. Allows members of the public to introduce new information to the patent office up to six months after the date of publication of the patent application to challenge the patent and to provide a final quality check (§10).

As indicated above, in committee a number of these provisions have been dropped or weakened, largely due to opposition from the pharmaceutical and biotechnology sector, but also from a number of large chemical firms, 3M, General Electric, and large companies in traditional technologies that are more or less satisfied with the current system. The provision that allows the patent office to restrict continuations has been removed because of biotechnology industry opposition; this industry has been and continues to be a heavy user of continuations (Graham 2002).

An interesting recent development on the continuation issue has come from the USPTO itself in the form of a set of proposed rule changes and request for comment in the *Federal Register* of January 3, 2006. As was clear from the Dudas testimony cited earlier, continuations have become of major concern to the office because they take examiner time away from new applications and often require reconsideration of material that has already been examined. Therefore, they are proposing that all continuations (including continuations-in-part and divisionals) other than the first be accompanied by a "showing as to why the amendment, argument, or evidence presented could not have been previously submitted."[9] It is not immediately clear that the change will have the desired effect, since it appears to call for even more documentation to be submitted with each continuation; presumably they are hoping that the requirement will reduce the actual number of continuations by sending a clear message to potential applicants.

The concerns of the computing sector lie in other areas. Apparently the Business Software Alliance (BSA) (representing Intel, Microsoft, and other big software producers) was strongly in favor of three "reforms"—a second window on opposition, no automatic injunctions where infringement is found, and the requirement that infringement damage calculations should be based on the contribution of the patented technology to the value of the product. They backed down on the first in the face of fierce pharmaceutical opposition. The second (and possibly the third) has been taken up by the Supreme Court when it granted *certiorari* in the *eBay/Merc-Exchange* case, although the outcome of that case is not yet known.[10]

[9] *U.S. Federal Register* 71(1):48-63.

[10] The patents in question in this case are also being re-examined at the USPTO and the final decision on their validity has not yet been reached.

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What effect that will have on legislation in this coming session is unclear, and the opposing sides appear not to have reached agreement on the question of either injunctions or damages when the patented technology is a small piece of the product. For reasons that are not entirely obvious, the pharmaceutical industry has been very opposed to changes in this area, whereas the computer hardware and software sectors are strongly in favor. Most observers (e.g., see Mark Lemley's testimony to the Senate subcommittee on June 7, 2005) would argue that the two sectors (pharmaceutical/biotechnology/medical devices on the one hand and information and communication technologies on the other) use the patent system in very different ways and face very different problems of enforcement and litigation because of the nature of their products and the technologies they involve. Apparently the pharma sector is reluctant to change a system that they perceive is working to their benefit, especially in directions that might weaken it, even though some of the proposed changes would have little impact on those whose products are not based on complex technologies where a patent on a very small piece of the product can wield disproportionate power.

With respect to injunctions, the concern of upstream research entities such as the Wisconsin Alumni Research Foundation (WARF) is easy to understand. The wording in the bill appears to require injury to the patent holder from absence of an injunction, which sounds like a patent "working" requirement. This requirement is likely to be difficult for universities and public research institutions to meet, and they are therefore opposed to any change in this area. On the other hand, such a provision is clearly targeted to the damage done by so-called "patent trolls." These are entities that are able to hold firms up for much larger sums than they would ordinarily receive in the form of licensing revenue because they have the capability to shut down an entire product line via injunction, even though their piece of the technology in the product might be very small.

In any case, many think a bill of some sort will pass in the next Congress, given the interest that has been raised by the hearings and the known problems in the patent system. However, it is known that the current House Judiciary Chair, James Sensenbrenner (R-Wisconsin) is sensitive to the concerns of WARF, which are similar to those of the pharma/biotech sector, whereas Smith (who introduced the bill) is possibly more attuned to the problems of the ICT sector in his home state of Texas. Because the committee chair is in a position to stop the bill from exiting committee if he or she does not like it, there is some incentive for delay on the part of those who would like to introduce changes in the use of injunctions and the apportionment of damages until the current chair is replaced.

6. POSTSCRIPT (AUGUST 2008)

As predicted, the stalemate over patent legislation in the 109th Congress continued and H.R. 2795 expired in committee. During the 110th Congress that began in January 2007, the issue was revived in late March of that year with the

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introduction of two bipartisan bicameral bills, H.R. 1098 in the House and S. 1145 in the Senate. This Patent Reform Act was the first put forward in the two houses simulataneously and with the backing of both parties.[11] Hearings on these bills were held by the House of Representatives in April of 2007 and by the Senate in July of the same year. This was followed by debate and markup of the bills; the House bill was reported out to the floor and passed on September 8, 2007 by a vote of 220-175. However, the Senate bill remains stalled in the Judiciary Committee and was taken off the calendar in May 2008.

The state of the two bills as of March 2008 has been summarized by the Intellectual Property Owners Association.[12] A summary of the more important and less technical features is given below.

- First inventor-to-file, which also eliminates the one-year grace period, except for the patent assignee and joint research agreements. The House bill makes this contingent on other jurisdictions following the U.S. on the grace period.
- Public use and on-sale activity outside the U.S. considered as prior art; pre-issuance submittal of prior art by third parties allowed.
- Damage apportionment to be selected by the court from the set (a) entire market value, (b) economic value attributable to invention's specific contribution over prior art, and a floor on damages equal to "reasonable royalty" from non-exclusive licensing. There are differences between the two bills in this area.
- Limitations on treble damages to cases with clear and convincing evidence of specific notice by the plaintiff, intentional copying, or continuing to sell the infringing product after being adjudged an infringer. Trials would be bifurcated so that willfulness is not considered until the patent has been found valid and infringed.
- Post-grant review window, either one (in the case of the House) or two (in the case of the Senate, where the second window is triggered only by an infringement charge. limited discovery. The House bill expands inter partes re-exam in lieu of the second window.
- Publication of all applications at 18 months, House bill contains an exception for those not patenting abroad (18 months or 3 months after 2nd office action).
- Mandatory search reports authorized (at the discretion of the USPTO) with an exception for micro entities.
- Additional flexibility for the USPTO in fee-setting and rule-setting.

At the time of writing, the prospects for patent reform in Congress seem low—as discussed earlier in this article, the gap between the needs of the IT

[11] *Managing Intellectual Property News*, 1 April 2007. <*http://www.managingip.com*>.
[12] <*http://www.ipo.org*>. Accessed August 2008.

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industry and those of the chemical industries seems to be very wide, making compromise difficult to reach. The most contentious areas remain damage apportionment and the operation of a second window for post-grant review.

In the meantime, things have been happening outside the legislative system, both in the executive system (the USPTO) and the judicial system (the Supreme Court). As discussed earlier, the USPTO has proposed changes in several areas, notably regarding continuations, but also increases in fees for applications with a large number of claims and providing applicants with a route toward accelerated examination.[13] Some of these changes have become the subject of litigation (*Tafas v. Dudas*) and are currently stayed awaiting the results of an appeal to the Federal Circuit by the USPTO.

Also, together with Professor Beth Noveck of New York Law School, the USPTO launched a one-year pilot of a Web-based project on the 18th of June, 2007, entitled Peer-to-Patent, that allows anyone to evaluate software patent applications that have been voluntarily submitted for public evaluation.[14] In July of 2008, this project was deemed successful and the pilot was extended another year, and expanded to class 705 (business method) patents.

The Supreme Court has also weighed in on patent policy, with two important decisions in 2007. On April 30, 2007, the Court reversed the CAFC decision in *KSR International Co. v. Teleflex Inc.*, with a precedential opinion that clarifies the meaning of non-obviousness. In particular, the court held that the obviousness inquiry "must ask whether the improvement is more than the predictable use of prior art elements according to their established functions." Essentially this decision removes the requirement that there be some suggestion to combine elements in the prior art for a determination of obviousness.

The second important decision by the court was in *eBay Inc. et al. v. MercExchange LLC*, which clarified the legal standard for granting injunctive relief in an infringement suit. The court held that granting an injunction should not be automatic, but should rely on a four-factor test to determine whether it is appropriate:

1. The plaintiff must suffer an irreparable injury in its absence;
2. Remedies available at law are inadequate compensation for that injury;
3. Considering the balance in hardships between the plaintiff and defendant, a remedy in equity is warranted; and
4. The public interest would not be disserved by a permanent injunction.

The implication of this decision is to shift the threat point of the plaintiff in any negotiation over licensing royalties. Formerly, failure to reach agreement

[13]<*http://www.uspto.gov/web/offices/pac/dapp/opla/presentation/focuspp.html*>. Accessed August 2008.

[14]<*http://www.peertopatent.org/*>. Accessed August 2008.

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meant the possibility that (a portion of) the defendant's business might be shut down in cases where there was a finding of infringement. Under the eBay decision, the courts would determine some level of royalties based on the contribution of the patented invention to the product in the absence of agreement (and in the presence of a finding of infringement).

Summing up, this is the state of patent reform in August 2008: changes to the law are stalled in the U.S. Congress, administrative reforms to patent prosecution at the USPTO await court decisions, and two of the more egregious problems with the operation of the system have been dialed back by the Supreme Court.

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Reform of Patent System in Japan and Challenges

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1. INTRODUCTION

Intellectual property rights (IPR) protection in Japan has been significantly strengthened since the early 1990s.[2] Initially, the impetus for such change came from abroad. Under the U.S.-Japan agreement in 1994, which resulted from the IPR policy dialogue in the framework of structural impediments initiative, both governments agreed to make important policy changes. In 1994, the Japanese government switched from the pre-grant opposition system to the post-grant opposition system. It also pledged not to invoke compulsory licensing to resolve a blocking relationship unless it was for the purpose of correcting anticompetitive conduct or for public or noncommercial use. Furthermore, it expanded the fast track system of patent examination to allow an applicant with an application to a foreign patent office to enjoy a fast track too. The U.S. government in turn pledged to introduce an early disclosure system for patent applications and a re-examination system and to continue refraining from the use of compulsory licensing.

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[2]Japan has a long history of intellectual property rights protection. The first full-fledged patent law was enacted in 1885. The first full-fledged copyright law was enacted in 1899 in the same year as Japan acceded to the Berne convention.

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Following this agreement, there was the TRIPs (trade-related aspects of intellectual property rights) agreement in 1995. It requires its member countries, among others, to make patent protection available for any inventions, whether products or processes, in all fields of technology, with only with a few specified exceptions, and to make the term of protection at least as long as twenty years from the filing date.

Subsequently, Japan has taken the initiative by making patent reform one of the cornerstones of its domestic reform initiative. Japanese policymakers and industrialists have recognized the increasing importance of intellectual property system in an economy where investments in intangibles have become very substantial. Many of them also believe that stronger protection of intellectual property rights in the United States since the beginning of the 1980s has been an important factor in the impressive recovery of the U.S. economy, which was fueled substantially by innovations in information technology (IT) and biotechnology, which depend significantly on IPR (although not necessarily on patents). The reform in Japan has become deep and extensive in the 2000s, including the implementation of the series of action plans coordinated by the Intellectual Property Policy Headquarters headed by the prime minister beginning in 2002, the enactment of the Basic Law on Intellectual Property in 2003, and the establishment of the Intellectual Property High Court in 2005.

Although it is too early to evaluate the economic effects of the overall reform of the intellectual property system, the experiences of the past decade or so have highlighted new challenges as well as provided useful policy experiments. This paper analyzes three major challenges facing patent systems in Japan and in the United States for the purpose of promoting innovations. Section 2 provides a brief discussion of the patent system reform in Japan in recent years. Section 3 covers the need for efficient patent examination to handle the rapidly growing number of patent applications and their growing complexity as well as to ensure high patent quality. Section 4 discusses efficient use of information disclosed in patent documents for industrial research. The question is how efficiently a firm is using this information in its R&D and patenting behavior. Section 5 discusses the patent thicket problem in standard development and other cumulative technology areas. This section clarifies how more patents may actually hamper innovation. Each section discusses brief policy directions for the future.

2. REFORM OF PATENT SYSTEM IN JAPAN SINCE THE EARLY 1990s

Although this section focuses on the changes since the early 1990s, it is worthwhile to note that important measures were already taken in the 1970s and the 1980s. The first measure was the introduction of product patent in 1976, and the second one was the liberalization of multiple claims for a patent in 1988. Before the change, a patent could accommodate only one claim, which made it difficult to protect the parts as well as the whole of an invention. The effect of

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this change has unfolded gradually and significantly in the 1990s, as will be seen in the next section.

Stronger deterrence against infringement was clearly one of the major policy changes. The government strengthened the private damage system, criminal sanctions, and the power of a patentee to collect evidence of infringement. The damage compensation awarded in the case of infringement used to be low in Japan. In addition to the high standard required for proving the causal link between infringement and lost profit, the opportunity cost was not included in estimating the lost profit. While the patentee would incur only incremental cost to achieve the output that he would be able to achieve if there were no competing entry infringing his patent, the average cost was used in determining the lost profit due to such infringement. The court rulings, however, began to adopt the concept of opportunity cost since the middle of 1990s.[3] A similar problem existed in the determination of royalties as damage. When the causality between infringement and damage is not proven, the damage is calculated as a royalty for a license. The basis of such royalty, however, used to be a standard rate such as the royalty rate of a government-owned patent, partly because the patent law provision on damage (Article 102) used to characterize it as "the value to be *ordinarily* received." Thus, it was not based on the hypothetical ex-ante royalty negotiation between the two parties as in the United States, which could reflect the profit made by an infringing firm.

The patent law was revised in 1998 to address these problems. The amendment introduced a new provision that allows a patentee to presume the amount of damages due to infringement based on the sales made by an infringer and on the profit rate of the patentee. It also dropped the term "*ordinarily*" in its stipulation of royalty damage and strengthened criminal sanctions. The law was further amended in 1999, strengthening the power of a patentee to collect evidence for showing the infringement of his patent, covering the submission by an accused party of the relevant documents.

Second, there was the expansion of patentable subject matter in the field of computer programs. The problem, which the United States resolved in the 1980s, was how an algorithm or mathematical formula that is not patentable can be separated from the patent claim.[4] A major constraint in Japan was that the patent law defines an invention eligible for patent as a "technical idea utilizing natural laws."[5] Reflecting this qualification, a computer program per se was not patentable until 1993, unless it was a part of an invention using hardware. It became patentable in 1997, when recorded in a computer-readable storage medium. In

[3]The first case articulating the use of incremental cost in calculating the lost profit was the 1995 decision by Tokyo Local Court, involving the infringement of copyright of computer program.

[4]*Diamond v. Diehr*, Supreme Court of the United States, 450 U.S. 175, 1981.

[5]Merges (1996) suggests that weak copyright and patent protection of software in Japan retarded the development of prepackaged software industry in Japan, since the protection of IPRs by contractual means is not effective for prepackaged software unlike custom software.

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2000 a computer program itself became fully patentable as a product patent, and this was affirmed in the 2002 patent law amendment, although the legal definition of an invention was not modified.

Third, the Supreme Court affirmed the "doctrine of equivalents" in 1998. The strength of patent protection critically depends on how broadly the court recognizes the equivalence of patented claims, since it determines, in particular, how much a firm has to spend to invent around an existing patent. The Supreme Court ruled, among other things, that "equivalence" should be determined based on technologies available at the time of infringement, not at the time of patent grant. Thus, the modifications that are obvious given the technologies available at the time of infringement keep equivalence. After this ruling, 140 litigations involving the issue of equivalence were initiated from 1998 to 2003, and equivalence was recognized by the courts in 15 cases in this period.

Fourth, in 1994 there was a switch from a pre-grant opposition system to a post-grant opposition system. The pre-grant opposition system allowed any person to oppose a patent before its grant. It was one source for the delay in the patent examination in Japan in the early 1990s. Even though it also provided a mechanism for a third party to add valuable information on prior art, it also opened the possibility for a competitor to file opposition without substantial merit. The post-grant opposition system was replaced by the enhanced invalidation trial system introduced in 2004 (see section 3.3 for further details).

Finally, based on the 1994 U.S.-Japan Agreement, the Japanese government made it clear that it would not order a compulsory licensing in order to resolve a blocking relationship (based on Article 92) unless it is for the purpose of correcting an anticompetitive conduct or for public or noncommercial use.[6] Such a blocking relationship can occur, for example, between a basic patent and an improvement patent and will usually be settled privately through unilateral or cross license. However, if a licensor refuses to give a license or demands an extremely high royalty rate, a potential licensee might ask the government to intervene under Article 92. Although there was not even a single case of the government actually ordering the compulsory license, there were at least 23 applications that were later settled privately. The threat of a government intervention itself has the effect of reducing royalty rates for blocking patents.

3. EFFICIENT PATENT EXAMINATIONS

The basic objective of a patent system is to promote innovation. Although patent protection is important for this objective, granting more patents does not necessarily promote innovations, if it occurs through protecting more low quality

[6]This commitment goes beyond the agreement of the TRIPs (*Article 31 Other Use Without Authorization of the Right Holder)*, which allow more extensive interventions, except for in the case of semiconductor technology.

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inventions, which do not adequately meet the patentability standards. The system has to be designed to make the patent system effective for promoting innovations. In the following, we discuss three issues from this perspective.

3.1 Increasing Patent Examination Requests and Increasing Complexity of a Patent

There has been a significant increase in the number of patent examinations requested as well as in the number of claims per patent in Japan for the past decade or so, as seen in Figure 1. Unlike the United States, Japan has not seen a significant increase in the number of patent applications relative to the level of real industrial R&D spending. However, the number of patent examinations relative to the level of real industrial R&D spending increased significantly over time,[7] even if we ignore the jump in 2004 (to be discussed later). As a result, the number of patent examinations doubled between 1990 and 2003 and increased by an additional 30 percent in 2004. Moreover, the average number of claims per patent applications has increased gradually but significantly from around three in 1990 to around nine in recent years. Thus, whereas industrial R&D increased by 30 percent for the period from 1990 to 2003, the number of requested patent examinations increased by 90 percent and the number of claims almost tripled in the same period.

The increase in the number of claims was made possible by the 1988 reform, which substantially liberalized the use of multiple claims per patent. The significant increase in requests for patent examinations relative to industrial R&D expenditure could have been caused by the increase in the value of a patent due to multiple claims of a patent and new measures enhancing the protection of a patent as well as the emergence of new opportunities for technology development in such fields as information technology, biotechnology, and nanotechnology.

In addition, the 1999 patent law amendment that forces a firm to decide whether it will seek a patent examination within 3 years after application caused a sharp increase in patent examination requests in 2004. A firm could postpone such decision up to seven years after application until September 2001. Under the old system, only one-third of patent examinations went to the examination process within three years after application. Thus, forcing a firm to make an examination request decision within three years after application seems to have resulted not only in a temporary acceleration in patent examination requests but

[7]In Japan, as in Europe, patent applications are examined only if it is requested. This is one reason why the Japanese patent examiners stand at around 1,300 in 2005, being less than a half of that of the U.S. patent examiners, while they have been able to handle patent applications more than those of the U.S. examiners. In the early 1990s only 40 percent of the applications were requested for examinations but this ratio increased to around 60 percent in early 2000s.

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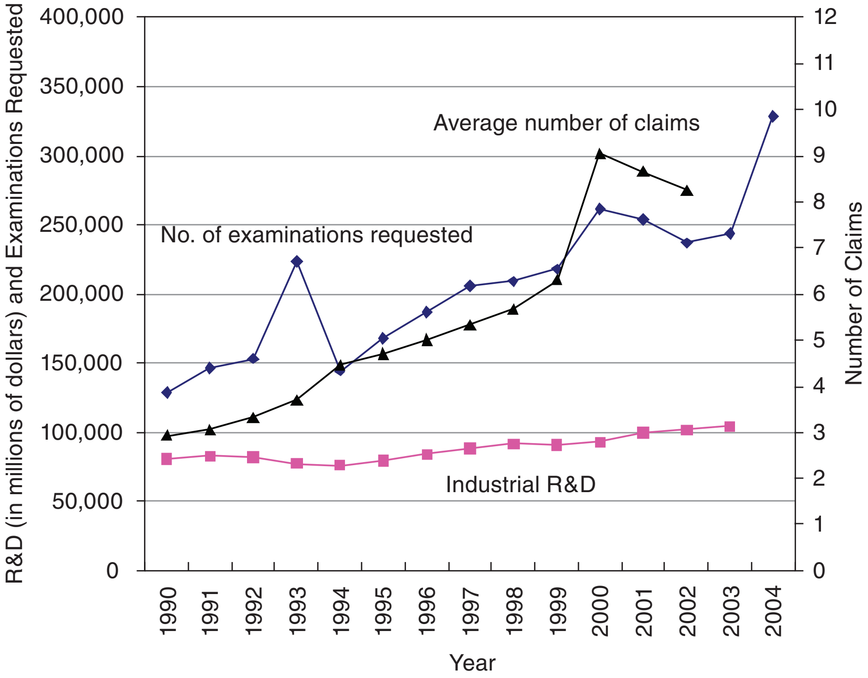

FIGURE 1 Increasing patent examination requests and increasing number of claims per patent.
SOURCE: The numbers of examinations requested are from the annual reports of Japanese Patent Office. The average numbers of claims per patent application are from the IIP patent database. Industrial R&D numbers are from the Science and Technology White Paper (Real industrial R&D expenditure in 1995 prices, Millions of dollars; [1 dollar=118 yen]).

also in its significant increase on a permanent basis, since a firm values the option value of a patent.[8]

The increasing complexity of a patent and increasing requests for patent examinations are putting strong pressure on the scarce examination capacity of the Japanese Patent Office (JPO). The pressure is reflected in the recent increase in the waiting period for examination, which increased from 19 months at the end of 1998 to 26 months at the end of 2004, as well as the increase in the "inventory" of the patents to be examined from 350,000 at the end of 1998 to 610,000 at the end of 2004. In order to prioritize the examinations, however, fast track examination have

[8]The examination request rate for the patents applied for in 1997 was 55.4 percent. It was 66.4 percent (or more than 20 percent increase) for the patents applied for during the three months from October to December 2001 immediately after the legal change.

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been available since 1984 for those who will use their patented inventions in the near future, those who will file foreign patent applications, university and public research institutions, and small and medium enterprises, including individuals.

3.2 Inventive Step and Patent Quality

Ensuring high patent quality in the sense of meeting the patentability criteria well has been an important issue in Japan, in the midst of the increasing number of patents with more complex structure. The grant rate of patents (the ratio of granted patent applications to the sum of granted and rejected patent applications, including abandoned patent applications) declined significantly in recent years to around 50 percent, compared to more than 60 percent in the late 1990s, as shown in Figure 2. Such a decline of the grant rate was due to the stricter standards applied by the JPO since 2000, in particular with respect to the inventive step.[9] Tightening the standards reflected the complaints of Japanese industry over the deterioration of patent quality in earlier years. The effect of a stricter application of the inventive step was especially substantial in the area of business-method related software patents, where the grant rate declined from more then 30 percent in late 1990s to 8 percent in 2004. Stricter standards are also apparent in the significant decline in the success rate of complaint trials against rejections and the significant increase in the success of invalidation trials.

Although international comparison is difficult to make due to the difference of the structure of patent applications across jurisdictions, industry observers often suggest that the JPO standard is higher than that of the U.S. Patent and Trademark Office (USPTO) but lower than that of the European Patent Office (EPO). The grant rate was 50.5 percent for the JPO, 59 percent for the EPO and 64 percent for the USPTO in 2003 (see JPO 2005). Such difference seems to be based significantly on the basic policy difference across jurisdictions. The U.S. system as a whole is designed to be favorable to inventors, which is reflected in the non-obviousness test, which sets a higher hurdle for an examiner to reject an application than does the inventive step test; no restrictions on continuation practices; and the presumption of validity.

3.3 Searching for the System of Efficient Examination

The JPO has taken a number of steps to address the challenge of achieving adequate patent quality and timeliness. The first measure was to increase the number of examiners significantly (500 over a 5-year period) and to expand outsourcing in patent search. This has reduced the growth in the inventory of patent applications waiting for review.

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[9]The JPO formulated the new examination guideline in 2000, which describes flexible reasoning by an examiner for assessing the inventive step of an invention.

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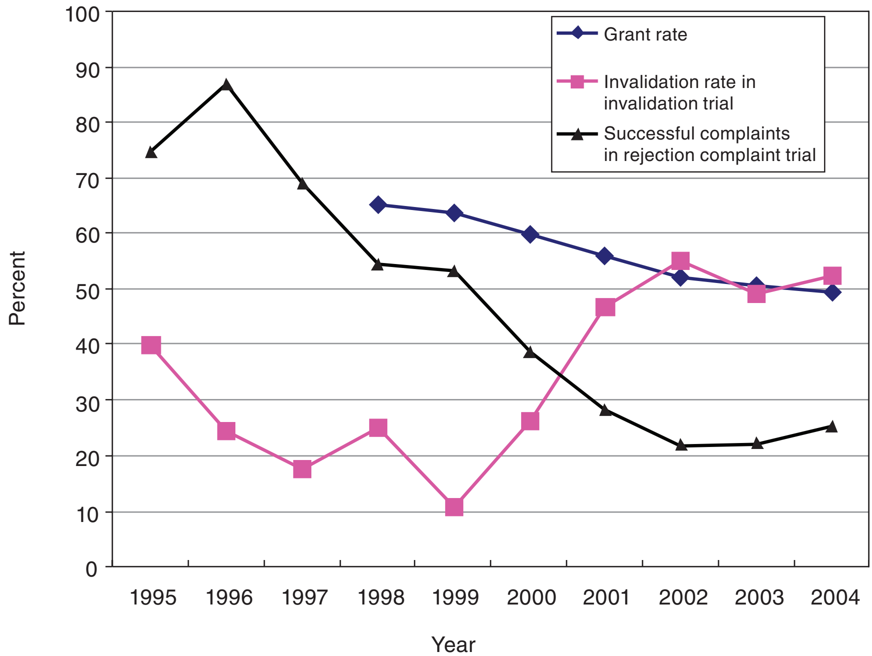

FIGURE 2 Application of stricter novelty standards since late 1990s.
NOTE: Grant rate equals the ratio of the granted patent applications relative to the sum of granted and rejected patents, including abandoned patents.
SOURCE: Derived from Japanese Patent Office Annual Reports.

The second measure was to double patent examination fees so that they would at least cover direct costs. In the past, the examination fee was significantly below cost and had to be heavily subsidized by the maintenance fees. The fee increase should have the additional effect of improving patent quality because it increases the threshold of the internal selection by a firm for examination requests. It is too soon to know if the increased fee, which was introduced in April 2004, is having the significant effect.

The third measure was to reform utility-model protection, which covers the technical ideas related to the shape of a product, its structure, and the way parts are combined. The inventive step requirement for this type of protection is lower than that for a patent. Utility-model protection was revised fundamentally in 1994 by adopting a registration system without examination and requiring technical evaluation by the JPO only when an applicant enforces it. The length of protection was 6 years and intended to provide quick protection for products with a short product cycle. However, the applications for utility-model protection fell dramatically after the change from 77,000 in 1993 to 7,983 in 2004. The applica-

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tions for a utility-model protection were already decreasing before 1993, due to the introduction of a multiple claim system. The reform measures effective as of April 2005 include the extension of the term of protection to 10 years and the provision of the option for the firm to switch a utility-model to a patent application. How significantly such measures will work for channeling patent applications to utility-model applications remains to be seen.

There is a general question of how intensively and how swiftly ex-ante examination of patent applications is to be done. Compared to the U.S. system, the Japanese system allows an applicant more discretion. The applicant has the option of requesting an examination for three years. It can request a fast-track examination and can use a utility-model protection. Lemely (2001) suggests in the context of U.S. patent reform that the society would be better off spending its resources more in judicial inquiry into the validity of those few cases in which it matters rather than in the examination of all patents applications ex ante and actually suggests that "the hybrid system along the [lines of the] Japanese system in which a patentee would register his invention" but one where "it would not be examined unless the patentee elects examination. However, the patentee could not enforce the patent against a third party unless it first has the patent examined." His idea of the hybrid system is actually a mixture of the patent and utility-model protection of Japan. On the other hand, Jaffee and Lerner (2004) argue that the United States should retain presumption of validity by strengthening the re-examination system, so that uncertainty does not deter investment for the development of innovations.

Although there is no solid empirical basis to evaluate whether the U.S. or Japanese system of patent examination is more efficient, we may be able to draw some useful observations from the experiences of both countries. First, Japan's experience with utility-model protection since 1994 suggests that the hybrid system of postponing the examination of an invention until the enforcement stage may not work. Inventing firms have preferred patent protection because they want to obtain a solid basis for protecting their inventions when necessary by asking the patent office to examine their inventions before they actually use them.[10] The availability of technical evaluation for a utility model does not help much.

Second, many firms value significantly the option to postpone the request for examination. Two-thirds of the requests for examination were made during the period from the fourth to the seventh year (final year) after application and the requests for examination were made for only half of the applications. This indicates that numerous uncertainties exist with respect to the commercial applicability of an invention and a long time is necessary for their resolution.

Forfeiting the option to postpone the request for examination as in the United States would probably not make sense. It would force a patent office to examine

[10]There is a presumption of negligence for an infringer of a patent right, but such presumption does not exist for that of the utility model registered.

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a patent that may not be used at all in the future, especially given the scarcity of its examination capacity. The recent Japanese reform to restrict this option from seven years to three years may also turn out to be counterproductive on the same grounds.[11]

Third, the participation of a third party in post-grant opposition system tends to improve patent examination quality significantly. A non-negligible number of patents were challenged (on the average 3.3 percent of the granted patents for the period from 1997 to 2003) and a substantial proportion of the oppositions were upheld (on the average 30 percent for the period from 1997 to 2003), even though the JPO has a relatively high standard of patent examination. It remains to be seen how the integration of the post-grant opposition system into the invalidation trial will work in Japan. Although such integration reduces some redundancy between the two systems and therefore improves efficiency, it may reduce the incentive for a third party to immediately challenge a granted patent, since there is no fixed window of opportunity for such challenge as was the case for the post-grant opposition system.

Fourth, international collaboration among U.S., Japanese, and European patent offices for mutual recognition of search results and examination results would significantly leverage the examination resources globally. Currently, applications from the United States and Europe to Japan add up to around 45,000 per year, which was around one-fifth of the examination requests to the JPO in 2004. Thus, even if foreign examination results for all of these patent applications are accepted by the JPO, it would not substantially reduce the examination burden of the JPO. However, in the long run, there will be more international applications in each jurisdiction, so that the benefit of mutual recognition will substantially increase. Deep collaboration would obviously require the significant convergence of patentability standards.

4. EFFICIENT UTILIZATION OF DISCLOSED INFORMATION IN LIGHT OF PRIORITY RULE

All patent applications are laid open in 18 months after application in the Japanese patent system. In addition, the first to file is the priority rule, which gives a strong incentive for a firm to file a patent early in the process of invention and innovation. Thus, we expect that the Japanese patent system has forced a firm to disclose technical information in a relatively early stage so that the information specified in patent applications may well be enhanced. According to the comparative survey by Cohen, Goto, Nagata, Nelson, and Walsh (2002), Japanese firms regard patents as the most important source of information on rivals' R&D.

The situation seems to be quite different in the United States, where a patent used to be disclosed only when it was granted and the first inventor to file rule

[11]One argument for the restriction is the social cost of uncertain right. But it is important to note that anybody can request for a patent examination.

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TABLE 1 Unexamined or Non-granted Prior Patent Applications Used for Rejecting Patent Applications

IPC Sections		Number of Cited Patents	Unexamined (%)	Nongranted (%)
A	Human Necessities	27,981	26.1	49.3
B	Performing Operations: Transporting	87,715	28.2	51.9
C	Chemistry, Metalurgy	62,307	27.3	45.4
D	Textiles, Paper	11,704	27.6	48.1
E	Fixed Constructions	10,684	23.5	45.9
F	Mechanical Engineering, Lighting, Heating, Weapons, Blasting	32,845	29.9	52.8
G	Physics	143,020	32.1	60.7
H	Electricity	115,305	33.2	61.4
	Total	491,561	30.3	55.6
	For ultimately granted patents total	582,737	27.8	49.3

SOURCE: Sadao Nagaoka, "How Does Priority Rule Work? Evidence from the patent examination records in Japan," Paper presented for Patent Statistics and Innovation Research Workshop, Research Center for Advanced Science and Technology, University of Tokyo, November 25, 2005.

governs the priority. U.S. firms have regarded patents as less important than academic publications as a source of information, according to the above study. The recent introduction of a disclosure system for patent applications in the United States may enhance the value of technical information disclosed in patents. The report of the National Research Council edited by Stephen A. Merrill, Richard C. Levin, and Mark B. Myers (2005), however, point out the two constraints: less than full disclosure (11 percent of the applications are withheld from disclosure) and the doctrine of willful infringement. To read patents may increase the risk of being exposed to the claims of willful infringement, which is quite contrary to the basic principles of the patent law.

The value of the disclosure of all patent applications, including those not granted, is indicated by the fact that the patent examiners in Japan cite only non-granted patents as the basis of rejection on novelty and/or inventive-step grounds in 50 percent of the ultimately rejected patents as shown in Table 1 (See Nagaoka 2005). That is, non-granted patent applications provide very important priority information for the examiners. This in turn implies that the availability of such information would significantly help firms to avoid duplicative R&D efforts.

If a firm efficiently exploits the information contained in disclosed patent documents in its patent application decision and/or in its R&D decision, we would expect that a rejection based on novelty and/or inventive-step grounds would be based on relatively recent patent documents. However, this is not the case. The median age of the prior patent applications cited for ultimately rejected patent applications based on novelty and/or an inventive-step reason is 4.8 years on

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average for the patent applications in the period from 1985 to 1993. It is younger for physics and electricity sections, where technological progress is relatively rapid, and older for fixed constructions and textiles & paper, where technological progress is relatively slow. A patent application that was almost five years old would surely have been available to a firm before it started preparing a patent application and even before its initiation of research in most cases. Furthermore, 10 percent of the patent applications rejected on novelty or inventive-step grounds have prior blocking patent applications that are 10 years old or older. These data suggest the possibility that a firm may not fully incorporate the information available in disclosed patent documents in its patent applications and/or research and development decision.

Exploiting patent information for choosing R&D projects would help a firm to avoid duplicative R&D, so that both private and social returns from R&D would increase. That is, a firm that can swiftly absorb the disclosed information from patents and can quickly undertake its research is more likely to be successful not only in getting a patent but also in obtaining a patent with broader scope. A firm with a shorter citation lag, thus presumably with higher R&D speed, does obtain more valuable patents evaluated in terms of the number of forward citations at the firm level.[12] Avoiding duplicative R&D would also help improve efficient use of R&D resource in the economy as a whole, enhancing its R&D productivity. Thus, it would be very important for the disclosed information of patents to be easily searchable and accessible to firms. Given that the marginal cost of making the search database and search tools of the patent office available for the public would be low and that its patent database is an important knowledge infrastructure for invention and innovation, it would be very important for the patent offices to facilitate the access to these databases and search tools, exploiting IT technology fully.

5. AMELIORATING THE PATENT THICKET PROBLEM

The proliferation of patents and the other intellectual property rights can deter innovation. First, the proliferation of patents in a given technology field and their stronger enforceability can deter a firm from using the developed technology efficiently, due to the "patent thicket" of high transaction costs, hold-up risk, inefficiency of the chains of vertical monopolies, and the difficulty of coalition formation (see Heller and Eisenberg 1988; Shapiro 2001; Lerner and Tirole 2002; and Aoki and Nagaoka 2004, 2005). The risk of hold-up encourages a firm to obtain a patent for a defensive reason, but not for appropriating returns from its inventions (Hall and Ziedonis 2001).

[12] See Hall, Jaffe, and Trajtenberg (2005) on how forward citations at firm level are linked with the market value of a firm. See also Nagaoka (2007) for the econometric evidence for the linkage between R&D management and its performance with various controls.

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Second, in the context of cumulative innovation in which an invention provides knowledge input for the next stage of R&D, easy patentability of second-generation products may erode the incentive for pioneer inventions and thus the efficiency of the entire innovation process, assuming that efficient ex-ante licensing is feasible for second-generation R&D (Scotchmer 1996 and 2004). On the other hand, in the context of a perpetual R&D competition model in which there is no distinction between a pioneer and a follower, the wider scope of protection, which makes the use of an invention for improving its subject matter an infringement, would increase the transaction costs for cumulative innovation so that innovation can be deterred. Although the problem of patent thicket is not new and firms have dealt with them using unilateral or cross-licensing agreements and non-assertion of patents (NAP) agreements, it may have become more serious in recent years due to the increase of patent rights. The problem looks to be most acute in IT-related standards areas, since network externality is significant in IT standards adoption so that the hold-up problem is most serious.

The basic problems can be illustrated by looking at the structure of essential patents for standards such as MPEG2, DVD, and 3G standards for mobile phones. First, standards can have many essential patents, which are owned by many firms with different interests, including vertically integrated firms and the firms with no manufacturing assets. In the case of MPEG2, at least 23 organizations own 127 essential patents (see Nagaoka, Tsukada, and Shimbo 2006). In the case of DVD, at least ten firms own more than 300 essential U.S. patents. The large number of essential patent holders and their heterogeneity exacerbates the patent thicket problem, given that each firm has an incentive to increase its license fees at the expense of others once its technology is incorporated in a standard.

Second, it is often possible, especially in the United States, for a firm to apply for new patents by using continuations and divisions even after the standard specification is set. A firm designs patent claims so as to cover the standard if it can find enough supports in the specifications of its patents applied for before the standard was published. The fact that this is not exceptional is shown by the fact that a substantial proportion of the patents were applied for after the standard specifications were set in the case of MPEG2, DVD, and W-CDMA as shown in Figure 3 (based on Nagaoka et al. 2006).[13] Third, the disclosure policy of the standard bodies typically covers only granted patents and applied patents, but not future applications. Even if patents are disclosed, the standard bodies provide no precise definitions of what reasonable and non-discriminatory licensing (RAND) means for a licensing decision of a firm. Fourth, the non-granted patent applications may not be published in the United States. Thus, it

[13]When the firms with essential patents commit themselves for a fixed royalty of the standard technology irrespective of the ex-post increase of the number of essential patents, such ex-post increase of the number of essential patents affect only the distribution of the royalty revenues among licensors and do not cause holdup problems. This is actually the case for MPEG2 and DVD patent pools.

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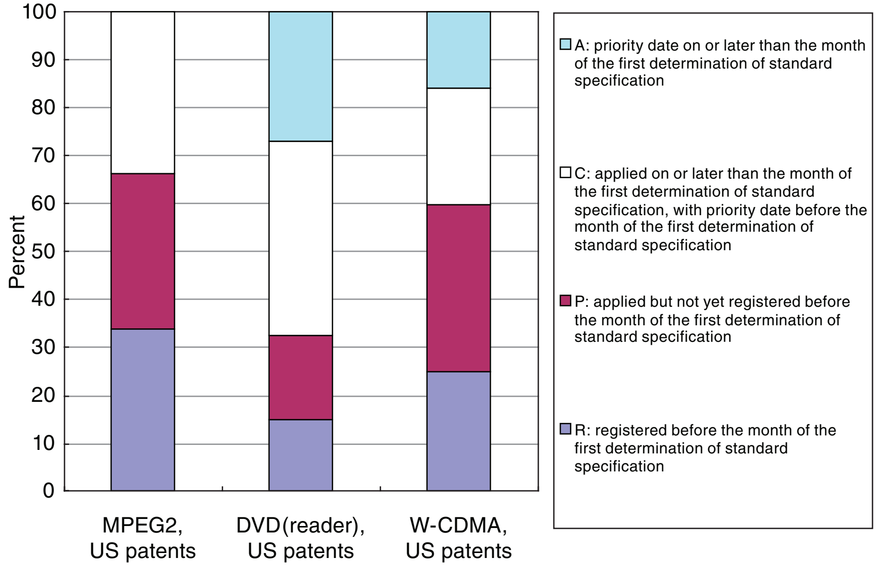

FIGURE 3 Time profile of the essential patents of three standards.
SOURCE: Based on Sadao Nagaoka, Naotoshi Tsukada, and Tomoyuki Shimbo, "The Emergence and Structure of Essential Patents of Standards: Lessons from Three IT Standards," IIR Working Paper WP#06-08, Institute of Innovation Research, Hitotsubashi University, 2006.

is possible for a firm to hold up the firms using a standard by obtaining a patent based on old (unpublished) patent applications, as is demonstrated by such cases as Symbol/Cognex v. Lemelson on bar code-scanning and FTC vs. Rambus on the DRAM JEDEC standard.

Several measures could be taken to address the patent thicket problem. First, raising the inventive-step standard would clearly help. This is demonstrated by a recent cross-licensing deal between two oil refining firms in Japan: Shin-Nihonn Sekiyu and Idemitsu. They agreed in 2005 to engage in royalty-free cross licensing of their patents in gasoline, kerosene, and other fuel products, all of which use relatively mature technologies. According to the news report,[14] the main motivation of such deal is to end the patent-acquisition and invalidation wars between the two firms, which has continued since the late 1980s when it was discovered that even minor technical improvement could be patented. A high standard of patentability would make such deals unnecessary. In addition, it would also shift patenting activities to pioneering inventions.

[14]Nikkei-Sangyo, November 12, 2003.

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Second, the continuations and division practices that allow a firm to enjoy the benefit of the earlier filing date of its patents could be more disciplined, complemented with full disclosure of patent applications. The danger that ex-post extension of the claims cover new technologies that are not the subject of an earlier invention increases as the lag between the earlier invention and the claim extension becomes long. Besides, such extension, which is not anticipated at the stage of the patent application of the earlier invention, would not significantly improve the ex-ante profitability of R&D, since it would be heavily discounted by the firm.

Third, the intellectual property policy of the standard bodies could be strengthened in terms of both the rule of disclosure and the rule with respect to the RAND conditions. The price of each patent has to be reasonable in light of the total royalty for related technologies as a whole. It should also be set ex-ante when inter-standard competition exists and before standard-users sink their investments. For this purpose, a standard body may wish to ask the group of firms sponsoring a standard to announce not only the technology specifications of the standard but also the maximum price of the standard before the standard is set. Such a requirement will force essential patent holders to focus on the pricing of the standard itself and to commit to it before the adoption of the standard.

Fourth, in order to introduce certainty for cumulative research the exemption for the use of the patented invention for improving its subject matter could be globally established. The patent law is very comprehensive in excluding the use of invention by others. It conceivably covers the use of invention for the research improving or leap-frogging it. There is an explicit provision for research and experimentation exemption in Europe and Japan, which gives (or is interpreted to give) such exemption on research on subject matter, but there is no corresponding legal provision in the U.S. patent law. Thus, there is a risk that merely experimenting with the invention of other firms for the purpose of improvement or inventing-around is an infringement, whereas forcing a firm to get a license for such use would significantly harm cumulative research.

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Industry-University R&D Partnerships in the United States

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INTRODUCTION

The appellation of the U.S. economy (as has happened in other nations) as a "knowledge economy" attests to the widespread assessment that a capacity for generating, absorbing, and implementing scientific and technological advances, both basic and applied, is essential to the economic competitiveness of firms, regions, and nations. Almost reflexively, this emphasis on knowledge has led to heightened attention to the role of research universities as sources of new scientific and technological discoveries and of the skilled scientific, engineering, and technical personnel who will populate the new occupations and positions needed to transform ideas and blueprints into processes, products, and services. This heightened attention has led to numerous efforts to develop and strengthen linkages between and among universities, industry, and government to accelerate the transformation of academic research findings (and inventions) into commercially viable technological innovations.

This chapter reviews selected trends and issues in university-industry R&D partnerships in the United States that bear on these linkages.[1] Learning, as high-

[1]More detailed comparisons of university-industry R&D relationships in Japan and the United States are provided by Hane (1999), Odagiri (1999), and Hashimoto (1999). For a sample of recent studies covering a cross-section of different aspects of university-industry R&D relationships in the U.S., albeit written mainly from the university side of these relationships, see Feller (1997); Mowery,

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lighted in the preface of the book, is indeed the proper way to characterize the past decade and the larger set of changes that have occurred in industry-university relationships since at least 1980. Firms and universities have each adapted their behaviors to previous experiences in R&D partnerships and to each other's evolving behaviors. Some of these experiences have been positive, others less so, and still others negative.

The specific issues affecting industry-university R&D relationships also have shifted over time. In the 1970s and 1980s, forums focused on cultural compatibility, timeliness of deliverables, and ivory tower syndromes. Present-day symposia center on disagreements relating to the monetary provisions of licenses and litigation about the ownership and validity of academic patents. Highly publicized and costly (for both winners and losers) university-industry patent suits (e.g., *University of California and Eolas v. Microsoft*; *Florida State v. American BioScience*) and the continuing legal dispute between the University of California and Microsoft now awaiting a second trial in the U.S. District Court about an earlier $521 million judgment on behalf of the university have changed the terms of the dialogue between the two sectors from how to consummate a courtship to how to live together in a generally mutually beneficial but at times fractious relationship

The controlling contemporary lesson from these experiences is the recognition by each sector of the need for an agreed-upon set of principles that would guide their future relationships. One example, occurring as this chapter is being written, is the statement of principles agreed to by four information technology companies (Cisco, HP, IMB, and Intel) and seven U.S. universities (Carnegie-Mellon University, Georgia Institute of Technology, Rensselaer Polytechnic Institute, Stanford University, University of California at Berkeley, University of Illinois-Urbana-Champaign, and the University of Texas-Austin) to accelerate collaborative research on open source software. Additional activities aimed at establishing guiding principles are in progress. The Industrial Research Institute (IRI), representing R&D-intensive U.S. firms, and the National Council of University Research Administrators (NCURA), representing research universities, have formed a working partnership toward this end, with their work to be capped by a university-industry summit entitled "Re-engineering the Partnership."

This chapter outlines the specific tensions in research agreements and technology transfer agreements that have led to the above endeavors. For beneath the aggregate national science indicators that point to viable, indeed robust, relationships in industrial funding of academic R&D and the outpouring of patents, licenses, license revenues, and startup firms proudly reported by university representatives, something is obviously not going well. The very title of the forthcoming IRI-NCURA summit is itself symptomatic of problems. As used in discussions of economic competitiveness, re-engineering implies some combina-

Nelson, Sampat, and Zeidonis (2003); Shane (2004); Stephan (2001); and Thursby and Thursby (2004).

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TABLE 1 U.S. R&D Data

- Universities perform 13 percent ($36 billion) of total U.S. R&D and 54 percent of basic research
- Industry share of academic R&D funding—7 percent
- Academic R&D is 1.3 percent of industry's estimated self-funded R&D ($177 billion)
- Federal share of academic R&D funding—59 percent
- Industry philanthropy to universities and college—$1.5 billion (cash and in-kind) (2003)
- University licensing revenue—$1.1 billion (2004)

tion of existing design flaws, production problems, or challenges from competitors with better technologies. What needs to be re-engineered and why?

First, I need to make some introductory comments about data, time periods, and analytical framework to better place and highlight the national context for the detailed analysis below.

NATIONAL INNOVATION DATA

As background, summary data on the facets of the U.S. innovation system explored in this chapter are presented in Table 1. The central characteristics of the U.S. system are well known: the federal government finances the largest portion of the nation's basic research; industry is the major source of funding and performer of R&D; universities are the major performer of basic research; industry's share of the funding of academic research, after rising in the 1980s and 1990s, has essentially stabilized at about 7 percent, down from its peak share of 7.4 percent in 1999; funds for academic research are a minor portion of self-financed industry R&D; and there has been a surge in university activity in patenting, licensing, and related measures. Perhaps the single least-known fact is that industry philanthropy to universities and colleges amounted to $1.5 billion in 2003.

As is well understood, the connection among these data sets is that the "frontiers of science" quality of academic research, at least in some fields and at some institutions, makes partnering with them of interest to industry. Industry support of academic research in effect represents economically efficient leveraging of much larger federal government investment in basic research for relatively modest sums. Also underlying the data is a national science and technology policy arrangement in which federal funding for academic research is allocated primarily to universities rather than to other performers such as government laboratories or state-supported research institutes. This arrangement provides for the co-location of basic research and doctoral education within a university setting, a distinctive if no longer unique feature of U.S. higher education (Clark 1995).[2]

[2]As noted by Rozenzweig and Turlington (1982) early in the period we are discussing: "To risk a tautology . . . what research universities do best . . . and are almost alone in doing . . . is fundamental research and the training for research" (p. 52).

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TIME FRAMES

A convenient and customary way to describe the recent past is as the post-Bayh-Dole era. To do so, however, tends to make patents and licenses the centerpiece of university-industry R&D partnerships, and unintentionally (and undeservedly) reinforces the view that patents and licenses are the necessary and most important means by which academic knowledge is transferred into commercially important technological innovations. This is not my intention. The chapter 's use of a quarter-century rather than a decade as the time period of interest is intended instead to highlight (1) the continuing evolution of university-industry R&D partnerships—for one can readily identify collaborative undertakings that started well before 1980 (Rosenberg and Nelson 1994); (2) that the lessons learned during the past decade were themselves responses to the experiences of the immediately preceding 15 years or so; and (3) the importance of adopting a longer-term, more holistic view of the evolving nature of these partnerships than suggested by concentration on best practices and/or salient issues of the moment (or decade).

These propositions would hold if the chapter 's focus were exclusively about the United States and directed at a U.S. audience. They are of greater importance when presented in a bilateral U.S.-Japan symposium, for what appear to be special achievements or problems of the moment in university-industry R&D relationships may actually represent shifts in the less visible but more fundamental substructures of a nation's innovation system.

Placing these relationships into a broader framework also helps highlight two emerging lessons. First, university-industry R&D partnerships emerge out of and are continuously influenced by the actions of the federal government and to a lesser but not unimportant extent by state governments, especially for public research universities. Second, R&D partnerships constitute only one portion of a larger and more diverse set of interactions, ranging from purchases of goods and services and student placements to the formation of political coalitions.

PARTNERSHIPS AND RELATIONSHIPS

Examples of what is meant by these lessons may be seen in two events that occurred even as this chapter was being written (and indeed required a considerable amount of just-in-time rewriting). The first was the brief report in the *Chronicle of Higher Education* that Andrew Grove, a Hungarian immigrant who cofounded Intel Corporation, had recently given City University of New York a $26-million gift, the largest single philanthropic contribution ever received by the university. There are many themes worthy of development from this episode: the economic gains that the United States historically has realized from being a haven for political refugees; the economic gains that it has realized from providing wide low-cost access to higher education; and the emergence of high-tech entrepreneurs as major philanthropic contributors to U.S. universities (Grove 2001).

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Viewed historically, Grove's contribution is an extension of industrialist behaviors that have significantly contributed to the formation and performance of U.S. research universities. Many of today's leading U.S. research universities, especially those founded in the later part of the 19th and early 20th centuries, owe their initial establishment to private benefactors: Stanford, Cornell, Johns Hopkins, Chicago, and the California Institute of Technology come immediately to mind (Geiger 1986, 1993; Thelin 2004). Private philanthropy has helped to finance state-of-the-art plant and equipment, make faculty salaries competitive with those in alternative occupations, subsidize tuition and related costs to students from low-income backgrounds, and diversify the institution's funding base, reducing their dependence on and subordination to the political dictates or volatility of national and/or state governments.

Endowments, the accumulation of past philanthropy, currently constitute a sizeable portion of the annual operating incomes of several of the most prestigious private research universities in the United States (Ehrenberg 2000). Capital campaigns likewise are becoming increasingly important to public research universities as they seek to offset the decline in the portion of their general operating budgets that they receive from state governments. Philanthropy also is projected to become even more important as a source of revenue over time, according to several of the most esteemed leaders of U.S. research universities (Vest 2005).

The relevance of this episode to an examination of trends in industry-university R&D partnerships is the interconnection between the market economy and the gift or grant economy. Grove's gift was totally discretionary. The *Chronicle* report notes several previous unsuccessful efforts by CUNY's president to elicit a gift. Only after Grove reached the conclusion that the City College, after a period of academic drift, was "heading in the right direction, with the right leadership," did he make a gift (Strout 2005, p. A27).

Abstracting from the influence of the U.S. tax code, which provides incentives to firms and individuals to make both in-kind and monetary contributions to universities, philanthropic contributions by firms to universities reflect industry's view that it has an interest in the advancement of U.S. science and technology and the training of advanced degree students in science, mathematics, and engineering. Philanthropy is an expression of belief in the public goods nature of the knowledge outputs of research universities. If, however, university-industry relationships are seen as competitive, as can arise in reaction to university efforts to incubate new, potentially rival firms, or adversarial, as can arise in the case of patent litigation, incentives for "free will" gifts may be reduced. The more universities are seen by industry to be operating as profit-maximizers with respect to industry-funded R&D agreements or subsequent technology transfer activities, the more likely this reduction is to happen.

Alternatively, as a polar opposite case, one could envision industry-university relationships as a series of discrete market transactions in which firms contract with universities for the performance of specific research projects, receiving

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a report as the primary contract deliverable. Likewise, when it comes to technology transfer, the transaction might consist primarily of universities marketing their intellectual property to firms entering into one-time, possibly competitive negotiations for access to the protected technology. In such cases, the "relationship" would consist of buyer-seller transactions akin to most other economic transactions, but not a partnership.

To speak then about university-industry R&D partnerships implies a form of interaction that extends beyond buyer-seller transactions. The concept of partnership focuses on mutually beneficial interactions that are directed at generating positive outcomes (in both economic and noneconomic objectives). A partnership arrangement implies trust in working through the language of initial agreements and resolution of any subsequent disagreements. In terms of the essential features of academic R&D, it accords weight to best efforts rather than to specific tangible deliverables. It also points to the prospects for repeated, continuing exchanges. These aspects of the interaction are what elevate a partnership above a transaction. But partnerships as used here represent something less than a "relationship." The latter terms imply a fuller, even longer-term set of interactions, both market and nonmarket.

Just as the transition from interactions based on transactions to partnership arrangements denotes changes in the time horizons and utility-maximizing behavior of each party, so too does the transition from managing R&D partnerships to managing the fuller relationship imply changes in how the parties engage with one another. In particular, the transition implies optimizing behavior over a larger set of transactions, which in turn means willingness to trade-off less than maximum gains to be garnered from any single transaction for the prospect of higher gains from another.

Figure 1 depicts these different levels of relationship as nested circles.

What makes all of this both interesting to the analyst and challenging to the practitioner is that the trade-offs relate to uncertain outcomes: the gains, say, from forceful university claims of ownership of intellectual property rights in industry-sponsored R&D being traded off for the economic and legal terms of licensing agreements, being traded off in turn for the prospects of future philanthropy from appreciative alumni. This is true in almost every case where the unit of analysis is an industry-sponsored agreement for academic research or the acquisition by a firm of a university's intellectual property, whether purchase of a patent or a running license.

The second recent event may be said to represent a paradigmatic example of the most mutually beneficial features of industry-industry R&D partnerships. In a news article titled, "3 Technology Rivals Join to Finance Research at Berkeley" (*New York Times*, December 15, 2005), there was a report on the formation of a new computer laboratory at the University of California-Berkeley. The laboratory is to be funded by Google, Microsoft, and Sun Systems, with each firm providing $500,000 annually for 5 years, for a total of $7.5 million. Underscoring the value

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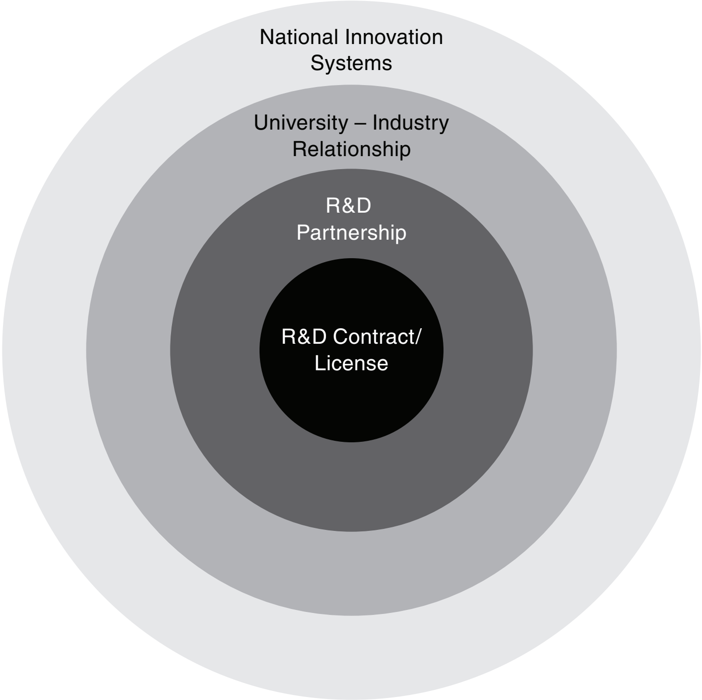

FIGURE 1 Levels of relationship.

to industry of universities as performers of precompetitive generic research, the article noted that the three sponsoring companies "are frequently rivals and only occasionally allies," but each has concluded that it "can operate most effectively by bringing technology innovations to market quickly."

Three other aspects of this partnership warrant emphasis. First, echoing the above observation about the joint production of new knowledge and human capital formation within the U.S. research university, the laboratory will have six faculty members and as many as 30 graduate students. Second, the "fruits of the research will be nonproprietary and freely licensed," reinforcing the earlier statement that patents and licenses are neither the only nor necessarily the best means of transferring academic research.[3]

[3]Reflecting emerging trends in industry-university R&D partnerships in the information industry, the intellectual property terms of this agreement closely mirror those of the recently announced statement of guiding principles described above (and indeed include several of the same participants). The key principle of interest here is that intellectual property arising from selected research collaborations is to be made available free of charge for commercial and academic use.

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A third aspect of the founding of this laboratory also is important. Motivation for securing industrial funding is described as flowing from the need of the UC-Berkeley researchers to seek industry support when they realized that the Defense Advanced Research Projects Agency (DARPA) was reducing its computer science support at universities. The faculty response in seeking industrial funding is consistent with the larger pattern of university-industry collaborative R&D ventures, especially those organized around centers, institutes, or laboratories. As detailed in the Cohen, Florida, and Goe 1992 survey, most of the initiative for these collaborations emerges out of the efforts of universities to secure industrial funding. These events also indicate that industry support of academic R&D represents more than a leveraging of federal R&D, as was described above. Instead, it may be a critical independent alternative source of basic research funding.

CURRENT ISSUES IN INDUSTRY-UNIVERSITY R&D PARTNERSHIPS[4]

The past decade, or again the post-1980 period, has seen the heightening and surfacing of a diverse set of issues in industry-university R&D partnerships. Generically, the issues relate to the terms of industry-sponsored research agreements and the terms of patent and licensing agreements, but they also cluster into several distinct subdivisions. Among the most important of these subdivisions are size of firm, industrial sector, and source of R&D funding. Table 2 presents a typology of these issues.

What follows are brief statements about several of these issues and about selective steps being taken by each party to redress recent confrontations. In the aggregate, they may be seen as constituting the problems that are causing national representatives of major U.S. corporations and leading U.S. research universities to step back and call for a new set of guiding principles.

1. Displeasure is building in the high-tech industrial sector about what are perceived to be overly assertive university claims to ownership of intellectual property generated under industry-funded research as well as about the “unrealistic” or “excessive” economic terms being sought by universities. (As voiced by one industrial representative in an industry-university workshop in which I participated, “universities have gone from if they invent it, they own it, to if they touch it, they own it.”)

2. As experience mounts over time about the technical and economic risks of commercializing academic patents, the divide between firms and universities about the form of payment for access to academic patents seems to be widening. Firms state a preference for contingent, back-end payments tied to technical and economic milestones proportionate to the levels of risk and investment each party contributes to the eventual commercial introduction and success of a university

[4]This section draws freely on Feller (2004).

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TABLE 2 Typology of Issues

Size of Firm	Industry Funded R&D	Federal/Other Funded R&D
Large	• Ownership of Intellectual Property • Royalty-free licenses • Exclusive licenses	• Upfront payments • Royalty rates • Sublicenses • Patent filing costs
Small	• Ownership of Intellectual Property • Payment mix	• Equity • Royalty rates • Spin-offs

patent. University representatives continue to favor high upfront payments, in part to ensure a firm's commitment to further development efforts.

These differences are evident in a comparison of position papers put out by the respective parties—"Technology Transfer in U.S. Research Universities: Dispelling Common Myths" (2000), by the Council on Government Relations (COGR), and "Industry-University Intellectual Property "(2002) by IRI's External Research Directors Network. The COGR document seeks to dispel what it terms several myths about university technology transfer. Among these myths are that (1) universities are doing too much patenting and that it would be better for economic growth to put more inventions into the public domain, and (2) "Universities over-inflate the value of their inventions, setting rates too high." To the first charge, the document states that "it is difficult to quantify how much patenting is 'too much'" and that the "real measure of useful patenting for universities is whether patenting encourages commercial licensing." After noting that in FY1998 universities issued 3,668 licenses/options, the authors of the position paper observe that "Whether companies would have picked up the 3,668 new university technologies to commercialize from the public domain is highly questionable" (p. 13). As to the second "myth" about royalty rates being excessive, the document states that, "Royalty rates are dependent upon market forces and determined through negotiation" (p. 7).

The perspective of large firms with specialized R&D operations that constitute IRI's primary membership is quite different. The IRI document notes that "Ownership and/or the rights to developing technology are probably the most contentious issues in the preparation of agreements between universities and industrial companies. When ownership and IP rights issues interfere with industry's aim to gain competitive advantage, then these issues impede open communications and collaboration" (p. 2). Further, in discussing how compensation should be calculated, the paper notes that the road to commercialization is a path requiring multiple—8 steps are identified—steps involving costs and risks. It then argues that "In most collaborations, the university participates only in the

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very first step (idea generation) with little or no cost or risk. It is not attractive to an industrial partner to share a large royalty after assuming all of the risk and executing most of the work, while the university is responsible for only the basic research" (p. 6).

Part of the explanation for industry's increasingly open challenge to university policies is that patents and intellectual property have recently taken on new strategic and economic saliency. Several earlier studies had pointed to the "modest" role that patents played as a source of intellectual property rights protection for most industries, with the notable exception of pharmaceuticals. This role has increased. Nationally, the number of patents granted annually tripled between 1983 and 2002 (Hall 2004). This increase in part reflects strategic changes in how firms view patents, with these changes, in turn, attributed to changes in the institutional and legal environment within which patents are granted and rights associated with them enforced. Although cross-licensing continues to be an important feature of many inter-firm exchanges in selected industries, firms have also increasingly taken to viewing their patent portfolios as revenue centers. Moreover, the increased frequency of patent infringement suits (some accompanied by sizeable damage awards) also has made firms increasingly vigilant in seeking to make sure that their "access" to a specific patent is not "blocked" by claims of a prior patent.[5] Indeed, according to some observers, the U.S. patent system is broken and sorely in need of repair. Indeed, a major undertaking of the National Research Council has been to formulate a "patent system for the 21st century" (National Research Council 2004).

These changes and the problems they are held to have caused stem essentially from causes independent of Bayh-Dole. Nevertheless, industry's changed general stance towards patents spills over to affect its relationships with universities. For example, it is seen in some cases as leading firms to demand rights to background patents held by the university, whether by the same faculty inventor or others. These demands in turn create new problems for universities in managing their holdings of patents. Since most university patent policies provide that a share of net intellectual property income be distributed to faculty, acquiescence to industry demands on background patents can raise legal and political questions about dispensing income claims of inventors. Faculty are not bashful about pursuing these claims, including suing their current or erstwhile employers.

Industry's concerns about ownership of patents and licensing terms are well known to university officials. Senior academic administrators, though, tend to see industry's challenge to university claims to ownership of intellectual property from industry-sponsored research grants as reflecting a confounding of industrial and university performance of industrially sponsored research. Contractual R&D

[5]As noted by Cohen, Walsh and Nelson (2000), "patent portfolio races have accelerated as firms have felt increasingly compelled to apply for patents because they need to protect themselves from being blocked or believe that they need a strong portfolio to force rivals to cede access to their technologies on more favorable terms" (p. 27).

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agreements between firms typically are cast as "work for hire" arrangements in which the purchaser has paramount claims to ownership of intellectual property. Industry's sponsorship of research at a university, although at times cast as a contract, is not viewed by university officials as necessarily conveying such rights, especially if work on a project involves commingling of the firm's support with resources provided by federal government agencies.

University officials also see themselves as being caught at times in a crossfire between different industrial sectors. As a general proposition, firms in the biomedical and biotechnology industries prefer that universities assert patent claims under Bayh-Dole; differences tend to arise over specific payment, milestone, and related clauses. In the information technology and electronics industries, in which patented technologies more typically serve as components of larger technological systems, firms tend to prefer to work in an environment unconstrained by university claims to intellectual property, especially if the alternative is to have the university transfer technology via exclusive licenses. Accepting different terms for different agreements is not always an easy matter to administer or to explain either to faculty or influential external observers, such as state government officials or the local media.

Perhaps the most troublesome area in the current state of industry-university R&D relationships is the emerging divergence in the perspectives of firm and university representatives about the financial terms of licenses to academic inventions. Industry, as highlighted in the IRI statement above, including both venture capital firms and established industrial firms, is increasingly pushing for flexible and contingent payments tied to technical, legal, and economic milestones. Besides whatever financial pressure or incentive they may have for guaranteed revenue streams to meet annual office expenses, university technology transfer representatives tend to view payment of patent filing costs, upfront fees, and running royalties as a form of earnest money. This earnest money is intended to foster serious efforts by firms to bring a university technology to commercial feasibility and to achieve the university's paramount objective of "getting the technology into the public's hands" via the private sector. Upfront fees and annual maintenance payments are seen as needed incentives to move the licensee to make the additional investments necessary to transform the license into a product. Also of concern to university officials is that without some modicum of upfront and early payments, firms could use licenses, especially if granted on an exclusive basis, to block or retard the commercialization of a university invention. Technology transfer staff are also aware that the university's patent likely competes for resources and attention with other prospective technologies within the R&D portfolio of firms, especially large firms, and that without some monetary cost attached to inattention, the patent might remain on the firm's "to-be-developed" shelf.

As indicated in the above typology, the issues that emerge differ between agreements with small or large firms and between industry and government

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funding. For the most part, large firms that sponsor university research are concerned about ownership issues and licensing issues on both industrially funded and federally funded research. In effect, they contend that their sponsorship of the research either entitles them to sole or partial ownership or to "preferential" treatment in licensing. In terms of license payments, equity is a nonstarter. Small firms, in general, are less apt to sponsor academic research, but when they do, ownership of intellectual property also surfaces as an issue. The more important issue in negotiations is the mix of payments that require early or ready cash in the form of upfront fees, royalties, etc., relative to equity.

Outsourcing of industrial R&D also has taken on new meaning in recent years and appears to be a new competitive tactic in industry's negotiations with universities. U.S.-based high-tech international conglomerates now report turning to non-U.S. universities and research institutes because of what these sources offer in the way of specialized or competitive scientific expertise, lower cost structures, and less-insistent claims for ownership of intellectual property.

University concerns about these incipient trends are compounded by what they also regard as the wavering commitment of federal agencies to the "spirit" of Bayh-Dole. Some federal agencies are seen by university representatives as turning to contracting procedures other than grants and contracts that have the effect of attenuating university claims to intellectual property ownership. In 2004, additional challenges surfaced to Bayh-Dole in the form of proposals to have the National Institutes of Health exercise the federal government's march-in rights in an effort to reduce the price of drugs. This proposal elicited a strong defensive response from the university community. The Council on Government Relations (COGR) and the Association of University Technology Managers submitted written testimony opposing the proposal on the grounds that it would diminish the value of academic patents (Malakoff 2004).[6]

More recently, an article in *Fortune* ("The Law of Unintended Consequences," September 19, 2005) claiming that Bayh-Dole's encouragement of academic patenting had stifled inventive activity, especially in the development of new drugs, raised a tempest among advocates of academic patenting and licensing. This response included an angry letter from Senator Birch Bayh to *Fortune*'s editor, claiming that the Act had indeed stimulated drug development, and in particular had benefited small businesses, described as the holders of more than 80 percent of university licenses. Universities also have to deal with the explosive growth in invention disclosures, now estimated at 15,000, that has resulted from their revised patent policies, increased staffing of technology transfer offices, and active promotion of faculty patenting. The Americanism that "too much of good thing is

[6]As expressed in the submitted testimony of Patricia Weeks (2004), AUTM's Immediate Past President, "Commercial concerns are unlikely to invest substantial resources in the commercial development of any invention, funded in part by the government, knowing that the government could challenge their competitive position after the product was introduced into the market."

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wonderful" holds only in a world without costs or budget constraints. Universities typically cannot now file all the invention disclosures they receive and have been forced to develop procedures to select the most promising, with still-undetermined effects on faculty behavior and university-industry relationships.

Several other trends during the past 10-15 years also point to a more complex environment within which firms and universities form R&D partnerships. Briefly, these trends include the increasing use of equity as payment for university licenses (Feldman, Feller, Bercovitz, and Burton 2002), increases in the number of university-based startup firms, increasing university willingness to invest in the prototype development of early stage inventions and patents, and consolidation by universities of their sponsored research and technology transfer offices in order to provide one-stop shopping to firms.

Another noticeable trend is the growth of master R&D agreements between firms and universities. These contracts generally provide for a commitment of a minimum amount of firm funding of research, periodic solicitations of proposals for faculty to work on topics related to the firm's interest, and perhaps most important, blanket agreements on intellectual property rights and related contractual terms. Master agreements are intended to reduce time, cost, and uncertainties. More generally, they reflect the assessment by a firm that a specific university or set of universities possesses useful scientific and technical expertise as well as a cooperative culture. The move to master agreements also suggests that firms are consolidating their search efforts to a smaller number of universities. My former academic home, Pennsylvania State University, is among the leading university performers of industrially funded R&D, and thus I cite it here as an example of what's occurring at the leading edge of university-industry R&D relationships (Figure 2).

Finally, increased recognition also is evident within university-sponsored research and technology transfer offices that most industry-sponsored research agreements produce little in the way of intellectual property, so that protracted negotiations insistent on ownership rights gain little in the way of future revenues, while detracting from the research interests of the faculty who are waiting for the funds to conduct the research (and support their graduate students), as well as possibly a larger relationship with the firm. Recently announced and pending principles calling for open, royalty-free dissemination of university intellectual property, again within the bounds of selected technologies and industries, is the larger manifestation of this recognition.

THIRD-PARTY PERSPECTIVE

Exclusive focus on industry-university R&D relationships (even with the federal government briefly noted as a background player) runs the risk of omitting other important societal effects of academic research. Even as technology transfer becomes a routine university practice, concern continues to be expressed

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- Air Products
- Ford Motor Company
- Cadbury Adams USA
- Coca-Cola
- Corning, Inc.
- General Motors
- Guardian Industries
- Kennametal
- Lockheed Martin
- Technology Collaborative
- ERA Power
- Norit Americas, Inc.
- IQS, Inc.
- Life Science Greenhouses
- Northrup Grumman
- Pratt & Whitney
- AGY
- Dana Corp.
- Hyundai Motor Corp.
- Toyota Manufacturing NA
- Nissan Motor Company
- Raytheon
- SaRonix

FIGURE 2 Industry master agreements.

about the harmful effects of academic patenting on the "public goods" character of academic research. Aggressive university policies toward promoting invention disclosures, patenting, and licensing are also seen as threatening the communal characteristics of science; in short, an anti-commons in science is held to be displacing traditional institutional and individual behaviors that have treated basic research findings as common pool resources. Competing evidence and perspectives, as detailed in Mowery et al., also exist about the need for universities to establish property rights in faculty discoveries in order to foster their conversion to market products.

CONCLUSION

The past decade-plus of industry-university R&D partnerships has produced benefits for each party while at the same time giving new force to long-recognized tensions in these relationships and giving birth to new ones that constitute serious impediments to the continuation and expansion of these relationships. The recently announced Google-Microsoft-Sun Systems agreement with UC-Berkeley likewise symbolizes the continuing high value placed by industry on academic research, especially pre-competitive generic research, as well as highlighting the importance to universities of industrial funding in maintaining and furthering leading-edge academic research. That this agreement provides for open licensing suggests that, at least for some industries, negotiations about patent ownership and licensing terms need not be an agonizing and fractious encounter. The agreement also is an important reminder that data on patents, licenses, and startups are

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neither complete measures of the economic value of academic research nor the full account of processes of technology transfer.

A useful indicator of the continuing importance placed by firms and universities on continuing R&D partnerships as well as likely a good guide to the discourse pervading future negotiations about sponsored research contracts and intellectual property agreements is the effort under way by IRI and NCURA to re-engineer the partnership. I interpret these efforts as both a reaffirmation of the importance of these relationships and recognition that they are beset by the problems outlined above. At the core of these efforts is the promulgation of a set of principles that would guide specific negotiations and interactions. In its present forms, these principles are as follows:

1. A successful university-industry collaboration should support the mission of each partner. Any effort in conflict with the mission of either party will ultimately fail.
2. Institutional practices and national resources should focus on fostering appropriate long-term relationships between universities and industry.
3. Universities and industry should focus on the benefit to each party that will result from collaborations by streamlining negotiations to ensure timely conduct of the research and the development of the research findings.

Important as I consider the substance and spirit of these principles to be, analytical rigor and a reading of history suggest the need for detached objectivity. The influences of these principles on actual behaviors cannot be stated at this time; as is often the case, the devil is in the details.

Set against the articulation of broad principles for cooperative and collaborative relationships are other influences that serve to keep or push the two sectors apart. U.S. R&D-intensive firms are increasingly scouring the globe for sources of fundamental research. Numerous science indicators point to the increased globalization of leading-edge research with a corresponding decline in the U.S.'s relative position. The effects of restrictions on the entry of foreign graduate students to U.S. universities, and thus their enrollments in leading universities in other predominantly English-speaking countries, cannot but further erode the U.S.'s standing in academic research in coming years. Also, in almost symmetrical fashion, pressures on firms to meet short-term profit or stock price targets and on university technology-licensing offices to meet revenue targets can lead either or both parties to push for sponsored research or licensing terms that vitiate the substance of these principles.

In all, even as U.S. firms and universities distill their recent experiences and work assiduously and in good faith to (re)build strong R&D partnerships for the 21st century, industry's self-interest will lead them to widen their search for the jointly produced knowledge outputs—research findings and graduate students—generated by U.S. research universities. Relatedly, even under the best,

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or least fractious, conditions affecting sponsored research agreements and intellectual property rights agreements, the scientific and technological importance of these R&D agreements (including possibly their number and dollar value) will decline unless U.S. universities continue to remain among the world leaders in basic research and graduate education.

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University-Industry Partnerships in Japan

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UNIVERSITY-INDUSTRY PARTNERSHIPS IN A NATIONAL INNOVATION SYSTEM

A national innovation system contains three knowledge-creating sectors: universities, public research institutes, and industry. Universities play an important role in basic research, and industry plays an important role in development. The division of labor among these sectors is clearer in the United States than in Japan. In the United States, universities conduct 62.0 percent of national basic research, whereas in Japan they conduct only 46.5 percent of it (Figure 1). Japanese public research institutes are important in basic research, whereas their U.S. counterparts are important in applied research.

Among these three sectors, only industry delivers new products and new processes to the market. Therefore, the question for policymakers and industry managers is how a nation can best use the science and technology capability of the two knowledge creating sectors, universities and public research institutes, to augment the science and technology capability of the industry sector for industrial innovation (Figure 2). In this chapter, we focus on universities.

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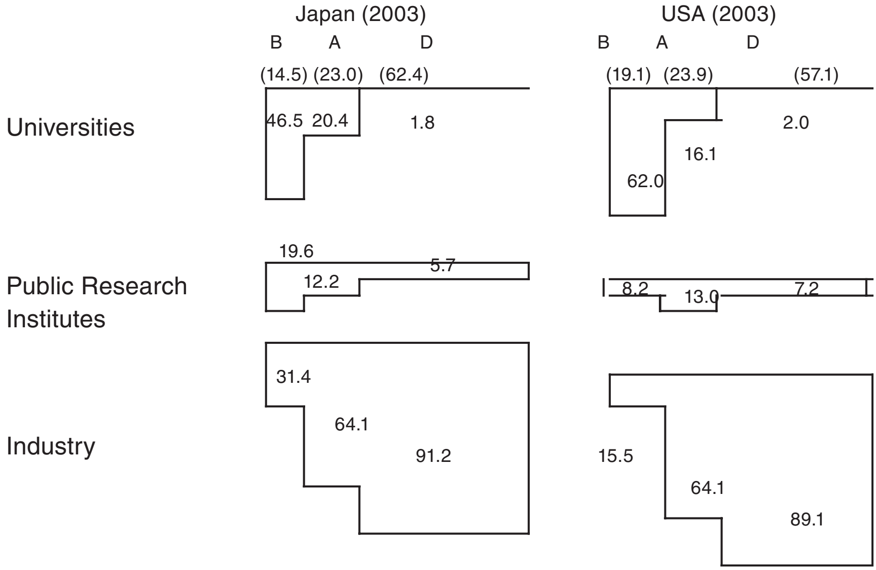

FIGURE 1 Role charts.
NOTE: Unit is percent.
SOURCE: Devised using data from Statistics Bureau, *Report on the Survey of Research and Development 2004*, (Japanese), Japan Statistical Association, 2004; and Organization of Economic Cooperation and Development, *Research and Development Statistics*, 2004 Edition, Paris: Organization for Economic Cooperation and Development, 2004.

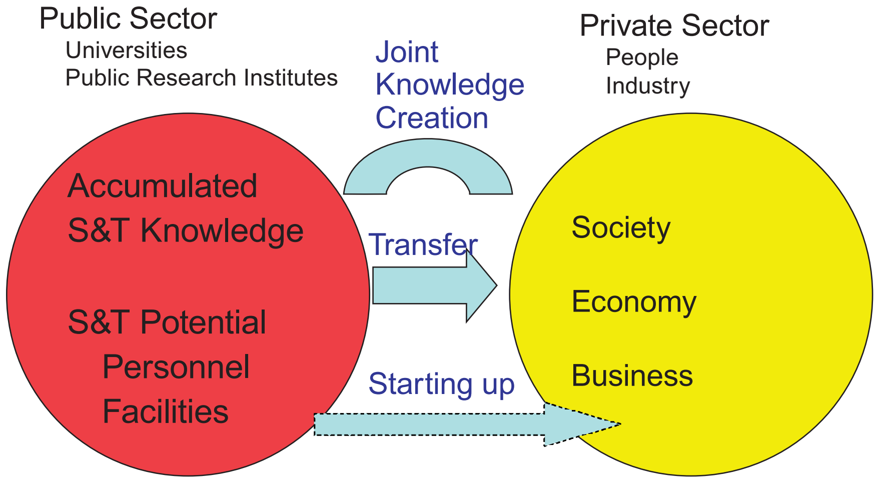

FIGURE 2 Question: How can we utilize S&T for society, economy, and business in a national innovation system?

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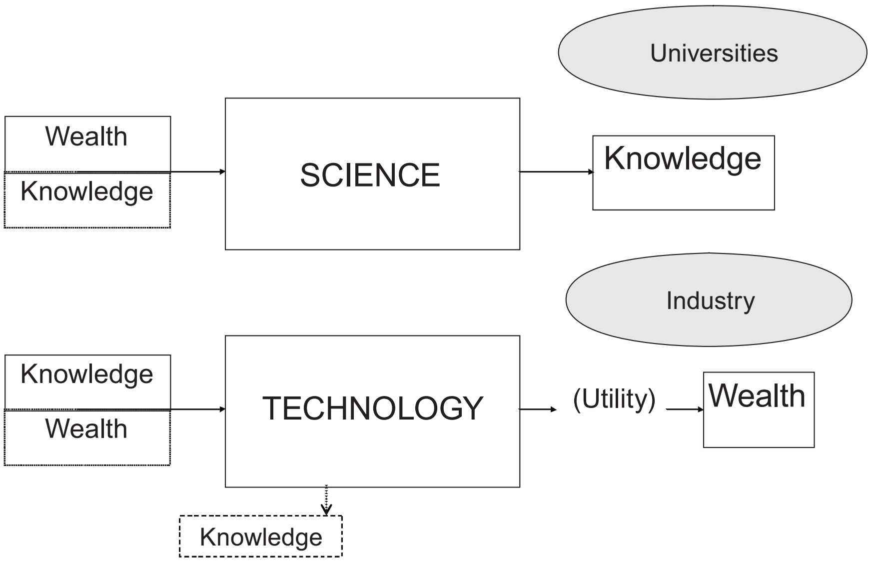

FIGURE 3 Science vs. technology.

Universities can contribute to industry innovation in three ways: knowledge transfer from universities to industry[1]; joint creation of knowledge by university and industry researchers; and formation of a new company based on university knowledge.

The involvement of the industry sector is essential to using university knowledge in the economy and society. Universities basically exist in the science in which knowledge is created using wealth (Figure 3). Industry lives in technology culture in which knowledge, including scientific knowledge is used to create utility.

These days, science and technology are becoming closer. According to Stokes (1997), research is categorized into three types (Figure 4): pure basic research (Bohr's quadrant), pure applied research (Edison's quadrant), and use-inspired pure basic research (Pasteur's quadrant). Pasteur-type research has been growing in importance because innovation has become more science-based. Thus, the importance of scientific knowledge created in the university sector and of university-industry partnership has grown.

[1]For the discussion of the difference between international technology transfer and domestic technology transfer, see Kondo (2005).

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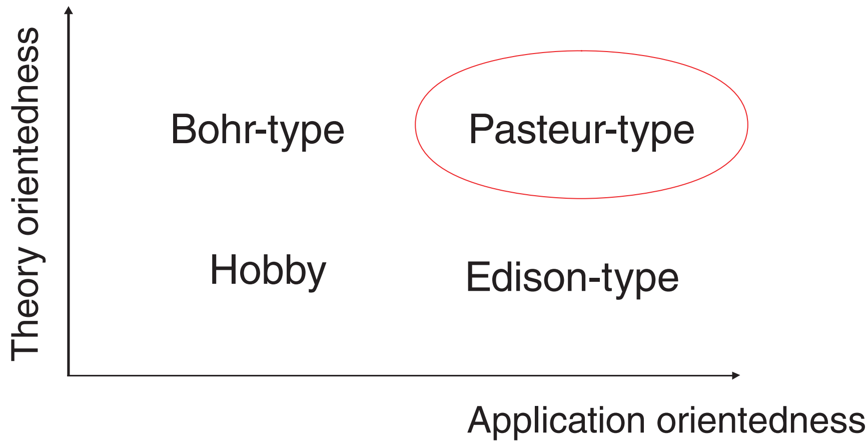

FIGURE 4 Science-based technology.
SOURCE: Modified from diagram of Donald E. Stokes, *Pasteur's Quadrant: Basic Science and Technological Innovation*, Washington, D.C.: Brookings Institution Press, 1997.

HISTORICAL VIEWS OF UNIVERSITY-INDUSTRY PARTNERSHIPS IN JAPAN

Though university-industry partnerships were not active in the 1960s and 1970s—in part because of student political movements and campus disruptions, there is a long-standing tradition of cooperation in Japan. In this section two cases of good university-industry relation are discussed: the establishment of the world's first Department of Engineering at the University of Tokyo and the work of the Institute of Physical and Chemical Research (RIKEN) in leading a large industrial group before World War II.

Department of Engineering, Tokyo University

At the start of Japan's modernization, Japan imported technologies from the West. In addition to importing machines and documents, the government hired many foreigners. These engineers were needed to construct infrastructure, such as railways and telegraph line networks, and to build and operate modern factories. However, these foreigners, some of whom earned more than did government ministers were too costly to hire for a long time.

The government decided to foster Japanese engineers to replace these foreigners. The government sent a certain number of young Japanese to study overseas and established an engineering school at home. The Imperial College of Engineering was established under the Ministry of Engineering, not the Ministry

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of Education, in 1873, and became the College of Engineering of Imperial University (now the University of Tokyo) in 1886.

The curriculum of Imperial College of Engineering was designed by Dr. Henry Dyer from Scotland, who was the president of the college from 1873 to 1882. It combined theoretical studies and practices. The six-year course of study included two years of basics such as mathematics, two years of study of a branch of engineering such as mechanical engineering, and two years were dedicated to practice. Graduates from the College worked in the industry, government, and academia.

Thus, the engineering departments of Japanese universities were application-oriented from birth.

RIKEN (Institute of Physical and Chemical Research)

I am aware of only one research institute in the world formed an industrial concern and enabled it to be profitable and to support the institute itself[2]: the Institute of Physical and Chemical Research (RIKEN) of Japan, which created the RIKEN Industrial Group. Many companies belonged to this group, and some such as Ricoh, a maker of cameras and copiers, became very successful. Since many of principal researchers of RIKEN held joint appointments as university professors, RIKEN can be considered an example of university-industry partnership.

RIKEN was established in 1917 at the initial stage of Japan's industrialization as the first full-scale national research institute with government support. The initiative to establish RIKEN started in 1913 when Dr. Jokichi Takamine, a scientist and millionaire living in the United States, pointed out the need for a National Science Research Institute. Prime Minister Ohkuma and influential business leader Baron Shibusawa were the key players in making this suggestion a reality.

RIKEN excelled in a wide range of R&D activities from basic research to commercial product development. At one extreme, it produced more than 3,700 research papers from 1922 to 1941, including 1,686 papers in Japanese and 1,072 papers in foreign languages. Moreover, the first two of Japan's Nobel Prize winners, Dr. Yukawa and Dr. Tomonaga, did research on the structure of an atom at RIKEN. Another Nobel Prize Laureate, Dr. Fukui, was a researcher under Prof. Kita, who was also a researcher at RIKEN.

In addition, RIKEN developed new processes, such as new methods to produce vitamins, and new products such as piston rings, photosensitive papers, gas microanalyzers, and light and strong aluminum cookware called Alumite. RIKEN was granted 0.7 percent of all patents registered in Japan during the period from 1918 to 1944, and these patents became an important source of revenue.

[2]The Chinese Academy of Science (CAS) is active in spinning off companies. In a sense, the case of CAS is similar to the case of RIKEN. However, CAS is a public organization and receives public financial supports unlike RIKEN. See Kondo (2003).

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TABLE 1 Revenue of RIKEN

Year	1927 Thousand Yen	1927 Percent	1939 Thousand Yen	1939 Percent	1940 Thousand Yen	1940 Percent
R&D contract	13	2.0	264	7.1	137	3.8
Patent royalty	0	0.0	1,793	48.4	2,182	60.4
Production work	206	31.2	53	1.4	44	1.2
Stock operation	37	5.6	740	20.0	6	0.2
Rent	6	0.9	1	0.0	1	0.0
Interests and dividends	143	21.7	793	21.4	876	24.3
Subsidies	250	37.9	0	0.0	0	0.0
Miscellaneous	4	0.6	61	1.6	367	10.2
Total	660	100.0	3,705	100.0	3,611	100.0

SOURCE: The author tabulated the data from Ken Saito, *Research on a New Concern: RIKEN Industrial Group* (Japanese), Jichosha, 1987.

In the early days, RIKEN depended financially on the government subsidies despite the efforts to create revenue from R&D. Even in 1927, eleven years after its founding, the top revenue category was subsidies, which occupied more than a third of total revenue (Table 1). Only 2 percent of the revenue came from contract R&D, and the revenue from production work accounted for 31 percent. Production work meant crafting some apparatus for outside needs or pilot production of products developed by RIKEN. Interest and dividends (mostly from subsidiaries as in 1939?) occupied more than a fifth of the revenue. There was no patent royalty revenue yet in that year. It first appeared in the following year, 1928.

The revenue structure after successful commercialization of RIKEN inventions was quite different from that of the early days. In 1939, when the number of companies in the group was largest and the revenue of RIKEN was at a maximum, no subsidies were received. Nearly half of the revenue was from patent royalties from 46 companies; and the revenue from R&D was a significant 7.1 percent. The interests and dividends revenue and the revenue from stock operation were also large, accounting for 21.4 percent and 20 percent of the total revenue respectively. The royalty, the dividends, and the revenue from stock operation were related mostly to the group companies, because most (98.6 percent) of the revenue came from them.[3] In 1940, when the royalty revenue was the largest, the revenue from patent royalty from 54 companies occupied 60.4 percent of the total revenue. In other words, the majority of RIKEN's revenue was created from intellectual capital.

RIKEN was also entrepreneurial in spinning off companies and was successful in commercializing its products through these companies. The RIKEN Industrial

[3]See Saito (1987), p. 353.

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Group was fairly large and successful as a conglomerate, though its life was short. The Group consisted of 63 companies at maximum. It started in 1927 when the first company was established and practically ended in 1941 when major member companies were merged to cope with financial difficulties, due to the War.

The RIKEN Industrial Group excelled in managing the transfer of technology from RIKEN to the group companies. Research was carried out in RIKEN; engineering development was done in RIKEN or Physical and Chemical Industrial Corporation, a group company specialized in engineering development; and production was carried out in the other group companies.

The success of RIKEN and the RIKEN Industrial Group depended heavily on Director Ohkohchi.[4] He managed RIKEN as "a free paradise for researchers,"[5] albeit with rigorous evaluation. He created two new management philosophies—science capital industry and intellectual management—and two new production management methods—combinatory management and rural industrialization.[6]

In science capital industry the dynamic forces of R&D and innovation create new industries with new products and production methods, and scientific knowledge plays the role of capital in capitalism. Typical Japanese capitalists at that time entered the business world with capital and made licensing agreement with overseas companies and bought equipment from overseas at high prices, whereas RIKEN entered the business world with its intellectual capital and entrepreneurship.

With intellectual management, RIKEN claimed that it could provide intellectual assistance to the group companies from various perspectives since RIKEN performed integrated research of physics, chemistry, electrical engineering, and mechanical engineering. This would lower the prices of products and improve their qualities at the same time. It would also increase the wage of workers and enhance their welfare. For example, in a chemical plant chemical engineers invented new processes and played a major role in quality improvement, while mechanical engineers designed and built actual plants and improved equipment to raise productivity.

Combinatory management seeks to create synergy by linking factories in a geographical area. One factory could use byproducts such as waste heat from other factories in this setting. If an output of one factory is an input of another factory, these two factories could be connected directly by pipes to reduce transportation costs. The combination of inter-related industries could be easily thought of

[4]On one hand, the success of RIKEN and the RIKEN Industrial Group was largely thanks to the advanced technology of RIKEN. On the other hand, their success was due to the fact most of Japanese companies did not possess advanced in-house R&D capabilities and the fact that it was difficult to import technologically advanced products because of an unfavorable international political situation between World War I and World War II. See Kondo (2005) for the discussion of their success factors.

[5]See Miyata (1983).

[6]See Ohkohchi Commemorative Foundation (1954).

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because RIKEN performed a wide range of research and developed a wide rage of products and processes. This production management method was applied to the production of magnesium for airplane production. Combinatory management was invented to increase production efficiency of small-scale plants that could not enjoy the economy of scale to compete with imported products.

Rural industrialization seeks efficiency through division of labor in the machinery industry. This method made use of unskilled low-wage labor in rural areas by simplifying skills required for producing mechanical products through replacing versatile machines with specialized single-use machines. RIKEN could break down a complex machining process into simple processes and design and produce single-use machines. Rural industrialization realized low-cost production and rural industrialization.

RIKEN and its Industrial Group did not last long. They were dissolved by the occupying allied forces in 1948 after the end of the World War II. An independent administrative agency whose name is RIKEN still exists, but its industrial group does not.

RECENT UNIVERSITY-INDUSTRY PARTNERSHIPS IN JAPAN

Forms of University-Industry Partnership

As described above, there are three ways to utilize the science and technology capability of the university sector for industrial innovation: jointly creating knowledge between university researchers and industry researchers, transferring university knowledge to the industry, and starting up new companies based on university knowledge.[7] For each way there are some forms of university-industry partnership. For joint knowledge creation, a representative form is joint research. Contract research also has some aspects of joint knowledge creation since research themes are given from the industry at the beginning of research and some feedbacks are provided during the research. Academic donation could be a weak form of joint knowledge creation. University researchers and company researchers exchange information and opinions through donation. Recently, a new form of partnership has appeared: the comprehensive collaboration agreement. This agreement covers a wide range of collaboration such as information exchanges, personnel exchanges, joint research grant application, joint research, and joint human resource development. This agreement can be made between one university and one company, between one university and multiple companies, and between multiple universities and multiple companies.

For knowledge transfer through diffusion the options include journal papers and books, the Internet, and conference presentations. More targeted forms of knowledge transfer include consulting by professors and patent licensing.

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[7]This is based on Kondo (2004a).

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Students can be good media for knowledge transfer when graduated students find jobs in the industry, current students find internships, and when a company sends its employees to study at a university.

For knowledge-based startups, academic spin-offs are created. They commercialize university research results for industrial innovation. In some cases, university knowledge is transferred through technology licensing or via other forms. In other cases, university knowledge is transferred through the involvement of university researchers or students in the management of startups.

As for university-industry partnerships, facility and equipment usage is another form of partnership. If the facilities are extremely expensive, as in the case of cyclotrons, this partnership is important. For small-and-medium-size companies, university facilities and equipment can be useful.

Policies to Promote University-Industry Partnerships in Japan

Though Japanese universities, especially engineering schools, have a pragmatic tradition, university-industry partnerships were not encouraged and were not active in the late 1960s and 1970s due to the student political movement and campus disturbances. However, the environment changed in the 1980s, and the government formulated and implemented various policies to promote university-industry partnerships.

For joint knowledge creation, the government established a formal scheme of joint research in 1983. In addition, the government helped establish Collaborative Research Centers in national universities beginning in 1987 (Figure 5). In 1999, the government began providing research grants to encourage university-industry joint research.

For knowledge transfer, the government started providing financial assistance to Technology Licensing Organizations (TLOs) in 1998. As of September 2005, there were 41 approved TLOs eligible for public assistance. In addition, the government started the University Intellectual Property Right (IPR) Management Center Program in 2003 to assist 34 universities to establish IPR management capability on campus.

For knowledge-based startups, the government established Venturing Business Laboratories (VBLs) in national universities in 1995. There were 45 VBLs as of March 2004. The policy aims at fostering young entrepreneurial researchers through commercialization research. In April 2000, to encourage university spin-offs the government relaxed the regulation that prevented national university professors from serving as board members of private companies. Further, beginning in 2001 the government started helping to construct incubators on campus in national universities. There were 23 incubators as of March 2004.

Drastic change occurred in April 2004, when the government changed national universities into national university agencies. Each national university agency has an independent legal status and can make its own management deci-

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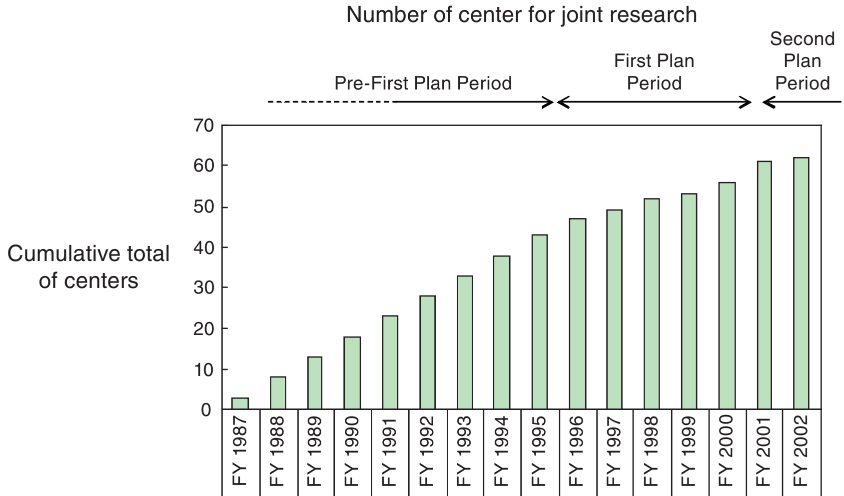

	FY 1987	FY 1988	FY 1989	FY 1990	FY 1991	FY 1992	FY 1993	FY 1994	FY 1995	FY 1996	FY 1997	FY 1998	FY 1999	FY 2000	FY 2001	FY 2002
Cumulative total of centers	3	8	13	18	23	28	33	38	43	47	49	52	53	56	61	62
(Number established annually)	3	5	5	5	5	5	5	5	5	4	2	3	1	3	5	1

FIGURE 5 Joint Research Centers at National University.
SOURCE: Ministry of Education, Culture, Sports, Science and Technology—Japan (MEXT), Web site.

sions and make contracts with other parties. Its employees are not civil servants anymore.

Performances of University-Industry Partnership

As a result of these policy efforts, the amount of collaborative research increased, especially since the mid-1990s.[8] In FY2003 more than 6,000 joint research projects were conducted between universities and industry according to NISTEP (2005) (Figure 6).[9] Recently, small-and-medium-size enterprises, especially new technology-based firms, have become active in university-industry joint research.[10] According to the studies conducted by Small and Medium Enterprise Agency, small-and-medium-size companies who had collaborated with

[8]See Wen and Kobayashi (2001) and Nakayama et al. (2005).

[9]Some argue that the informal university-industry collaboration, such as the form of academic donation from companies, became formalized as joint research and that the real university-industry collaboration did not increase. The fact is that the amount of academic donation also increased rapidly from 2000 according to NISTEP and MRI (2004).

[10]See Nakayama et al. (2005) and Motohashi (2005).

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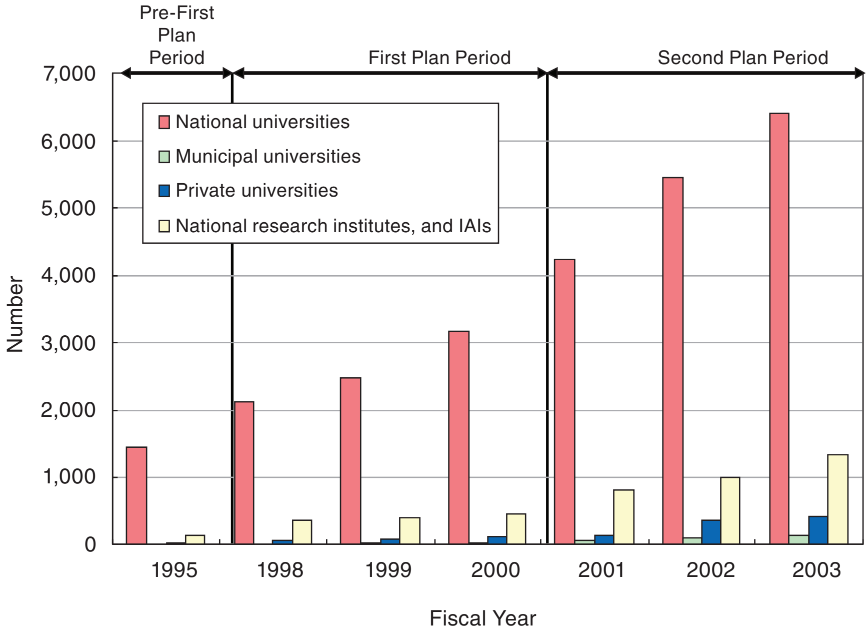

FIGURE 6 University-Industry Joint Research.
SOURCE: National Institute of Science and Technology Policy (NISTEP), *Study for Evaluating the Achievements of the S&T Basic Plans in Japan—Highlights,* (Japanese), NISTEP Report No. 83, 2005.

universities absorbed new knowledge and established new technologies[11] and those who collaborated with universities and public research institutes showed higher growth rates of profits.[12]

The increased collaboration between universities and industry appeared in paper co-authoring. More than half the research papers written by company researchers were coauthored with university researchers in Japan in 2001 according to NISTEP (2004) (Figure 7). This co-authorship ratio was comparable to the ratio in the United States.

A more detailed case analysis of Yokohama National University (YNU) revealed that deepening and diversification were observed at the same time according to Sakamoto and Kondo (2004). For deepening, they found that the number of joint research projects per company was increasing, that the number of joint research projects with large budgets was increasing, and that local university-

[11]See METI (2003).
[12]See METI (2005).

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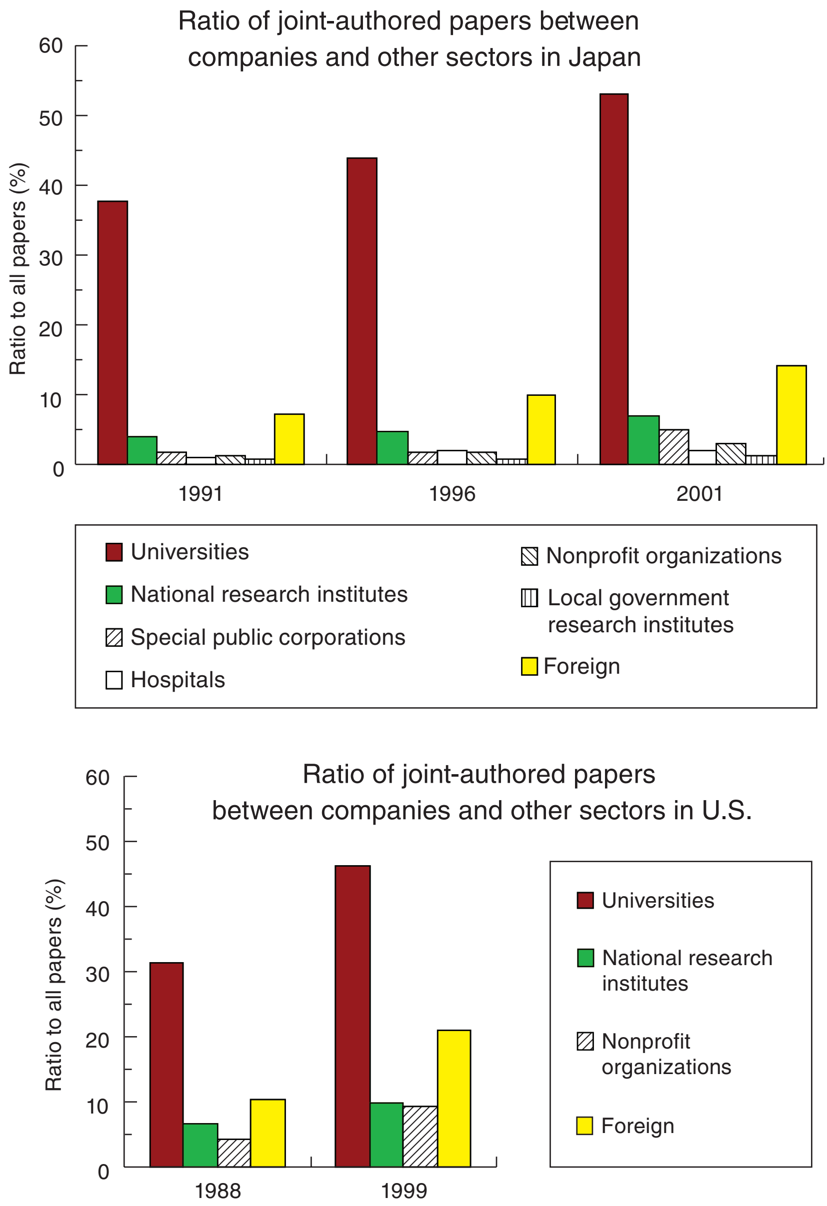

FIGURE 7 Coauthorship between Company Researchers and University Researchers.
SOURCE: National Institute of Science and Technology Policy (NISTEP), *Study for Evaluating the Achievements of the S&T Basic Plans in Japan—FY2003 Highlights,* (Japanese), NISTEP Report No. 74, 2004.

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industry joint research was increasing in terms of number and total budget. For diversification, they found that new types of companies, such as multinational companies and service industry companies, had started joint research with YNU recently, new faculty members were starting university-industry joint research, and the difference between the largest project budget and the smallest one was widening.

However, science linkage has been weak in Japan. The science linkage is measured as the number of research papers per registered patent using patents registered in the United States. The patents applied for by U.S. nationals had a strong science linkage compared to the patents applied for by Japanese nationals according to NISTEP (2004) (Figure 8).

In order to see the technology transfer, we examined the performance of the Japanese university sector from R&D investment to license income compared with the U.S. university sector. The R&D investment of the Japanese university sector was 3.3 trillion yen in 2002, whereas the U.S. university sector invested 5.4 trillion yen in 2002. The ration was 1:1.6 (Table 2). For patent applications, the ratio was 1:3.9, and for licensing contracts, the ratio was 7.0. However, when it comes to license income, the ratio was 1:264. This is partly due to the fact that the history of formal technology transfer from universities in the form of patent licensing in Japan is short.

Academic Spin-offs—From "Collaboration" to "Cross-over"

University-industry partnership has entered into a new stage in Japan, evolving from university-industry collaboration to "university-industry cross-over" (Figure 9).[13] In this university-industry cross-over, universities and some faculty members become entrepreneurial and engage in commercial activities. Traditionally, these activities took place only in the industry sector. Now, universities or university members conduct these activities by crossing over the traditional boundary between universities and industry.

The academic spin-off activities in Japan increased beginning in 2000, when the regulation on national university professors to serve as board members of private companies was relaxed (Figure 10). In recent years, more than 150 academic spin-offs were established per year. Many of them were in high-tech areas. A quarter of them belonged to information and communication technology (ICT) and a fifth belonged to the life sciences as of August 2003. A recent trend shows that the largest number of academic spin-offs was established in the life sciences.

The number of newspaper articles on university spin-offs also increased (Figure 11) beginning in 2001. In 2002, one saw an article on university spin-offs almost every day. In 2004, one saw nearly two articles on university spin-offs per day.

[13]See Kondo (2004b).

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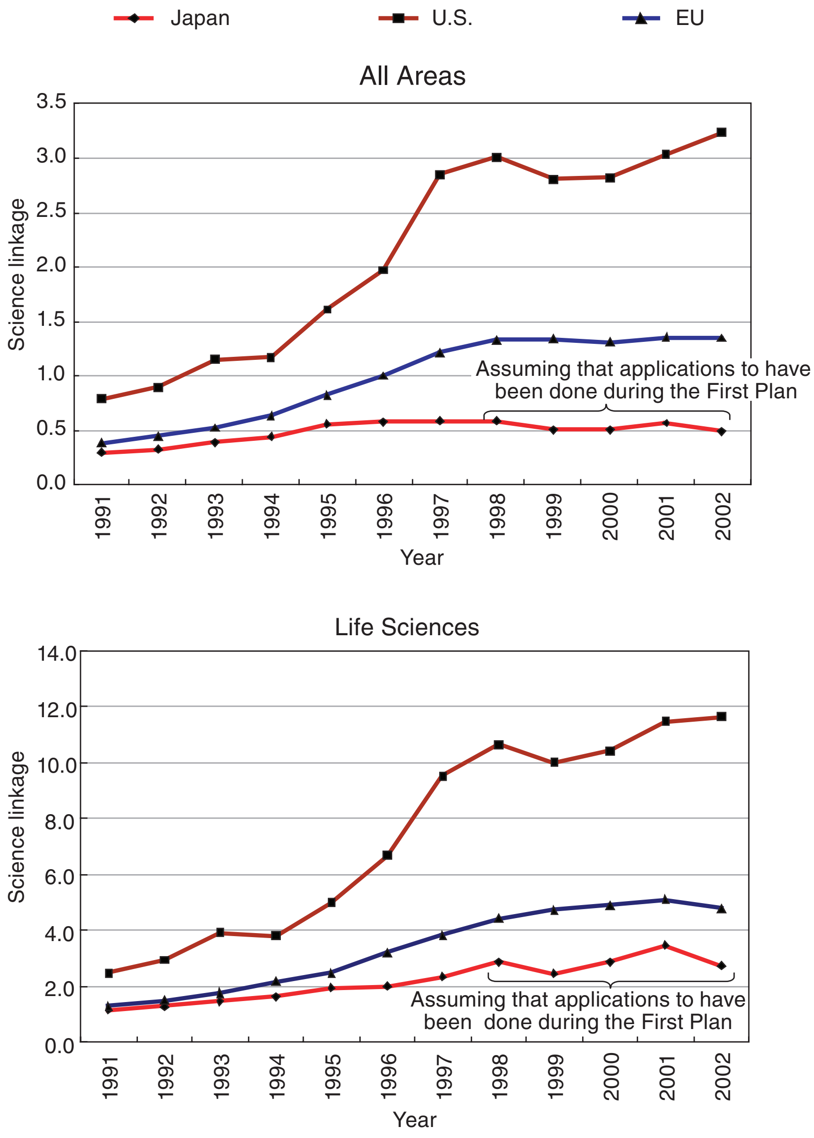

FIGURE 8 Science linkage in U.S. patents.

NOTE: "Science linkage" is the number of cited scientific papers in the U.S. patent examination reports per registered patent. It indicates a frequency of the use of scientific knowledge among patents.

SOURCE: National Institute of Science and Technology Policy (NISTEP), *Study for Evaluating the Achievements of the S&T Basic Plans in Japan—FY2003 Highlights,* (Japanese), NISTEP Report No. 74, 2004.

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TABLE 2 University Licensing (Japan-U.S. Comparison)

	Japan	United States	Ratio
R&D	3.3 trillion yen (in 2002)	5.4 trillion yen (in 2002)	1.6
Patent applications	1,680 (in 2003)	6,509 (in 2002)	3.9
Licensing contracts	531 (in 2003)	3,739 (in 2002)	7.0
License income	0.55 billion yen (in 2003)	145 billion yen (in 2002)	264
cf. Academic spin-offs	179 (in 2003)	364 (in 2002)	2.0

SOURCE: The author calculated and tabulated using the data of National Institute of Science and Technology Policy (NISTEP), *Study for Evaluating the Achievements of the S&T Basic Plans in Japan—Highlights,* (Japanese), NISTEP Report No. 83, 2005.

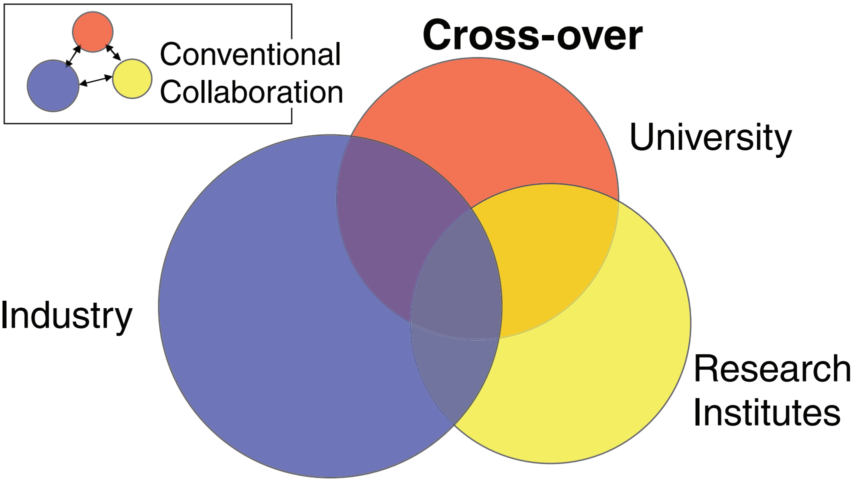

FIGURE 9 Cross-over among industry, universities, and public research institutes.
SOURCE: M. Kondo, "University Spin-offs in Japan," *Asia Pacific Tech Monitor*, March-April 2004, pp. 37-43, Asian and Pacific Centre for Transfer of Technology, ESCAP, UN.

Nearly 70 percent of founders of spin-off companies were faculty members (Table 3). Among student founders, about half were doctoral students. This indicates that many of academic spin-offs are based on solid technologies.

The spin-off companies seem to occupy a middle ground between universities and industry. Only 16.1 percent of spin-off companies intend to become manufacturer (Table 4). Others intend to conduct R&D, collaborate with universities, sell technologies in one form or another, or ask other companies to manufacture their products.

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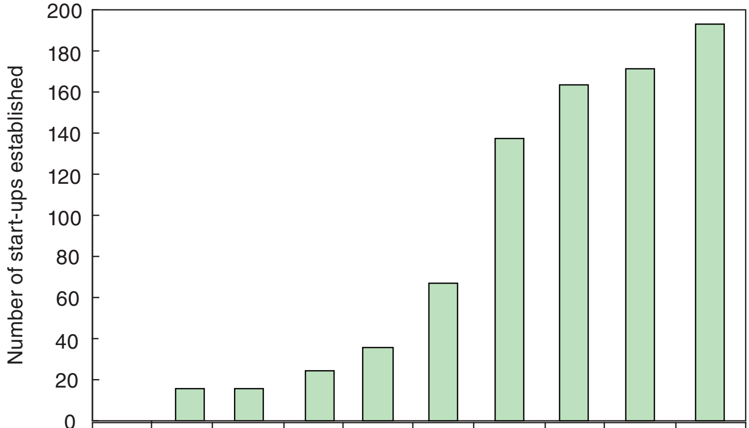
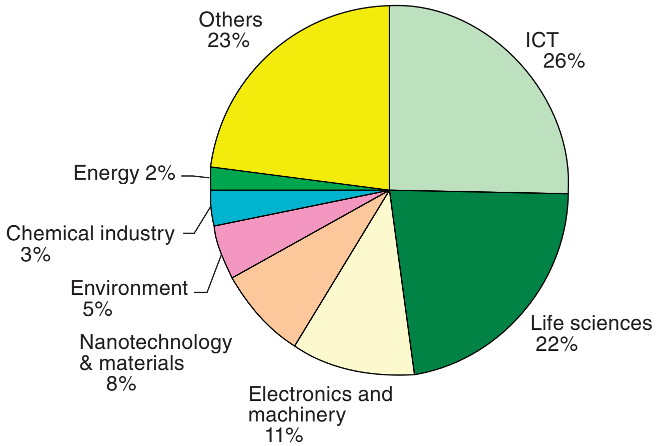
Academic Spin-Offs

*Accumulated total is 916 as of August of 2004.



	Up to 1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Number of start-ups annually established	38	14	15	22	33	62	127	152	159	179

Academic Spin-Offs by Areas



*Breakdown of 916 companies as of August 2004.

FIGURE 10 Academic spin-offs in Japan.
SOURCE: National Institute of Science and Technology Policy (NISTEP), *Study for Evaluating the Achievements of the S&T Basic Plans in Japan—Highlights,* (Japanese), NISTEP Report No. 83, 2005. Data calculated by NISTEP based on Tsukuba University and Yokohama National University, "University Spin-off Survey FY2004."

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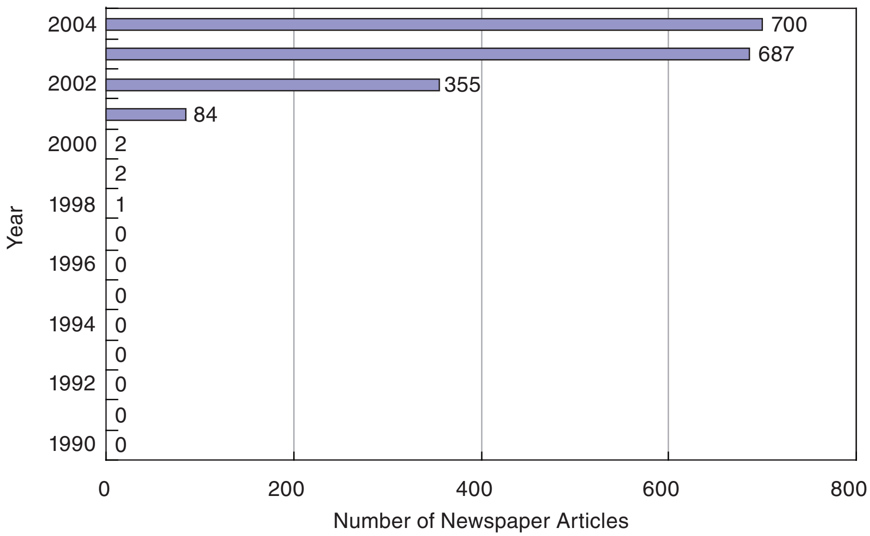

FIGURE 11 Newspaper articles on "university spin-offs" in Japan.
NOTE: The number of articles in four newspapers published by NIKKEI.
SOURCE: Author counted using NIKKEI TELECOM 21.

CONCLUSIONS

For healthy development of university-industry partnerships, some reservations need to be pointed out. First, a university needs to keep its identity. A university is responsible for higher education and for the advancement of human knowledge as well as for contribution to the society. This is a part of the reason why a university is largely financed by public funds and/or is favorably treated regarding taxation

Second, and more pragmatically, Japanese universities need to establish rules to avoid conflicts of interests at the working level.[14] Student education should not be jeopardized by university-industry partnerships, and academic freedom needs to be guaranteed. In addition, insider transactions of equity shares should be avoided since universities and faculty members can now become equity shareholders of academic spin-offs.

Third, practices to handle research-tool patents in academic research need to be established. On the one hand, once universities become entrepreneurial and engage in commercial activities such as licensing, they also need to respect patent

[14]A guideline on conflicts of interests was issued by the working group of the Council for Science and Technology and Academic Affairs in 2002.

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TABLE 3 Profiles of Academic Spin-off Founders

Founders	Percent
Faculty	69.7
of which professors	44.2
Students	22.9
of which doctor course students	11.2
of which master course students	7.5
of which undergraduate students	3.0
Researchers/Technicians	7.5
Total	100.0

SOURCE: Tsukuba University and Yokohama National University, "University Spin-off Survey FY2004."

TABLE 4 Future Business of Academic Spin-offs

Intended Future Business	Percent
Licensing out	25.7
Product sales using OEM	22.4
Product manufacturing and sales	16.1
Contract research and design	14.6
Sales of developed patents	11.5
Others	9.6

SOURCE: Tsukuba University and Yokohama National University, "University Spin-off Survey FY2004."

rights of others. On the other hand, the patent rights of research tools should not jeopardize academic research.

Nonetheless, university-industry partnerships are important for science-based innovation in Japan. At the national level, they narrow the gap between Japanese high science and technology potential and low industrial performance help strengthen innovation capability of Japanese industry.[15] Through university-industry partnerships, Japanese universities are expected to strengthen the technology transfer process and to be exposed to competition in the global collaborative or sponsored research market.

At the regional level, local university-industry partnerships are needed for speedy exchanges of sticky information. They play a key role in creating innova-

[15]For example, OECD (2001) shows that Japanese business R&D intensity became higher and that its multi-factor productivity (MFP) went down from the 1980s to 1990s. IMD competitiveness ranking these days also shows that Japanese competitiveness ranking is around the 25th while Japanese science ranking is 2nd and Japanese technology ranking is within top 10.

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tion networks and clusters. They are also important for fostering local human resources.

University-industry partnerships after all have crucial importance in creating knowledge and using knowledge in a national innovation system.

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The Connected Science Model for Innovation—The DARPA Role

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INTRODUCTION—FUNDAMENTALS OF DEFENSE TECHNOLOGY DEVELOPMENT[2]

The rise of the U.S. innovation system in the second half of the 20th century was profoundly tied to U.S. World War II and Cold War defense science and technology investment.[3] However, this late 20th century military technology evolution was only part of a much bigger picture of innovation transformation. Growth economist Carlotta Perez argues that an industrial and therefore societal transformation has occurred roughly every half century, starting with the begin-

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[2]Major portions of this paper appeared in William B. Bonvillian, "Power Play, The DARPA Model and U.S. Energy Policy," *The American Interest* II(2):39-48, 2006, and appear here by permission of that journal.

[3]Vernon W. Ruttan, *Is War Necessary for Economic Growth, Military Procurement and Technology Development*, New York: Oxford University Press, 2006. For a review of the growth of R&D in the United States in the period between the two twentieth century world wars, see A. J. Field, "The Most Technologically Progressive Decade of the Century," *American Economic Review* September 2003, p. 1406.

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ning of the industrial revolution in Britain in 1770.[4] These technology-based innovation cycles flow in long multi-decade waves. Arguably, not only do these waves transform economies and the way we organize societies around them, they transform military power as well; U.S. military leadership has paralleled its technological innovation leadership. Perez found that the U.S. led the last three innovation waves—the information technology revolution represents the latest. Will this leadership continue? At stake is not only economic leadership but U.S. military leadership.

In other words, for the U.S. there has been a deep interaction between war and technology—war has greatly influenced technology evolution, and the converse is also true. While this has been the case for centuries, this interaction has been accelerating. Defense technology cannot be discussed as though it is separate and apart from the technology that drives the expansion of the economy—they are both part of the same technology paradigms. Military historian John Chambers has argued that few of the critical weapons that transformed 20th century warfare came from a specific doctrinal need or request of the military;[5] Instead, the availability of technology advances has driven doctrine. If technology innovation is a driving force in both U.S. economic progress and military superiority, and these elements have interacted, we need to understand the causal factors behind this innovation.

One factor involves critical institutions, which represent the space where research and talent combine, where the meeting between science and technology is best organized. Arguably, there are critical science and technology institutions that can introduce not simply inventions and applications, but significant elements of entire innovations systems. We will focus on aspects of the U.S. innovation system supported by the defense sector—particularly the Defense Advanced Research Projects Agency (DARPA). An Eisenhower creation, DARPA was the primary inheritor of the WWII connected science model embodied in Los Alamos and MIT's Rad Lab. DARPA came to play a larger role than other U.S. R&D mission agencies in both the Cold War's defense technology and the private sector economy that interacted with it.[6] DARPA will be used as a tool to explore the deep interaction between U.S. military leadership and technology leadership. As we attempt to understand where DARPA came from, we will also ask where it goes next, particularly in IT, as a way of focusing on the continuing strength of the defense innovation system.

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[4]Carlota Perez, *Technological Revolutions and Financial Capital*, Edward Elgar, 2002. See also Robert D. Atkinson, *The Past and Future of America's Economy—Long Waves of Innovation That Power Cycles of Growth*, Cheltenham, UK: Edward Elgar, 2004.

[5]John Chambers, ed., *The Oxford Companion to American Military History,* Oxford, UK: Oxford University Press, 1999, p. 791.

[6]Richard Van Atta, et al., *DARPA Technological Accomplishments: An Historical Review of Selected DARPA Projects,* Alexandria, VA: Institute for Defense Analysis, 1991; James C. Goodwin, et al., *Technology Transition*, Arlington, VA: Defense Advanced Research Projects Agency, 1999, accessed at <*http://www.darpa.mil/body/pdf/transition.pdf*>.

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ROLE OF TECHNOLOGY INNOVATION AND TALENT IN GROWTH

Defense and civilian sector innovation in the U.S. are part of one economic system; that system includes not only sharing the same technology paradigms but sharing the societal wealth—economic growth—thrown off by that economic system, which funds both the military and the technology it increasingly depends on for leadership. Therefore, we need to understand the nature of innovation in economic transformation. Keeping in mind the argument that economic growth has dramatically affected military transformation, what are the causal factors in economic growth?

To briefly summarize three plus decades of work in growth economics, Professor of Economics Robert Solow of MIT won the Nobel Prize in 1987 because he was profoundly dissatisfied with the growth model of classical economics, where growth was understood in a static model of the interaction between capital supply and labor supply. Solow posited a dynamic model, arguing that while capital and labor supply remained significant, there was a much bigger factor. Studying five decades of U.S. economic growth he found that more than half of this growth flowed from technological and related innovation.[7] He argued that growth rates aren't in an equilibrium but can be altered through innovation advance, with societal well-being expanding correspondingly. The key factor behind his growth through innovation thesis, his work suggests, was the research and development system. However, because technology development is complex and not easy to measure, he treated it as "exogenous" to the economy. Professor of Economics Paul M. Romer of Stamford University articulated what I will call a second direct growth factor.[8] If the first is Solow's technological innovation founded on R&D, Romer argued that knowledge drives economic growth, and that it is an "endogenous" element in the economy. The key factor standing behind this knowledge is science and technological talent, the "human capital engaged in research." He suggested a prospector theory of innovation–the nation or region that fields the largest number of well-trained prospectors will find the most gold, i.e., the most innovative advances.[9]

These two direct factors, in shorthand, talent and R&D, don't stand in isolation from each other, they are interacting parts of an intricate ecosystem of innovation. There are many other factors that are important parts of this system, elements that are more indirect, implicit, and peripheral to innovation advance than the two direct factors essential to economic growth posited above, but these

[7]Robert M. Solow, *Growth Theory: An Exposition*, New York: Oxford University Press, 2nd edition 2000, pp. ix-xxvi (Nobel Prize Lecture, December 8, 1987), accessed at <*http://nobelprize.org/nobel_prizes/economics/laureates/1987/solow-lecture.html*>.

[8]Paul Romer, "Endogenous Technological Change," *Journal of Political Economy* 98:72-102, 1990.

[9]See discussion of Solow and Romer in David Warsh, *Knowledge and the Wealth of Nations*, New York: W.W. Norton, 2006.

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indirect factors are nonetheless ones that a society must also get right for innovation advance.

The list of indirect innovation factors is long and, because growth economics is relatively new to the economics scene, the metrics for understanding the interaction of these factors are largely unexplored. On the government side they include fiscal, tax, and monetary policy, trade policy, technology standards, technology transfer policies, government procurement, intellectual property protection, the legal and liability systems, regulatory controls, accounting standards, and export controls. On the private sector side, which in a capitalist enterprise must dominate innovation, they include investment capital, including angel, venture, IPO's, equity, and lending, markets, management principles and organization, talent compensation and reward and quality of plant and equipment. Keep in mind that that these direct and indirect innovation factors all interact and it is the interaction that is most important. Therefore, they represent a common system for both economic and defense sector advance.[10]

IS THERE A THIRD DIRECT INNOVATION FACTOR?

In addition to the two direct and the numerous indirect innovation factors suggested above, arguably there is a third direct factor: the way that R&D and talent, in particular, come together to form an innovation system. In other words, if R&D is factor A, and talent is factor B, they form an interacting combination, AB, which in itself is a third factor, the meeting space for science and technology and the talent behind it. It is not enough to have the ingredients of R&D and talent, they have to come together in an effective way for a highly productive innovation system. We'll call this third factor innovation organization. Linking two factors

[10]We have been discussing innovation in the context of economics, but growth economics, because it is founded on a dynamic model of innovation, has begun to break down the focus of economics, since the late 1940s (neoclassical economics) on the mathematical modeling suited to analysis of limited numbers of variables in a closed equilibrium. Instead, as growth economist Brian Arthur has argued, innovation can create increasing returns not just diminishing returns, leading to transformational phase shifts in an economy. Growth economics requires not only the neo-classical economics of physics-like fundamental principles subject to formulaic proof, but an economics of complexity, where a rich array of interacting elements must be accounted for in systems that are not static but evolve. For example, if innovation organization is a key factor in innovation and therefore economic growth, this element pushes economics towards its original roots in the social sciences and away from neo-classical economic modeling which cannot fully capture organizational elements. This concept puts an orange in what economics has viewed as a mix of apples. In other words, growth economics is gradually broadening economics' explanatory depth and toolset to reach and understand complex systems, and the third innovation factor discussed below, innovation organization, arguably pushes it further in that direction. *See, generally*, M. Mitchell Waldrop, *Complexity: the Emerging Science at the Edge of Order and Chaos*, New York: Simon & Schuster, 1992, pp. 144-148, 250-255, 284-313, 325-327. Since the author drafted this article and footnote in 2006, another book has been published discussing some of these points, Eric D. Beinhocker, *Origin of Wealth—Evolution, Complexity, and the Radical Remaking of Economics*, Cambridge, MA: Harvard Business School, 2007.

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together, AB, is shorthand in math for multiplying them; arguably, there is a multiplier factor here, too—the way R&D and talent join and are organized can be a multiplier for each. If innovation organization is a kind of multiplier for the two key direct innovation factors, then the way defense and civilian innovation systems organize R&D and talent, and the massive areas where the two systems overlap, will be profoundly determinative of innovation advance for the two systems, and therefore of economic and military leadership.

What does innovation organization look like? This factor must be seen and understood at least two levels, the institutional level and the personal, face-to-face level. We will explore these in succession.

U.S. INNOVATION ORGANIZATION AT THE INSTITUTIONAL LEVEL

Governmental science and technology organization in the U.S. largely dates from WWII and the immediate post-war. As suggested earlier, technology evolution in this country comes from a kind of "PushMi-Pullyu" relationship between civilian economic and defense sectors, and WWII was a transformative period where the pressure for military technology advance later led to a dramatic economy-wide advance.

Vannevar Bush led this charge,[11] acting as President Roosevelt's personal science executive during the war. He was allied to a remarkable group of fellow science organizers, including Alfred Loomis, an investment banker and scientist, physicist Ernest Lawrence of Berkley, and two university presidents, James Conant of Harvard and Arthur Compton of MIT. Successively, Bush created and took charge of the two leading organizing entities for U.S. science and technology, the National Defense Research Council (NDRC) and then the Office of Science Research and Development (OSRD). These became the coordinating entities for U.S. wartime R&D, creating crash research projects in critical areas, such as the Rad Lab at MIT and Los Alamos, and the and, in turn, insured interaction and coordination with a rich mix of research components. Influenced by the frustrations of his WWI military research experience where technology breakthrough could not transition past bureaucratic barriers into defense products, Bush kept civilian science control of critical elements of defense research, insisting that his science teams stay out of uniform and separate from military bureaucratic hierarchies which he found unsuited to the close-knit interaction needed for technology progress.

[11]G. Pascal Zachary, *Endless Frontier: Vannevar Bush, Engineer of the American Century*, Cambridge, MA: The MIT Press, 1999. See also Jennet Conant, *Tuxedo Park*, New York: Simon & Shuster, 2002 (biography of Alfred Loomis, founder of MIT's Rad Lab). For a discussion of U.S. pre-WWII science organization see David Hart, *Forged Consensus*, Princeton, NJ: Princeton University Press, 1998.

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To summarize, Bush brought all defense research efforts under one loose coordinating tent, NDRC then OSRD, and set up flat, non-bureaucratic, interdisciplinary project teams oriented to major technology challenges, like radar and atomic weapons, as implementing task forces. He created "connected" science, where technology breakthroughs at the fundamental science stage were closely connected to the follow-on applied stages of development, prototyping and production, operating under what we will call a technological "challenge" model. Because Bush (and his ally Loomis) could go directly to the top for backing from Roosevelt, through Secretary of War Henry Stimson and Presidential Aide Harry Hopkins, Bush made his organizational model stick during the war, despite relentless military pressure, from the Navy in particular, to capture it.

Then, immediately after the war, he systematically dismantled his remarkable connected science creation.

Envisioning a period of world peace, convinced that the wartime levels of government science investment would be slashed, and probably wary of a permanent alliance between the military and science, Bush decided to try and salvage some residual level of federal science investment. He wrote the most influential polemic in U.S. science history, "The Endless Frontier," for Roosevelt, arguing that the federal government should fund basic research, which would deliver ongoing progress in economic well-being, national security and health to the country.[12] In other words, he proposed ending his model of connected science, and dropping his challenge model, in favor of making the federal role one of funding one stage of technology advance, exploratory basic research. His approach would become known as the "pipeline" model for science investment. The federal government would dump basic science into one end of an innovation pipeline, and somehow early and late state technology development and prototyping would occur inside the pipeline, with new technology products emerging, genie-like, at the end. Because he assembled a connected science model during WWII, Bush no doubt realized the deep connection problems in inherent this pipeline model, but likely felt that salvaging federal basic research investment was the best he could achieve in a period of anticipated peace.

He did argue that this basic research approach should be organized and coordinated under "one tent" to direct all the nation's research portfolios, proposing what would become the National Science Foundation (NSF). Because he wanted this entity controlled by a scientific elite separated from the nation's political leadership, Bush got into a battle with Roosevelt's successor, Harry Truman. In his typical feisty, take-charge way, Truman insisted that the scientific buck would stop on his desk not on some Brahmin scientist's desk, and that NSF appointments would be controlled by the President. Bush disagreed.

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[12]Vannevar Bush, *Science: The Endless Frontier,* Washington, D.C.: U.S. Government Printing Office, 1945, p. 1-11) (FDR and Bush letters, Summary, Introduction). Available at <*http://www.nsf.gov/od/lpa/nsf50/vbush1945.htm*>.

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Truman therefore vetoed Bush's NSF legislation, stalling its creation for another five years.[13] Meanwhile, science did not stand still. New agencies proliferated, and the outbreak of the Korean War led to a renewal of defense science efforts. By the time NSF was established and funded, its potential coordinating role had been bypassed. It also became a much smaller agency than Bush anticipated, only one among many. Despite Bush's support for one tent where scientific disciplines and agencies could coordinate their work, as they did in WWII, the U.S. thus adopted a highly decentralized model for its science endeavor.[14]

Bush's concept of federal funding focused on basic science did prevail, however, with most of the new science agencies adopting this model for the federal science role. These twin developments left U.S. science fragmented at the institutional level in two ways: overall science organization would be fragmented among numerous science agencies, and federal investment would be focused on only on one stage of technological development, exploratory basic research.[15] Remarkably, Bush left a legacy of two conflicting models for scientific organizational advance: the connected, challenge model of his WWII institutions, which he dismantled after the war,[16] and the fundamental-science focused, disconnected, multi-headed model of post-war U.S. science institutional organization.

[13]William A. Blanpied, "Inventing U.S. Science Policy," *Physics Today* 51(2):34-40, 1998 (post-WWII evolution of U.S. science organization and NSF); George Mazuzan, *The National Science Foundation: A Brief History (1950-1985),* (NSF 88-16), Arlington, VA: The National Science Foundation, 1988. Available at <*http://www.nsf.gov/pubs/stis1994/nsf8816/nsf8816.txt*>, pp. 1-25 (history of NSF in the context of post-WWII science).

[14]It must be emphasized that there are major advantages to decentralized science. It creates a variety of pathways to science advance and a series of safety nets to ensure multiple routes can be explored. Since science success is largely unpredictable, the "science czar" approach risks major failures that a broad front of advance does not. Nonetheless, the U.S. largely lacks the ability to coordinate its science efforts across agencies particularly where advances that cut across disciplines require coordination and learning from networks.

[15]See discussion of these developments in, Donald E. Stokes, *Pasteur's Quadrant: Basic Science and Technological Innovation*, Washington, D.C.: Brookings Institution Press, 1997.

[16]The term "dismantled" is used to indicate that the structure for science management in WWII was ended, and many wartime science entities were shut down, including MIT's Rad Lab. Obviously, other existing science entities continued in operation, such as NACA, which Bush chaired before the war, and was an early example of a connected, challenge model approach. See Alex Roland, *Model Research: The National Advisory Committee for Aeronautics, 1915-1958,* pp. 225-258 (Ch. 10), Washington, D.C.: National Aeronautics and Space Administration, available at <*http://history.nasa.gov/SP-4103/*>. However, even within DoD, the Office of Naval Research was largely set up after the war around a fundamental science model. Harvey M. Sapolsky, *Science and the Navy—The History of the Office of Naval Research*, Princeton, NJ: Princeton University Press, 1990, pp. 9-81 (Ch. 2-4).

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SUMMARY OF THE INNOVATION ANALYTICAL FRAMEWORK

To summarize the discussion thus far, innovation is not only about R&D investment levels, it's about content and efficiency.[17] U.S. post-war policy institutionally severed R from D, which had been connected in the wartime model, and posited a pipeline theory of innovation where the federal government dumped research funding into one end of the pipeline, then mysterious things occurred within the innovation pipeline, then remarkable products emerged at the other end. Neoclassical economics, through the work of Robert Solow, came to realize the central role of innovation in economic growth but was unable to apply existing economic models to the mystery inside the pipeline, so treated innovation as "exogenous" to the economy. That response was ultimately unacceptable—it as though economics, after finally discovering the innovation monster in the economic growth room, then declined to look at it. So a group of growth economists, initially led by Paul Romer, gradually began to whittle away at the monster, treating it as "endogenous," slowly delineating its economic attributes. However, this delineation process still has barely begun.[18] Economic institutions still collect extensive data on the two factors classical economics tied to economic growth, capital supply and labor supply, and data on R&D investment totals; we have little data on the monster, the content and efficiency of the innovation system.[19] Few are searching for and analyzing the new factors and metrics for innovation evaluation. Interestingly, two decades after Solow won the Nobel Prize for identifying the innovation monster, the U.S. Department of Commerce has announced the need to begin an intensive data collection process around innovation, although this effort is not yet funded.[20] The National Science Foundation, which has long collected data on innovation investment levels and science education,[21] has begun an effort to look at data and analysis around innovation with a program entitled the Science of Science and Innovation Policy.

But what is the framework for the innovation metrics and analysis? Although we track R&D investment, what about the composition and efficiency factors? This paper attempts to identify some of the elements lurking inside the innovation

[17]Gregory Tassey, *The Innovation Imperative*, Cheltenham, UK: Edward Elgar, 2007, Ch. 3, 7, 8.

[18]For a critical view of the progress of endogenous growth theory in economics, see Robert Solow, "Toward a Macroeconomics of the Medium Run," *Journal of Economic Perspectives* Winter 2000.

[19]Despite the emergence over two decades ago of growth economics and its doctrine that growth is predominantly innovation based, the two U.S. political parties are still largely organized around the old factors posited by classical economics as responsible for growth, capital supply and labor supply.

[20]U.S. Department of Commerce, *Innovation Measurement: Tracking the State of Innovation in the American Economy*, Report to the Sec. (Jan. 2008), Washington, D.C.: U.S. Department of Commerce, available at <*http://www.innovationmetrics.gov/Innovation%20Measurement%2001-08.pdf*>; Michael Mandel, "A Better Way to Track the Economy: A Groundbreaking Commerce Dept. Report Could Lead to New Yardsticks for Measuring Growth," *Business Week* Jan. 28, 2008, p. 29.

[21]National Science Board, *Science and Engineering Indicators*, Arlington, VA: National Science Foundation, 2006, available at <*http://www.nsf.gov/statistics/seind06/toc.htm*>.

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pipeline. Following Solow and Romer, it argues, as noted, that R&D and talent (shorthand terms for their extended ideas) can be considered *two direct innovation factors*, indispensable to innovation, and are surrounded by an ecosystem of indirect factors, less critical but none the less significant.

This paper further posits that there is a *third direct innovation factor*, innovation organization, the space where the talent and R&D converge. An essential aspect of innovation organization requires evaluation at the institutional level. Summarized above is the brilliant success the U.S. experienced at the institutional level during WWII with a connected science model built around technological challenges, formed under one organizational tent. The U.S., following the war, shifted to a highly-decentralized model, scattering government-funded research among a series of mission agencies. It was predominantly a basic-science focused model, not connected science, and left what later became known as a "valley of death" between research and development stages, so the handoff from publicly-funded research and to private sector development lacked institutional bridging mechanisms. As we will see, the major exception to that U.S. institutional rule was DARPA.[22]

We turn now from a review of innovation at the institutional level to a second analytical perspective on innovation organization, innovation at the personal, face-to-face level. Following this review, we will examine how these twin perspectives on innovation organization have operated within an arguably critical U.S. innovation organization, DARPA, evaluating how it has worked at both levels, institutional and personal.

INNOVATION SYSTEMS AT THE PERSONAL LEVEL— GREAT GROUPS

Innovation organization should be analyzed it the institutional level, as discussed above, but also requires understanding at the ground level, from the personal, face-to-face point of view. Innovation is different than scientific discovery or invention, which can involve solo operators. Instead, innovation requires taking both scientific discovery and invention and piling applications on a breakthrough

[22]This is not to assert that the fundamental science mission agencies dating from the 1940s have remained frozen in time. While the basic science mission remains paramount at agencies such as NSF, NIH and the DoE Office of Science, at the National Science Foundation, for example, there is funding not only for small individual investigator basic research but larger areas of interdisciplinary advance, such as nanotechnology, which can incorporate grand challenges. For example, NSF's issue workshops and similar organizing mechanisms bring in ideas for coordinated science-engineering advance for initial buy-in and research program design by fundamental and applied communities. As another example, NSF's engineering directorate supports engineering centers tying science advance to fundamental engineering advance. Somewhat similar efforts around interdisciplinary centers have evolved at NIH and DoE. The point remains that these functions supplement established fundamental science efforts.

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invention or group of inventions to create disruptive productivity gains that transform significant segments of an economy and/or defense system. So innovation is a third phase built on phases of discovery and invention. Innovation requires not only a process of creating connected science at the *institutional level*, it also must operate at the *personal level*. People are innovators, not simply the overall institutions where talent and R&D come together. Warren Bennis and Patricia Beiderman have argued that innovation, because it is much more complex than the earlier stages of discovery and invention, requires "great groups" not simply individuals.[23] Rycroft and Kash make a similar argument but use a different term: Innovation requires collaborative networks[24] which can be less face-to-face and more virtual. As we look at innovation organization at the personal level, we will explore the rule sets for three sample "great groups" of innovators.

1. Edison's "Invention Factory" at Menlo Park, New Jersey

Thomas Edison formed the prototype for innovator great groups.[25] Edison placed his famous Menlo Park lab in a simple 100-foot long wooden frame building, a lab, on his New Jersey farm. In it, he placed a team of a dozen or so artisans, mixing a wide range of skills with a few trained scientists. They worked intensely, sometimes 24/7, and took midnight breaks together, eating pies, reciting poems and singing songs. They mixed a range of disciplines and organize their intense effort around the challenge of electric light. They were a great group, highly collaborative. Great groups also require collaboration leaders and Edison was a remarkable team leader. They worked on the idea of filling the gap between electric poles with a filament placed in a vacuum tube. But that was only the breakthrough invention, not the innovation. To make their light usable, Edison and his team then must invent much of the infrastructure for electricity—from generators to wiring to fire safety to the structure of a supporting electric utility industry. Edison and his team become inventors and innovators, visionaries and (as initiators of a network of companies with Wall Street backing) vision enablers.

Interestingly, as part of this process, Edison had to derive elements of electron theory to explain his results—his "Edison Effect" helped lead to atomic physics advances. There is a major lesson in this: Science is not simply a linear pipeline going from basic to applied, it goes both ways: basic to applied and applied to basic. Menlo Park teaches us parts of the rule set for great groups. *It is organized around a challenge model, with the group trying to solve a specific challenge or goal; it applies an interdisciplinary mix of both practical and basic science to get*

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[23]Warren Bennis and Patricia Ward Biederman, *Organizing Genius*, New York: Basic Books, 1997.

[24]Robert W. Rycroft and Don E. Kash, "Innovation Policy for Complex Technologies," *Issues in Science and Technology,* Fall 1999.

[25]See discussion in Sir Harold Evans, *They Made America*, Sloan Foundation Project, New York: Little, Brown and Company, 2005, pp. 152-171.

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there, and it uses a connected science model, tying invention to innovation and incorporating all stages of innovation advance. The group was under Edison's clear leadership, and that leadership factor was vital, but it was a non-hierarchical, relatively flat, two-level, highly collaborative effort. The team mixed experimentalists and theorists, artisans and trained scientists and engineers, for a blend of experimental and theoretical capability and disciplines.

2. Alfred Loomis and the Rad Lab at MIT, 1940-1945

Alfred Loomis loved science but family needs compelled him to become lawyer; he combined his science and legal skills to become a leading Wall Street financier for the emerging electric utility industry in the 1920s.[26] Anticipating the market crash, he sold out in 1928 with his great fortune intact. He used it to pursue science, setting up his own private lab at his Tuxedo Park, New York estate in the 1930s and assembling there a who's who of pre-war physics. Loomis' own field of study there was microwave physics. As WWII loomed, Vannevar Bush, respecting Loomis' industrial organizing skills, asked him to join Roosevelt's NRDC to mobilize science for the war.

Because the American military was initially uninterested, the British handed over to Loomis a suitcase with their secrets to microwave radar in his penthouse in the Shoreham Hotel in Washington in 1940. As the Battle of Britain raged, Loomis' microwave expertise enabled him to grasp immediately that this was a war winning technology for air warfare. He promptly persuaded his cousin and mentor, Secretary of War Henry Stimson, that this technology must be developed and exploited without delay. With Bush's and Roosevelt's immediate approval, Loomis within two weeks set up the Radiation Laboratory (Rad Lab) at MIT. Because he knew them from his Tuxedo Park lab, Loomis and his ally and friend Ernest Lawrence of Berkeley called in the whole talent base of U.S. physics to join the Rad Lab, and nearly all came. Because the government was not used to establishing major labs literally overnight, Loomis personally funded the startup while government approvals and procurement caught up.

The Rad Lab was non-hierarchical and flat, with only two levels, project managers and project teams, each devoted to a particular technology path. It was characterized by intense work, often around the clock, and by high spirits and morale. Loomis and Bush purposely kept it out of the military. The Rad Lab used a talent base with a mix of science disciplines and technology skills, it was highly collaborative, it was organized around the challenge model, and it used connected science, moving from fundamental breakthrough to development, prototyping and initial production. Interestingly, the Rad Lab organizational model was systematically adopted at Los Alamos, and ten leading Rad Lab scientists shifted to Los

[26] Details from Loomis' biography, Jennet Conant, *Tuxedo Park*, op. cit.

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Alamos to implement it.[27] The Rad lab developed great advances in microwave radar and the proximity fuse, technologies vital to success of the allies. Eight Nobel prizewinners came out of the Rad Lab and it ended up laying the foundations for important parts of modern electronics. It also embodied another feature key to successful great groups—through Loomis and Bush, the Rad Lab had direct access to the top decision makers able to mandate the execution and adaptation of its findings, Stimson and Roosevelt.

3. The Transistor Team at Bell Labs (1947)

Bell Labs' Murray Hill facility was consciously set in the New Jersey countryside after Edison's Menlo Park model and also drew from the great military labs of WWII, the Rad Lab and Los Alamos. AT&T's R&D Vice President, Mervin Kelly and his lead researcher, William Shockley, wanted a solid state physics team of fifty scientists and technicians from various fields with capability for fundamental research leading to practical applications. Their task was to develop a solid state physics-based replacement for vacuum tubes so that AT&T's switching capability could continue to advance telephone speed and capacity. John Bardeen and Walter Brattain, two of the leading solid state physics researchers who joined this team, developed a profoundly close collaboration, where the scientific and personal skills of one matched the other's—one a theorist, the other an experimentalist, one outgoing, the other reflective. They were social friends and held a strong mutual respect. Backed-up by Bell Labs' deep industrial technical support system, with the latest equipment and very strong technical staff, the two entered into a "magic month" from mid-November to December 16, 1947, and developed the first transistor.

As Bardeen's biographers put it, "The solid-state group divided up the tasks: Brattain studied surface properties such as contact potential; Pearson looked at bulk properties such as the mobility of holes and electrons; and Gibney contributed his knowledge of the physical chemistry of surfaces. Bardeen and Shockley followed the work of all members, offering suggestions and conceptualizing the work."[28] Brattain later commented, "It was probably one of the greatest research teams ever pulled together on a problem. . . . I cannot overemphasize the rapport of this group. We would meet together to discuss important steps almost on the spur of the moment of an afternoon. We would discuss things freely. I think many of us had ideas in these discussion groups, one person's remarks suggesting an idea to another. We went to the heart of many things during the existence of this

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[27]See discussion of Los Alamos in Martin Sherwin and Kai Bird, *American Prometheus*: *The Triumph and Tragedy of J. Robert Openheimer*, New York: Alfred A. Knopf, 2005, and Jennet Conant, *109 East Palace,* New York: Simon & Shuster, 2005.

[28]Lillian Huddleson and Vicki Daitch, *True Genius–The Life and Science of John Bardeen*, Washington, D.C.: Joseph Henry Press, 2002, pp. 127-128.

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group, and always when we got to the place where something needed to be done, experimental or theoretical, there was never any question as to who was the appropriate man in the group to do it."[29]

Unfortunately, Shockley's reaction wrecked further working collaboration in the group. He attempted to garner credit for Bardeen's and Brattain's work, then worked secretly at his home designing a further breakthrough improvement, where a semiconductor "sandwich" replaced the transistor's electrical contact point, without telling the rest of the group. Before distrust descended, however, the group followed many of the rules of the other groups cited above—it was highly talented, relatively non-hierarchical, organizationally flat with essentially two levels, highly collaborative, and brought to bear a range of expertise and disciplines, including theorists and experimentalists, with each participant working in his strongest skill area. It was organized on a challenge model and the connection to AT&T's VP Mervin Kelly assured a tie to a decision maker who could enable development of breakthroughs. The group traded ideas on a continuous basis, meeting frequently with each providing thoughts to assist the others' progress, and Bardeen and Shockley played a leadership role by continually moving conceptual ideas among the group.

Many of the organizational features of these three "great groups" are common to others, including the development of atomic weapons at Los Alamos, the integrated circuit and microchip at Fairchild Semiconductor and Intel, the aeronautics and stealth advances at Lockheed's Skunk Works, the personal computer at Xerox Parc and Apple, biotech at Genentech and Craig Venter's genomics projects.[30] These projects are not unique. A venture capitalist has commented that he looks for these same kinds of characteristics every time he funds a startup. To summarize, a common rule set seems to characterize successful innovation at the personal and face-to-face level; the rules include ensuring: a highly-collaborative team or group of great talent; a non-hierarchical, flat and democratic structure where all can contribute; a cross-disciplinary talent mix, including experimental and theoretical skills sets networked to the best thinking in relevant areas; organization around a challenge model; using a connected science model able to move breakthroughs across fundamental, applied,

[29]Ibid.

[30]Kai Bird and Martin Sherwin, *American Prometheus: The Triumph and Tragedy of J. Robert Openheimer*, op. cit., pp. 205-228, 255-259, 268-285, 293-297; Jennet Conant, *109 East Palace*, op cit, pp. 106, 108, 110, 255; Leslie Berlin, *The Man Behind the Microchip: Robert Noyce and the Invention of Silicon Valley,* New York, NY: Oxford University Press, 2005, Ch. 3-8; Ben Rich, *Skunkworks*, Back Bay Books, 1996; Sir Harold Evans, *They Made America*, op. cit., pp. 420-431 (Boyer and Swanson found Genetech and start biotech); Warren Bennis and Patricia Ward Biederman, *Organizing Genius*, op. cit., pp. 63-86 (Xerox PARC and Apple); Daniel S. Morrow, *Dr. J. Craig Venter—Oral History*, Computer World Honors Program, April 21, 2003, available at <*http://cwheroes.org/archives/histories/venter*>, pp. 3-53, 56-58; J. Craig Venter, *A Life Decoded*, New York: Viking Press, 2007, Ch. 12.

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development and prototype stages; cooperative, collaborative leaders able to promote intense, high morale; and direct access to top decision makers able to implement the group's findings.[31]

DARPA AS A UNIQUE MODEL—COMBINING INSTITUTIONAL CONNECTEDNESS AND GREAT GROUPS

We have discussed the concept of innovation organization as a third direct innovation factor, and noted that it operates in macro and micro ways, at both the institutional level and the personal level. Our focus now shifts to the Defense Department's Defense Advanced Research Projects Agency. Created in 1958 by Eisenhower as a unifying force for defense R&D in light of the stove-piped military services' space programs that had helped lead to America's Sputnik failure, DARPA became a unique entity. In many ways, DARPA directly inherited the connected science, challenge and great group organization models of the Rad Lab and Los Alamos set up by Bush, Loomis and Oppenheimer. However, unlike the personal-level models discussed above, DARPA has operated at *both* the institutional and personal levels. DARPA became a bridge organization connecting these two institutional and personal organizational elements, unlike any other R&D entity set up in government.

J.C.R. LICKLIDER AND THE BEGINNINGS OF THE DARPA MODEL

The DARPA model is perhaps best illustrated by one of its most successful practitioners, J.C.R. Licklider, who, as an office director at DARPA working with and founding a series of great technology teams, laid the foundations for two of the 20th century's technology revolutions, personal computing and the internet.[32] In 1960, Licklider, trained in psychology with a background in physics and mathematics, wrote about what he called the "Man-Machine Interface" and "Human-Computer Symbiosis": "The hope was that in not too many years, human brains and computing machines will be coupled together very tightly, and that the resulting partnership will think as no human brain has ever thought."[33] By

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[31]For discussion of additional great groups and variations in this suggested rule set, see Warren Bennis and Patricia Ward Biederman, *Organizing Genius,* op. cit.

[32]Discussion in this section drawn from Licklider's biography by M. Mitchell Waldrop, *The Dream Machine*, Viking, 2001. For discussions of DARPA's and DoD's central role in fostering the many phases of the IT revolution, see Vernon W. Ruttan, *Is War Necessary for Economic Growth, Military Procurement and Technology Development*, op cit, pp. 91-129; Glenn R. Fong, "ARPA Does Windows: The Defense Underpinning of the PC Revolution," *Business and Politics* 3(3), 2001; National Research Council, *Funding a Revolution: Government Support for Computing Research*, Washington, D.C.: National Academy Press, 1999, pp. 85-187.

[33]J. C. R. Licklider, "Man-Computer Symbiosis," *IRE Transactions on Human Factors in Electronics* March 1960.

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1960, Licklider envisioned timesharing as a path to real time personal computing (as opposed to the then-dominant main-frame computing), digital libraries, the internet (the "Intergalatic Computer Network"), what we now call the World Wide Web, and most of the features, like computer graphing, simulations and modeling, that we are still evolving to implement those revolutions. Licklider was hired by DARPA[34] to work on what was being called the "command and control" problem, and then that problem took off in importance. Because Kennedy and MacNamara became deeply frustrated with a profound command and control problem—their inability to obtain and analyze real time data and interact with on-scene military commanders during the Cuban Missile Crisis—DARPA gave Licklider major resources to tackle it. It was the rare case of the visionary being placed in the position of vision-enabler. Strongly backed by noted early DARPA Directors Jack Ruina and Charles Herzfeld, Licklider found, selected, funded, organized and set up a remarkable support network of early information technology researchers at universities and firms that over time built personal computing and the internet. He served at two different periods in DARPA.

At the institutional organization level, DARPA and Licklider became a collaborative force among the Defense Department's research agencies controlled by the services, using DARPA IT investments to leverage participation by the agencies to solve common problems under connected science and challenge models. DARPA and Licklider also kept their own research bureaucracy to a bare bones minimum, using the service R&D agencies to carry out project management and administrative tasks, so that DARPA's efforts created co-ownership with the service R&D stovepipes. Institutionally, although it certainly did not always succeed, DARPA attempted to become a research supporter and collaborator, not a rival competitor to the DoD service research establishment.[35]

At the personal level of innovation organization, Licklider created a remarkable base of information technology talent both within DAPRA and in a collaborative network of great research groups around the country. This team of apostles, including Doug Engelbart, Ivan Sutherland, Robert Taylor, Larry Roberts, Vint Cerf, Robert Kahn, and their many comrades, are a who's who of personal computing and internet history. Because of ongoing progress, DARPA was willing to be patient and able to look at the long term in these IT talent and R&D invest-

[34]DARPA Director Jack Ruina later concluded that hiring Licklider was his most significant act at DARPA. In seeking an office director, Ruina realized he had found a visionary. M. Mitchell Waldrop, *The Dream Machine*, op. cit.

[35]The military service R&D organizations initially saw DARPA as a usurper and competitor for scarce research funds. DARPA's efforts over the decades to link with the service R&D organizations and become their collaborator and banker for advanced projects they might not otherwise obtain approval for has helped defuse service hostility, and frequently the collaboration has been highly mutual and beneficial. But resentment remains of DARPA as a favored child, even after a half century. Licklider's efforts mark an early success at cross-stovepipe collaboration, although such success is not uniform.

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ments in a way that corporations and venture capital firms are not structured to undertake.[36] Licklider's DARPA model was also not a flash in the pan—internally it was able to institutionalize innovation so that successive generations of talent sustained and kept renewing the technology revolution over the long term. At the personal level of innovation, the great groups Licklider started, in turn, shared key features of the Menlo Park, Rad Lab and other groups previously discussed. Licklider's Information Processing Techniques group was the first and greatest success of the DARPA model, but this success was not unique; DARPA was able to achieve similar accomplishments in a series of other technology areas.[37]

One more key point: DARPA has been willing to spawn technology advances not only in the defense sector but in the non-defense economy, recognizing that an economy-wide scale as opposed to a defense sector-only scale may be needed to speed the advance. DARPA has made specific choices to encourage and support technology advances with non-defense organizations, both academic and commercial, rather than defense-only organizations, as its best means of gestating new concepts into implementation.[38] This enables the Department of Defense (DoD) at a later stage to take advantage of this technology evolution speed up, with corresponding shared and therefore reduced development and acquisition costs. This was exactly the case with the IT revolution that Licklider and DARPA made crucial contributions to. Although IT has been in a thirty year development process which is still ongoing, DARPA's support for and reliance on a primarily civilian sector development process enabled DoD to obtain much more quickly and cheaply the tools it needed to solve its initial command and control problem.

Actually, it got far more. When Andy Marshall, DoD's legendary in-house

[36]Licklider, as DARPA's IPTO head, received strong backing from DARPA Directors Jack Ruina and Charles Herzfeld, who bet on his vision, which enabled Licklider to build a cadre of successors—Ivan Sutherland, Bob Taylor and Larry Roberts—who shared and enhanced his vision for a coherent program with ongoing technical process steps that led to the Internet and personal computing and a network of related advances. There was no special management doctrine at DARPA that enabled this successive effort but it was allowed by DARPA leaders to proceed full throttle for a decade, until scrutinized somewhat by DARPA Director George Heilmeier. Fluent with practical electronics, he imbedded the "Heilmeier Catechism" which insisted on more application relevance, to Licklider's frustration during his second DARPA tour. M. Mitchell Waldrop, *The Dream Machine*, op. cit.

[37]Richard H. Van Atta, et al., *DARPA Technical Accomplishments,* Volumes I-V, Alexandria, VA: Institute for Defense Analysis, 1991. See also Richard Van Atta, "Fifty Years of Innovation and Discovery," in *DARPA: 50 Years of Bridging the Gap*, Defense Advanced Research Projects Agency, April 2008, pp. 20-29. Dr. Van Atta has been generous to the author with his insights on DARPA which are reflected at a number of points in this paper.

[38]J. C. R. Licklider and his colleagues largely relied on universities for idea-creation and the subsequent spin-out of these ideas into new commercial firms (such as Digital or Sun) for their application. While existing smaller commercial firms, such as BB&N, which set up the internet for DARPA, also played a role, the larger commercial firms, defense contractors and defense R&D organizations were usually not the source of new concepts or their implementation. DARPA thus played an vital role in creating the highly productive pathway in the U.S. late 20th century IT economy of academic-startup-venture funding-commercialization, and the institutions that grew up to line this pathway.

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defense theorist and head of its Office of Net Assessment, argued in the late 1980s that that U.S. forces were creating a "Revolution in Military Affairs,"[39] this defense transformation was built around many of the IT breakthroughs DARPA initially sponsored.[40] Admirals Bill Owens and Art Cebrowski, and others, in turn, translated this IT revolution into a working concept of "network centric warfare"[41] which further enabled the U.S. in the past decade to achieve unparalleled dominance in conventional warfare. And the foundation of this IT revolution, that enabled this defense transformation, was a great innovation wave that swept into the U.S. economy in the 1990s, creating strong productivity gains and new business models that led to new societal wealth creation[42] which, in turn, provided the funding base for the defense transformation. To summarize, the DARPA model can support traditional technology development within the defense sector where that technology is primarily or overwhelmingly defense-relevant (like stealth). Alternatively it can support joint defense-civilian sector technology development where the technology is relevant to both. This enables DoD potentially to take major advantage of academia's openness to new ideas, the willingness of entrepreneurs to commercialize these innovations, and the corresponding scale of an economy-wide advance.

[39]Andrew Marshall, "Some Thoughts on Military Revolutions–Second Version," Memorandum for the Record, August 23, 1993; Nicholas Lehman, "Dreaming About War," *The New Yorker* July 16, 2001. Available at <*http://www.comw.org/qdr/0107lemann.html*>.

[40]William Perry and Harold Brown, Defense Department leaders during the Carter Administration, for example, developed what Perry later called an "offsets" theory of defense technology. During the Cold War, the Soviet Union held a roughly three to one advantage in numbers of troops, tanks, and aircraft. Perry has argued that the U.S. at first accepted that disparity because it held an advantage in nuclear weapons. When the Soviets achieved rough parity in nuclear weapons and the missiles to deliver them, U.S. deterrence theory was at risk, so Brown and Perry decided to achieve parity in conventional battle through systematic technological advance. They began a process of translating advances in computing, information technology, and sensors, which had been initiated and long-supported by defense research investments, including DARPA's in particular, into precision weapons at the service level. First exhibited in the Gulf War, these became a massive "force multiplier" for U.S. conventional forces. See, generally, Richard H. Van Atta and Michael Lippitz, *Transformation and Transition: DARPA's Role in Fostering an Emerging Revolution in Military Affairs*, Vol. 1, Overall Assessment, Alexandria, VA: Institute for Defense Analysis, April 2003(15 years of DARPA research in areas such as Stealth and precisions strike enabled the implementation in the 1990s of the offsets theory of Brown and Perry).

[41]William Owens with Edward Offley, *Lifting the Fog of War*, Baltimore, MD: Johns Hopkins University Press, 2001, Ch. 3; David Alberts, John Garska and Frederick Stein, *Network Centric Warfare*, Department of Defense Command and Control Research Program, 1999, available at <*http://www.dodccrp.org/files/Alberts_NCW.pdf*>; Arthur Cebrowski and John Garska, "Network Centric Warfare: Its Origin and Future," *U.S. Naval Institute Proceedings,* January 1998. See, generally, Richard O. Hundley, *Past Revolutions, Future Transformations: What Can the History of Revolutions in Military Affairs Tell Us About Transforming the U.S. Military*, RAND Corporation, National Research Institute, 1999.

[42]*See, for example*, Dale Jorgenson, "U.S. Economic Growth in the Information Age," *Issues in Science and Technology* Fall 2001 (role of IT drivers in 1990s growth).

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ELEMENTS IN THE DARPA MODEL

At the Institutional level, DARPA undertakes connected science not simply fundamental research. Its model focuses on revolutionary technology development, not simply incremental advance,[43] moving a technology from fundamental science connected through the development up to prototyping stages, then encouraging and promoting its concepts with partners who move it into service procurement and/or the civilian sector for initial production, enabling full innovation not simply invention.

There are other ways DARPA assures connectedness, as suggested above. DARPA developed ability to make technology development connections across the DoD R&D stovepipes by using its funding to leverage contributions from other DoD military service technology development organizations, which in turn promotes service adaptation and procurement of its prototypes. DARPA also uses the other DoD R&D agencies as its administrative agents which, on those days when these stars get al.igned, likewise promotes cross-institution collaboration and follow-on procurement.

Other DARPA characteristics enhance its ability to operate at both the Institutional and personal innovation organization levels. The following list, which we will call the twelve commandments, is largely drawn from DARPA's own descriptions of its organizing elements:[44]

- *Small and flexible*: DARPA consists of only 100-150 professionals; some have referred to DARPA as "100 geniuses connected by a travel agent."
- *Flat organization*: DARPA avoids military hierarchy, essentially operating at only two levels to ensure participation.
- *Autonomy and freedom from bureaucratic impediments*: DARPA operates outside the civil-service hiring process and standard government contracting rules, which gives it unusual access to talent, plus speed and flexibility in organizing R&D efforts. Stated technically, DARPA has "IPA" hiring authoring authority, which gives it the ability to take personnel employed by industry or universities, and it invented "other transactions authority" in contracting which gives it great

[43]Looked at in another way, DARPA historically has had two significant roles, breakthrough military applications and systems, such as stealth or precision strike, and broad generic emerging technologies, such as information processing, microsystems or advanced materials. Both roles interrelate and both have transformational effects. See Richard Van Atta, Institute for Defense Analysis, "Energy and Climate Change Research and the DARPA Model," Presentation to the Washington Roundtable on Science and Public Policy, November 3, 2004, p. 7. DARPA has also developed concept prototypes and demonstrations to meet established military needs which have not yet been defined as military requirements, aside from its breakthrough technology role. Richard Van Atta, "Fifty Years of Innovation and Discovery," op cit, p. 25-27.

[44]Defense Advanced Research Projects Agency, *DARPA—Bridging the Gap, Powered by Ideas*, February 2005; Defense Advanced Research Projects Agency, *DARPA Over The Years,* Arlington, VA: Defense Advanced Research Projects Agency, October 27, 2003.

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flexibility and speed in contracting outside the normally lengthy federal procurement process.

- *Eclectic, world-class technical staff* : DARPA seeks great talent, drawn from industry, universities, and government laboratories and R&D centers, mixing disciplines and theoretical and experimental strengths. This talent has been hybridized through joint corporate-academic collaborations.
- *Teams and networks*: At its very best, DARPA creates and sustains great teams of researchers that are networked to collaborate and share in the team's advances, so that DARPA operates at the personal, face-to-face level of innovation. It isn't simply about funding research; its program managers are dynamic playwrights and directors.
- *Hiring continuity and change*: DARPA's technical staff are hired or assigned for 3-5 years. Like any strong organization, DARPA mixes experience and change. It retains a base of experienced experts that know their way around DoD, but rotates most of its staff from the outside to ensure fresh thinking and perspectives.
- *Project-based assignments, organized around a challenge model*: DARPA organizes a significant part of its portfolio around specific technology challenges. It works "right-to-left" in the R&D pipeline, foreseeing new innovation-based capabilities and then working back to the fundamental breakthroughs that take them there. DARPA doesn't build aircraft carriers; its projects typically are designed to develop technologies over three to five years. However, major technological challenges in related fields may be addressed over much longer time periods, ensuring patient long-term investment on a series of focused steps and keeping research teams together for ongoing collaboration.
- *Outsourced support personnel*: DARPA uses technical, contracting and administrative services from other agencies on a temporary basis. This provides DARPA the flexibility to get into and out of a technology field area without the burden of sustaining staff, while building cooperative alliances with the line agencies it works with.
- *Outstanding program managers*: In DARPA's words, "The best DARPA Program Managers have always been freewheeling zealots in pursuit of their goals." The DARPA director's most important job historically has been to recruit highly talented program managers and then empower their creativity to put together great teams around great advances. In particularly fruitful areas, DARPA has created a succession of project leaders that share and build a common vision for progress over time, as in the case of Licklider and his successors.
- *Acceptance of failure*: At its best, DARPA pursues a high-risk model for breakthrough opportunities and is very tolerant of failure if the payoff from potential success is great enough.
- *Orientation to revolutionary breakthroughs in a connected approach*: DARPA historically has focused not on incremental but radical innovation. It emphasizes high-risk investment, moves from fundamental technological

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advances to development, and then encourages the prototyping and production stages in the armed services or the commercial sector. From an institutional innovation perspective, DARPA is a connected model, crossing the barriers between innovation stages.

- *Mix of connected collaborators*: DARPA typically builds strong teams and networks of collaborators, bringing in a range of technical expertise and applicable disciplines and involving university researchers and technology firms that are often new and small and not significant defense contractors (which generally do not focus on radical innovation).[45] The aim of DARPA's "hybrid" approach, unique among American R&D agencies, is to ensure strong collaborative "mindshare" on the challenge and the capability to connect fundamentals with applications.

These DARPA "twelve commandments" provide important R&D organizing lessons for any innovation entity, whether in the private or public sectors.

DARPA TODAY—THE FUTURE OF THE MODEL

Economic innovation sectors are best described as ecosystems. Marco Iansati and Roy Levien have argued that within these systems frequently are keystone firms that, like critical species, take on the task of sustaining the whole ecosystem by connecting participants and promoting the progress of the whole system.[46] Iansati and Levien have also argued that these innovation systems start to decline or shift elsewhere when the keystone firms cease being thought leaders and instead shift to what they call "landlord" status. In this state, the "landlord" firm shifts to simply extracting value from the existing system rather than continuously attempting to renew and build the system. There have been concerns voiced in recent years and considered below, that DARPA could be moving away from its keystone role, particularly in IT.

QUESTIONS ABOUT THE DARPA ROLE

DARPA since September 2001 has been increasingly focused on wars in Iraq and Afghanistan, asymmetric conflicts against terrorism requiring different approaches from the symmetric nation state conflict technologies it evolved in the past. While DARPA had been concerned with asymmetric conflicts at least since the demise of the Soviet Union, many noted that the two wars created a significant shift in emphasis at DARPA toward shorter-term military issues and

[45]There are, of course, exceptions to this, particularly in projects involving systems engineering. Stealth, stand-off precision weapons, and night vision were projects contracted to major defense contractors. Lockheed's Skunk Works has long worked with DARPA as well as the Air Force, and represents a radical innovation model operated within a more standard defense firm.

[46]Marco Iansati and Roy Levien, *The Keystone Advantage*, Cambridge, MA: Harvard Business School Press, 2005.

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away from some longer-term technology support areas. Concerns about a change in DARPA's role in IT areas, where it has played a keystone role, came up in a series of forums: in a 2005 House Science Committee hearing reviewing DARPA's continuing role in its computer science mission, in a discussion in a Defense Science Board report over its shifting role in microprocessors, in concerns over DARPA's role from PITAC (the President's Information Technology Advisory Council, which was subsequently disbanded by the White House) in IT and cybersecurity, and in papers from a number of IT sector R&D leaders.[47] DARPA has long been famed as the most successful U.S. R&D agency, so these concerns appear worth weighing.

Let's review some of the questions raised about DARPA's future role. Most involve arguments that DARPA has been shifting out of the IT field it played an historic role in creating, even though this technology revolution is still in its youth—after all, we are still not even close to artificial intelligence. DoD's Defense Science Board (DSB) of leading defense technologists issued a report that recognized the critical gains DoD achieved from DARPA's historic role supporting university and industry-led R&D in microprocessor advances. But it concluded that DoD and DARPA were "no longer seriously involved in . . . research to enable the embedded processing proficiency on which its strategic advantage depends."[48] Since DoD's strategic superiority in symmetric and potentially asymmetric warfare has become in significant part its network centric capability, and secure semiconductor microprocessors are the base technology for this capability, DSB found that DoD faces a serious strategic problem as the newest generation of semiconductor production facilities is increasingly shifting to China and other Asian nations. In fact, the U.S. share of the world's leading-edge semiconductor manufacturing capacity dropped from 36 percent to 11 percent in the past 7 years.[49] This problem may be compounded if semiconductor design and research, which historically have had to be co-located with production facilities, shift abroad as well. DARPA's departure from its systematic support of U.S. technology leadership in this field appears to present a serious defense issue if other parts of the Department do not absorb some of this function. DARPA's view in recent years

[47] House Science Committee Hearing on the Future of Computer Science Research in the U.S., May 12, 2005, (Testimony by Wm. A. Wulf, Pres., National Academy of Engineering, Prof. Thomas F. Leighton, Chief Scientist Akamai Tech. Inc., Joint Statement of the Computing Research Community, and Letters in Response to Committee Questions from W. Wulf and T. Leighton, (July 2005)); Edward D. Lazowska and David Paterson, "An Endless Frontier Postponed," *Science*, 308(5723):757, May 6, 2005; John Markoff, "Clouds Over 'Blue Sky' Research Agency," *New York Times,* May 4, 2005, p. 12; President's Information Technology Advisory Committee, Report to the President, "Cybersecurity: A Crisis of Prioritization," February 2005; Defense Science Board, *High Performance Microchip Supply*, February 2005, pp. 87-88. Compare DARPA's responses, House Science Committee Hearing, May 12, 2005, DARPA Testimony with Appendices A-D.

[48] Defense Science Board, *High Performance Microchip Supply*, op. cit.

[49] Norman Augustine, *Is America Falling Off the Flat Earth?* Washington, D.C.: The National Academies Press, 2007, p. 17.

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has been that semiconductor advance should be led by industry, increasingly dominated in the U.S. by mature, large-scale firms that DARPA's leaders feel should manage their own problems. But if industry increasingly is being forced to shift abroad because of cost pressure from massive industrial subsidies available there,[50] DoD has a long term problem with what still appears to be a foundation technology. It is serious enough that a 2005 Defense authorization bill directed DoD to implement DSB's proposals to try to control the problem and retain U.S. technology leadership in this area.[51] A DARPA chip strategy, some would argue, should be to try to secure leadership in a post-silicon, post-Moore's Law world in bio-nano-quantum-molecular computing; DARPA would respond that it is working in a number of those fields. Others would dispute whether it is doing enough to nurture leadership in these emerging areas.

STATUS OF THE HYBRID MODEL

More broadly, DSB notes that one of DARPA's critical roles was to fund through its applied research portfolio (known in DoD as "6.2") "hybridized" university and industry efforts through a process that envisioned revolutionary new capabilities, identified barriers to their realization, focused the best minds in the field on new approaches to overcome those barriers and fostered rapid commercialization and DoD adoption." The hybrid approach bridged the gaps between academic research and industry development, keeping each side knowledgeable about DoD's needs, with each acting a practical prod to spur on the other. DSB expressed concern that this fundamental DARPA approach was breaking down as it cut back its 6.2 university computer science investments, and shifted more of its portfolio to classified "black" research, under pressure from the ongoing war, which cannot include most universities and non-defense tech firms, and, so DSB suggested, reduces DARPA's intellectual mindshare on critical technology issues.[52]

[50]Thomas Howell, "Competing Programs: Government Support for Microelectronics," in National Research Council, *Securing the Future: Regional and National Programs to Support the Semiconductor Industry,* Charles W. Wessner, ed., Washington, D.C.: The National Academies Press, 2003; Thomas Howell, et al., *China's Emerging Semiconductor Industry*, San Jose, CA: Semiconductor Industry Association, October 2003.

[51]Defense Auth. Act for 2005, H.R. 1815 (Sen. Amend. 1361). DoD has established a "trusted foundry" program, initiated in cooperation with IBM, to try to protect its own access to a stable supply of secure semiconductor chips, a particular concern of intelligence agencies, but this does not assure it long term access to technology leadership in what many continue to argue remains a critical technology.

[52]Total DARPA university funding as a percentage of DARPA science and technology funding fell from 23.7 percent in FY2000 to 14.6 percent in FY2004 according to 2005 DARPA data, supplied with hearing testimony, op. cit. A series of major university computer science research department underwent DARPA funding cutbacks of 50 percent and more in the past six years; some observers have argued that new generations of graduate students are no longer trained in DARPA-hard problems and tied to the agency, so that DARPA has reduced connections to its future talent base.

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GRID SECURITY

PITAC's report[53] on cybersecurity noted DARPA plans to terminate funding for its High Confidence Software and Systems development area, aiming to curtail cybersecurity funding except for classified work. Historically, one of Eisenhower's key aims in establishing DARPA was to make sure the U.S. was never again subject to a major technology surprise like Sputnik, and it is widely acknowledged that defense and critical private sector IT systems remain vulnerable to cybersecurity attack. Defense theorists, noting the major economic consequences of the 9/11 attack on financial markets and the insurance sector have argued that asymmetric cyber attacks on fundamental financial infrastructure by largely unidentifiable state or non-state actors could be devastating to the developed world, potentially striking a powerful blow to the world economy. PITAC has noted that because IT is dominated by the private sector, and even DoD's proposed secure high speed Global Information Grid must interact with the internet, shared solutions between defense and private sectors must be developed, so classified research in many cases cannot be effectively implemented. PITAC identified ten defense-critical IT research areas, from authentication technologies to holistic security systems, it believes require future DARPA investment.

ALTERING THE ECOSYSTEM

Dr. Thomas Leighton, Chief Scientist of Akamai Corp., in response to questions from the House Science Committee, argued that DARPA's most important contribution to IT has been, "its unique approach (and commitment) to developing communities of researchers in both industry and academia" focused on "'pushing the envelop' of computer science."[54] Although DARPA continues to look at some IT problems, "its growing failure to support the university elements of that community is altering the innovation ecosystem" that it created "in an increasing negative way, with no other agency ready or able to pick up that role." Some university computer science departments and labs report that although the DARPA cutbacks in funding have been at least partially made up by industry support, this is often short term and not breakthrough-oriented, and often is from Asian firms that control the IP for technology developed and for obvious competitive reasons preclude it going into U.S. spin-offs. It should be noted that an increase in NSF computer science funding has offset some of the effects of the decline in DARPA university funding. DARPA's leadership has argued, as justification for the cutback, that it was not seeing enough new ideas from this sector.

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[53]President's Information Technology Advisory Committee, Report to the President, "Cybersecurity: A Crisis of Prioritization," op. cit.

[54]Response of Dr. Tom Leighton to Questions from the House Science Committee, July 7, 2005, op. cit.

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Dr. William Wulf, a computer scientist and until recently President of the National Academy of Engineering, told the House Science Committee that, "There is now no DoD organization like the 'old DARPA' . . . that fills the role of discovery of breakthrough technologies."[55] Although he acknowledged that DARPA was looking at cognitive computing, he argued that there were problems in the subjects DARPA was selecting for IT research because it was not confronting key security areas. For example, "our basic model of computer security (perimeter security) is fatally flawed" and will not be solved by the "short term, risk-adverse approach being currently taken by DARPA." He argued that our "ability to produce reliable, effective software" is tottering on "the brink of disaster" but DARPA has not focused on solutions, and also is not reviewing the fact that our basic model for computing is not yet close to human brain capability, and requires a new model "of parallel computing" with "architectures and algorithms of immense power." He also argued that the "use of computers in education has progressed little from the 'automated drill' model of the Plato system of the 1960s" although "we know much more about how people learn physiologically and psychologically" including how "emotion interacts with learning" which we could put to good use in quickly training troops in urban combat and counter-insurgency, and DARPA should also be more involved in this area. DARPA spokesmen have noted in response to these arguments that DARPA has funded, as has the Army, soldier training simulation systems at USC's center for this work, and that it was the primary initial funder of grid computing. Perhaps one part of the answer is that DARPA may lack a Licklider with the vision to see and evolve a new IT territory. Critics respond that that because of a top-down management style in recent years at DARPA, office directors and program managers lack the authority to initiate in this way.

It is generally understood that DARPA has had to be increasingly focused on solving a problem it ran into at the end of the Cold War with its resulting cuts in defense procurement starting in 1986: the breakdown of technology transition from DARPA into services. DARPA even during the Cold War had a transition problem with the services as it focused on disruptive, change-state, radical innovation. It solved some of these problems in the past by transitioning technology, such as IT, into the civilian economy, In other areas, it had to rely on the clout of the Secretary of Defense and, when available, a strong Director of Defense Research &Engineering (DDR&E). DARPA typically did not enjoy a consensus with the military unless it was hammered out by the Office of the Secretary of Defense and the service secretaries. Nonetheless, following the Cold War, technology transition declined. Unsuccessful in building a new consensus with the military services for transferring the results of revolutionary technology investment into service procurement, DARPA technology strategy has been moving from its his-

[55]Dr. William A. Wulf, Response to Questions from the House Science Committee, July 2005, op. cit.

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tory of radical innovation to more incremental innovation, shifting a larger part of its investment into later stage development efforts that the services are more ready to invest in. Defense budget analysts report that shorter term incremental work, space launch, and satellite "repair" are requiring growing parts of the DARPA budget. A new DARPA review process, mandated by improving transition to the services, of frequent "up or out" decisions with limited development time is placing more of its R&D on a shorter-term course. Congress may be playing a role in this, as well, focusing more on DARPA's record rather than it's overall impact. The current emphasis on a pre-agreed transition plan may further limit disruptive work. Some believe that resulting more frequent policy reversals and turns may limit DARPA's ability to mount enough creative, longer-term investment programs so important to past development. Although the heart of DARPA's creativity in the past was in highly talented and empowered project managers, some believe that the role of project managers has been significantly limited by this short term review approach. Although DARPA has always been able to pick among the brightest technologists in the nation, its larger focus on classified programs[56] may limit its access to some of the university researchers it has relied on in the past, creating difficulty over time in attracting talent.

DARPA in the past has operated in both the civilian and defense economies, understanding they are the same economy. As noted, it has built "great groups" and spun off civilian-relevant technology, such as in computing, to the civilian sector where it evolved further, enabling DoD to buy it back at radically lower costs and to take advantage of civilian development advances. Alternatively, it has spun off to the defense sector defense-only technologies like stealth and unmanned aerial vehicles (UAV's). DARPA's need to focus on the current asymmetric conflict and corresponding classified work, as well as shorter term technology transition, may make it less able to spin off technology to the civilian economy, despite DoD's growing capital plant cost crisis and its need to take better advantage of advances in that sector.[57] Given DARPA's historic role in successfully straddling both sectors, DARPA's needs to protect its ability to play in both worlds.

Much of the above debate is driven by IT sector concerns. But there is a larger debate emerging over DARPA's role in IT. Because DARPA, starting with Licklider, played a profound role at the center of most aspects of the IT revolution, there is a question whether its current focus on shorter-term and classified

[56]DARPA has always had, of course, a large classified program base separate from its academic research. The assertion here is that the balance has changed with more of a tilt toward classified work.

[57]Research investment also affects defense capability. With defense R&D, nations generally "get what they pay for," with weapon system capability and quality directly corresponding to intensity of research investment. Andrew Middleton and Steven Bowns, with Keith Hartley and James Reid, *The Effect of Defense R&D on Military Equipment Quality, Defense and Peace Economics* 17(2):117-139, April 2006.

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programs due to the war inevitably will signal a broader retreat from this sector[58] and does the state of the sector justify such a retreat?[59]

The first question that must be asked is where are we in the IT revolution? In the past, innovation waves fully matured in 40 or 50 years and society moved on to the next innovation stage. Accordingly, some argue that the IT revolution is maturing and that we need to move on to the next big things.[60] Where do we measure the IT wave from? If we measure it from the first post-World War II mainframe, ENIAC, the half century mark for the revolution ran out in 1995. 1995, however, was the period when we were bringing on personal computing and internet access at levels that reached a major portion of our society. If we measure the IT innovation wave from around 1995, when real time and networked computing took off with the public, then we are still a decade into an IT revolution wave. Perhaps DARPA should be moving on to another innovation wave?

On the other hand, the IT revolution may be different from steam engines or electricity. The four- or five-decade model for past innovation waves may not be fully relevant to the IT revolution. When we work with the information domain, we have to keep in mind that we are working with a fundamental force that Norbert Weiner suggested in 1948 was a coequal to mass and energy.[61] We have already been through a succession of unfolding and sometimes parallel IT waves, from business (and military) computational capability, to data retrieval, processing and display, to advanced digital communications, to data mining and using mass data as a predictive tool, and we are beginning to make progress on symbolic manipulation and computer theorem proving and are thinking about quantum computing. The grail quest of computing is true artificial intelligence. This is not a technology pursuit similar to past efforts because it is ultimately a quest to take on a godlike power.[62] We have a long, long way to go in achieving this stage. Progress on the Turing Test—can a computer's thinking be mistaken for a human's—has been limited.[63] Although computers now play chess at the highest level and drive SUVs through DARPA's desert and urban obstacle courses, computing isn't even close yet to the intuitive powers of the human brain. Although an artificial intelligence quest may ultimately be futile or only partially achievable, even if we have to

[58]Vernon Ruttan has raised the concern that with the post-Cold War decline in defense innovation, the U.S. innovation system may not now be strong enough to launch new breakthrough technologies in either the public or the private sector. Vernon W. Ruttan, "Will Government Programs Spur the Next Breakthrough?" *Issues in Science and Technology* Winter 2006.

[59]House Science Committee Committee Hearing on the Future of Computer Science Research in the U.S. (Testimony of William Wulf and Thomas Leighton) and letters from same in response to Committee questions, op. cit.

[60]Robert Atkinson, "Is the Next Economy Taking Shape?" *Issues in Science and Technology* Winter 2006, p. 62.

[61]Norbert Wiener, *Cybernetics or Control and Communication in the Animal and the Machine*, Cambridge, MA: The MIT Press, 1948.

[62]Ann Foerst, *God in the Machine*, New York: Penguin Books, 2005.

[63]Mark Halpern, "The Trouble with the Turing Test," *The New Atlantis* 11(Winter 2006):42-63.

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settle for Licklider's "Man-Machine Symbiosis" we have a long way to go before this more limited vision is close to being played out. In other words, there may be decades of radical, breakthrough innovation to go in IT, not simply incremental advances. If this is right then DARPA, given its historic breakthrough technology mission and responsibility to avoid Sputnik-like technology surprises, continues to have a future in IT.

Even setting aside the ultimate artificial intelligence challenge, Victor Zue has argued that the next generation of computing challenges are more profound than ever.[64] While yesterday's problem was computation of static functions in a static environment within well-understood specification, today, adaptive systems are needed that operate in environments that are dynamic and uncertain. While computation was the main past goal, communication, sensing and control are also now critical. While computing used to focus on the single operating agent, it must now focus on multiple agents that may be cooperative, neutral or adversarial. While batch processing of text and homogeneous data used to be the task, stream processing of massive heterogeneous data now is. While stand-alone applications once prevailed, deep interaction with humans is now key. While there was a binary notion of correctness in computing, now there is a trade-off between multiple criteria. In today's computing world these opportunities arise in a far more complex environment of cheap communication, ubiquitous communication, overwhelming data, and limited human resources. Major IT tasks for the military become, for example, much deeper human computer interface, social and cultural modeling; far more robust and secure computation; smart, self-directed autonomous surveillance; and robots ready for human interaction.

DARPA strongly maintains it is funding IT, even though an increasing amount of its work must be classified. It is also funding what it believes is a critical breakthrough area in computing, cognitive computing, and supports bio computing and robotics. The ongoing wars in Iraq and Afghanistan appropriately force DARPA toward shorter term solutions for the military; it went through a similar evolution during the Vietnam War. DARPA has had, as noted, a profound problem with technology transition with the military services and to solve it, must focus on better meeting service needs. Still, the question must be asked whether there is a danger that DARPA may be over time retreating into Iansati's and Levien's "landlordism"—not continuously renewing but living off incremental improvements on past advances. For example, it is felt by some observers that DARPA should evaluate its tactical technology vision as that program threatens to become increasingly smaller-scale, less coherent and non-tactical. DARPA should also evaluate the emerging new dimensions of whether it has a coherent IT vision for approaching some of the challenges Zue and others suggest. Given DARPA's unique historical role in U.S. technology advance,[65] this is a significant

[64]Victor Zue, "Introduction to CSAIL," MIT, April 15, 2008, pp. 6, 14.
[65]Richard H. Van Atta, et al., *DARPA Technical Accomplishments,* Volumes I-V, op. cit.

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issue. Because even great technology advances take a decade or two to produce, the pipeline of advance is hard to see, but problems we may have now in filling that pipeline will have a profound effect on our future a decade or more out.

DARPA is not the only aspect of DoD technology leadership facing difficulties. DoD depends on a strong fundamental physical science research to support its breakthrough potential, but these programs and funding levels are in decline.[66] Boomer generation scientists have been the mainstay of DoD science talent in its labs and research centers, but are now retiring in droves, and are not being adequately replaced. DoD faces a very serious science talent supply problem and needs hiring and retention flexibility beyond civil service limits, but a rigid position in the past by DoD personnel staff that there must be only one personnel system for all at DoD has thwarted Congressional reform efforts to create more flexibility for scientists. The pressure of the tempo of ongoing military operations is, in turn, putting pressure on funding for science in the military services. The pattern of technology leadership in DoD may not be as strong as in the past. DDR&E leaders of the caliber of John Foster, Malcolm Currie and William Perry have been infrequent, and the overall depth of technical competence in the Office of the Secretary of Defense to backup DARPA and push for technology implementation has declined. Overall, the picture for DoD science is not getting prettier, and this is against a backdrop of serious problems in U.S. physical science in general, as explored in recent major reports by the National Academies.[67]

Yet our security challenges are growing. The emergence of the terrorist model, of non-state actors relatively immune to state-to-state pressure, represents a profound asymmetric challenge to a Western military model that has been world-dominant since the 15th century. In parallel is the emergence of other peer competitors, working on both symmetric and asymmetric approaches, pursuing a technology innovation model for economic development which, as discussed, has significant military implications. This raises a fundamental concern: Can U.S. technological superiority be the continuing basis of U.S. security in an increasingly globalized technological and economic world? Since U.S. economic and military success, as argued at the outset, has relied on profound integration between defense and civilian elements of its innovation system for technological superiority both military and economic, consequences on one side of this equation, such as long term DARPA capability, have major effects on the other side.

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[66]James A. Lewis, *Waiting for Sputnik*, Washington, D.C.: Center for Strategic and International Studies, March 1, 2006. See also John Young, Director of Defense Research and Engineering, Info Memo for Secretary of Defense Robert M. Gates, DoD Science and Technology Program, August 24, 2007 (need and corresponding proposal for increased DoD S&T funding, listing potential high pay-off research areas).

[67]National Academy of Sciences/National Academy of Engineering/Institute of Medicine, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future,* Washington, D.C.: The National Academies Press, 2007; Norman Augustine, *Is America Falling Off the Flat Earth?* op. cit.

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SUMMARY

Arguably innovation organization—the way in which the direct innovation factors of R&D and talent come together, how R&D and talent are joined in an innovation system—is a third direct innovation factor. DARPA emerged as a unique model—operating at both the institutional and personal level of science organization. Building on the Rad Lab example, it built a deeply collaborative, flat, close-knit, talented, participatory, flexible system, oriented to breakthrough radical innovation. It has used a challenge model for R&D, moving from fundamental, back and forth with applied, creating connected science linking research, development, and prototyping, with access to initial production. In other words, it followed an innovation path not simply a discovery or invention path.

Like all human institutions, these organizational models are transitory. The DARPA model has been one of the longest lasting, unique in the federal government, and seemed to be the most capable of ongoing renewal.

But that DARPA model now may be shifting under pressure of ongoing operations, particularly regarding DARPA's role in the IT sector, with potential long term effects on U.S. defense as well as civilian sector technology superiority. This shift occurs against a backdrop of overall problems in U.S. physical science strength. DARPA has long served a keystone function in the U.S. innovation system and it is in the nation's national security and economic interest that it continue to avoid "landlord" status.

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Public-Private Linkage in Biomedical Research in Japan: Lessons of the 1990s[1]

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1. INTRODUCTION

To promote public-private linkage in scientific research through policy initiatives, it is essential for policymakers to understand the mechanism for producing, transmitting, and using scientific knowledge between private and public sectors. However, institutional and organizational features of public-private linkage appear to differ from one country to another. Indeed, Japanese innovation system is quite distinct from those of the other advanced countries in many respects.[2]

This paper explores salient institutional characteristics that are likely to affect public-private linkage in Japan. In particular, we would like to present policy challenges distilled from the experience in the 1990s in view of (i) public funding scheme, (ii) Japanese pro-patent policy for the public sector, (iii) institutional constraint on clinical trials, and (iv) mobility of researchers across private and public sectors. We examine these policy questions focusing on biomedical research because producing scientific knowledge in biomedical research is closely

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[2]See, for example, Nelson ed. (1993), Odagiri and Goto (1993, 1996), and Henderson et al. (1999).

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associated with implementing the knowledge into commercialization and because life science has been one of the top four prioritized areas (along with information and communications, environmental science, and nanotechnologies & materials) in Japanese science and technology policy since the late 1990s.[3]

Section 2 explains legislative measures facilitating public-private linkage and public funding scheme in Japan. Traditionally, the Japanese government gave top priority to energy-related research such as nuclear fusion. But *The Basic Plan for Science and Technology*, which has been introduced every five year period since 1996, has gradually reallocated research expenditures to other technology fields, putting more weight on life science. Since the introduction of the Basic Plan, more than 400 billion yen has been allocated to life science every year.[4] The establishment of the Council for Science and Technology Policy (CSTP) attached to the Cabinet office in 2001 is one of the watershed events that facilitated more flexible allocation of the research budget. Unfortunately, however, there are still a lot of defects in the public funding scheme. For instance, the share of competitive research grants is still small, and the grant is very rigid to use.

Section 3 examines the Japanese pro-patent policy. Since the latter half of 1990s, the Japanese government has actively promoted pro-patent policy in order to advance research collaboration among industry, university, and government and to facilitate commercialization of their research findings. These initiatives reflected considerable interest among Japanese policymakers in emulating the U.S. Bayh-Dole Act of 1980, which is widely credited with stimulating significant growth in university-industry technology transfer and research collaboration. We depict the trends in government and university patenting by assignee types in biomedical fields and discuss possible effects of the Japanese version of the Bayh-Dole policy on biomedical research. We believe that the Japanese version seems to be just beginning to have some impact on the patenting activity of government research institutes. On the other hand, it does not appear to dictate the patenting behavior of university researchers. Institutional and organizational features of government research institutes and universities are keys to elucidate their differential responses.

Section 4 discusses institutional constraints on clinical trials. The clinical trial is an important institutional infrastructure for promoting *translational research*, which is the combination of basic and applied research producing clinically effective biomedical products or gene therapy/diagnoses. Inventing biomedical products is one of the ultimate goals of biomedical research. Therefore, if institutional constraints on clinical trials are severely binding, it may be all the more difficult to obtain an approval for commercialization of a new biomedical product

[3]The present study mentions "public sector" as indicating both government and university. It should be noted, however, that university researchers and government researchers may be very different from each other in propensity to patent, to the extent of their affinity to open science culture, and the resulting values of their patents. We will discuss these points in later sections.

[4]See Council for Science and Technology Policy (2005) for more detail.

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from competent regulatory agencies. Consequently, a deficient system of clinical trials may weaken the incentive to do clinical research not only in the private sector but also in the public sector even if the government actively promotes the pro-patent policy for the public sector.

Section 5 examines the mobility of Japanese researchers. An inflexible career trajectory is one of salient characteristics of Japanese researchers. Furthermore, Japanese public sector researchers at government research institutes and national universities were burdened with rigid office regulations as well as restrictive dual-employment rules until quite recently. Accordingly, the low mobility of researchers has possibly hindered mutual understanding regarding institutional missions, organizational features, and researchers' incentives among industry, government, university. Section 6 closes the present paper with brief concluding remarks.

2. LEGISLATIVE INITIATIVES AND PUBLIC FUNDING SCHEME

Legislative Initiatives Promoting Public-Private Linkage

After the enactment of the *Basic Law on Science and Technology* in 1995, a wave of legislations took place encouraging collaborative research among industry, government, and universities. Several legislative measures actually emulated relevant U.S. policies such as the Bayh-Dole Act and the Small Business Innovation Research (SBIR) program.

Many legislative initiatives were introduced between 1998 and 2000, primarily by the Ministry of Economy, Trade, and Industry (METI). Among these policy initiatives, *The Law on the Special Measures for Revitalizing Industrial Activities* (The Japanese Bayh-Dole Act) was quite important because it was widely expected to have profound effect on the patenting activity and technology transaction of the public sector in the biotechnology sector.

The Japanese Bayh-Dole Act, enacted in 1999, granted researchers permission to retain patents to inventions derived from publicly funded research and allowed for exclusive licensing of state-owned patents.

The Japanese Bayh-Dole Act appears to have had significant effect on the way in which public sector researchers produce privately appropriable research results. As will be discussed in the next section, patenting by government research institutes and universities has exploded since 1999. In addition, the number of patent applications that were filed jointly by private and public sector researchers also increased somewhat since 1999. However, it is less certain whether the Japanese Bayh-Dole policy really encourages the public sector to file *valuable* patents.

Basic Plan for Science and Technology

In spite of severe economic and fiscal conditions in the 1990s, public funding for science and technology (S&T) has dramatically increased since the latter

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half of 1990s and reached around 3.58 trillion yen as of FY2005. In addition to increasing the budget, policymakers have shifted more resources into life science research.

The First Basic Plan for Science and Technology (1996-2000) initiated several institutional reforms such as a tenure system, a program to support 10,000 postdoctoral fellows, and industry-government-university collaboration in research. Government R&D expenditures during the First Basic Plan was 17 trillion yen over five years. The Second Basic Plan for Science and Technology (2001-2005) raised government R&D expenditures to 21 trillion yen over five years and commanded strategic priority setting in life science, information and communications, environmental science, and nanotechnologies & materials. The Third Basic Plan for Science and Technology (2006-2010) further raised government R&D expenditures to 25 trillion yen (targeted figure) over five years, and the strategic priority setting of the 2nd Basic Plan was reformulated to extend to other technology fields such as robotics and fuel cells.

Council for Science and Technology Policy

The Council for Science and Technology Policy (CSTP) was established in the Cabinet Office along with the comprehensive reshufflings of administrative organizations in 2001. The main role of this council, which is headed by the prime minister, is to harmonize S&T policies across ministries and agencies. The establishment of the CSTP was one of the watershed events for public research funding because it reduced the power of the individual agencies to control spending.

The result is that CSTP's review of a research project proposed by a ministry or an agency is now considered in light of the priorities of the Basic Plan. This review process was officially stipulated as a mission of the CSTP in 2001. For example, every research project is ranked in one of four categories by the CSTP. Although there are no clearly stated rules requiring agencies to follow CSTP guidance, a favorable review is very likely to influence agencies' funding decisions.

Prioritization of Public Research Fund

With respect to the allocation of the research budget in FY2005, there are three noteworthy characteristics. First, competitive research grants consist of just around 13 percent (470 billion yen) of the total budget. Although funding for competitive grants has grown in recent years, their share of total government research funding is far below the U.S. percentage of more than 35 percent.[5]

Second, there are many government research institutes such as national laboratories and independent administrative agencies (IAAs) that are generally well funded. The Japan Science and Technology Agency (JST), National Institute of

[5]See Council for Science and Technology Policy (2002) for detail.

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Advanced Industrial Science and Technology (AIST), Institute of Physical and Chemical Research (RIKEN), National Agriculture and Bio-oriented Research Organization (NARO), and National Institute of Agrobiological Sciences (NIAS) are closely involved in biomedical research, and they account for about 20 percent of total public R&D subsidies to all IAAs. The funding for government research institutes (with about 34,000 researchers) is roughly equivalent funding for universities (with about 291,000 researchers) in FY2004.[6]

Third, government research funds are sprinkled through many vertically divided funding agencies. Japan has no equivalent of the U.S. National Institutes of Health (NIH), which incorporates almost all biomedical science funding. In addition, agencies do not share information about which researchers they fund, and there is no common guiding principle of peer review across agencies. This could explain why a small number of star scientists receive a large share of research funds from multiple funding agencies.

These characteristics are likely to reinforce the tendency of the so-called *Matthew effect* in science (Merton, 1968; Dasgupta and David, 1994), by which an eminent scientist will obtain more research funds than a comparatively unknown researcher even if their works are similar to each other.[7] Furthermore, research grants have been concentrated on a few prominent top national universities. The top 10 national universities receive about 50 percent of research grants in Japan, and Tokyo University alone receives roughly 15 percent of total grants-in-aid from the Ministry of Education, Culture, Sports, Science, and Technology (MEXT).[8]

The four prioritized research areas accounted for almost 40 percent of the total public R&D expenditures in 2001, and the share was increased during the Second Basic Plan for the years 2001-2005, thanks to CSTP's influence. Significant shifts in budget al.locations are rare in Japan because each segment of the budget is closely related to vested interests of vertically divided ministries and agencies.

Research Grants

Almost all Japanese universities and government research institutes are funded predominantly by the government and are tightly controlled by various ministries and agencies.[9] The most important sources of research grants for Japanese universities are grants-in-aid (188 billion yen in FY2005), Center-

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[6]See Section 5 for detail.

[7]*"For unto every one that hath shall be given, and he shall have abundance: but from him that hath not shall be taken away even that which he hath."* (Matthew XXV:29, KJV).

[8]See Council for Science and Technology Policy (2002) for more detail.

[9]Odagiri and Goto (1993, 1996), Odagiri (1999), Kneller (2003), and Walsh and Cohen (2004) provide beneficial information about organizational and institutional differences between Japan and the U.S. regarding public research and its collaboration with industry. They suggest that public research has a substantial impact on industrial R&D in both countries, although the institutional environments for university-industry linkages in the two countries are quite distinct.

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of-Excellence 21st Century Grants (38 billion yen) by MEXT, and Adjustment Outlays for Promoting Science and Technology (40 billion yen) by JST.

The United States and Japan differ considerably in the way that they manage their research budgets. The use of research grants in Japan is very restrictive. For example, personnel expense for core project researchers is prohibited except for part-time employment of graduate students and postdoctoral fellows; carrying over expenses from one fiscal year to the next is not allowed; and the opportunity of subscriptions is once a year in all types of research grants in Japan.

Inflexible use of research grants appears to have induced some university researchers to prefer informal collaboration with industry researchers to muddling through red-tape routines in applying for collaborative research grants, hiring temporary researchers, contracting commissioned research, and negotiating the ownership of research outcomes.[10]

3. GOVERNMENT AND UNIVERSITY PATENTING IN BIOMEDICAL FIELDS

Japanese Bayh-Dole Act

Among the policy initiatives, the Japanese Bayh-Dole Act is particularly important because it has been widely expected to have profound effect on patenting activity and technology transaction of the public sector. As is well known, the Japanese economy in the 1990s is called as "a lost decade" with gnawing stagnation.[11] The economic condition behind the pro-patent movement in the 1990s is in marked contrast to U.S. economic conditions in the 1970s, which motivated the introduction of the Bayh-Dole Act in 1980.

The Japanese Bayh-Dole Act and other auxiliary measures appear to have had a significant effect on the way public sector researchers produce privately appropriable research results in biomedical fields. Patenting by both government research institutes and universities has exploded since the introduction of the Japanese Bayh-Dole Act. In addition, the number of patent applications that were filed jointly by private and public sector researchers also increased since 1998.

In biomedical research, there is an increased trend of patenting by the public sector.[12] The share of patents that were filed by the public sector almost trebled in the late 1990s and reached almost 30 percent of total patents in 2002 if we include co-applications with industry.[13]

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[10]See Odagiri (1999) and Kneller (2003) for similar observations.

[11]See, for example, Hayashi and Prescott (2002).

[12]See Nakamura et al. (2007) in detail.

[13]Here we define the share of the public sector patents consisting of a single assignee (i.e., government and university) and multiple co-assignees (i.e., government and corporation, university and corporation, and government and university). The share of the public sector patent was less than 10 percent in the early 1990s, but it has been rapidly increased since the late 1990s and reached 29.1 percent in 2002.

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With respect to the trend of patenting by assignee types, it is worth noting that patenting by the public sector as a single assignee has increased particularly since the introduction of the Japanese Bayh-Dole Act. The number of jointly filed patents by private and public sectors is also increasing but lagging behind somewhat. We think that institutional features of government research institutes and universities are keys to elucidate the salient differences in their responses.

Patenting by Government Research Institutions

The patenting by government research institutions is highly concentrated in the following top five government research institutes: JST, AIST, RIKEN, NARO, and NIAS.[14] They account for almost 70 percent of all government patents, and the top three government institutions (JST, AIST and RIKEN) occupy the majority of government research institutes' patents. This may partly reflect the fact that government research expenditures are somewhat concentrated on these research institutes.[15]

We believe that the government research institutes have been strongly encouraged to file patents by supervising authorities since the introduction of the First Basic Plan for Science and Technology because the number of patents (as well as patent licenses) is regarded as one of important performance indexes in the annual reviews by CSTP. In addition, the government research institutes are tightly supervised by a vertically divided bureaucracy and are therefore quicker to respond to administrative guidance than are with universities.

University Patenting

For most university researchers, patenting may be far from their ordinary academic lives. Most major research universities are national universities, and although they are closely supervised by MEXT, the publication of academic papers seems to be much more important than patenting, as is also the case in the top U.S. research universities.[16] The trend toward increased university patenting since 1998 may be partly explained by the recent facilitating policy measures, which somewhat alleviated the red-tape burden in government research funding

[14]The top five government institutes are defined by the order of the total patent applications since 1991 through 2002 in biomedical research. Jurisdictional authorities are as follows: MEXT for JST and RIKEN; METI for AIST; and Ministry of Agriculture, Forestry and Fisheries (MAFF) for NARO and NIAS. The jurisdictional relationships were not changed before and after reorganizations which had occurred several times in the 1990s.

[15]These five research institutes account for around 20 percent of total public R&D subsidies to independent administrative agencies (IAAs). Concerning the distribution of government research expenditures among public research institutes, see National Institute of Science and Technology Policy (2005) for detail.

[16]See, for example, Mowery et al. (2001) and Agrawal and Henderson (2002).

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and negotiations with the private sector concerning the ownership of research results and licensing conditions. However, as we discuss below, transferring scientific knowledge from university to industry through formal contracts such as patent licensing appears to be at a rudimentary stage.

Commercialization of Scientific Knowledge and Patent Value

The Law on the Promotion of Technology Licensing by Universities etc. (the TLO Act), which was enacted in 1998, states that the government should support technology licensing organizations (TLOs) of universities and government research institutes. In addition, universities and government research institutes should obtain partial remission of patent fees, and the licensees from the government-approved TLOs may be given government investment under certain conditions. The TLO Act also targeted the public sector, but with less success. Although patenting by the public sector was significantly stimulated by the Japanese Bayh-Dole Act, the licensing activity by TLOs has not been very impressive, as yet, in Japan. Although the number of patents that are owned by the Japanese TLOs is now quite large, royalty revenues by them are still at a low level.

As Argyres and Liebeskind (1998) indicate, the commercialization of government/university research would be hampered because of their historic commitment to create and sustain the "intellectual commons" for the public at large. Informal free flow of knowledge between public and private sectors can be an important source of social benefit. Patenting may thereby inhibit diffusion of scientific knowledge, which has been christened "the tragedy of anti-commons" by Heller and Eisenberg (1998).

In a related vein, Mowery and Sampat (2005) argue convincingly that the efforts at emulation of the Bayh-Dole policy are likely to have modest success at best without greater attention to the underlying structural differences among the higher education systems. Mowery and Sampat (2005, p.123) also suggest that adoption of Bayh-Dole-inspired policies by OECD countries, including Japan, "ignore one of the central justifications for Bayh-Dole, i.e., that government ownership of publicly funded inventions impedes their commercialization."

Even though patent statistics should be a beneficial source of information about the role of the public sector and its research collaboration with the private sector in commercializing research outcome, it is less certain whether the value of patents filed by the public sector is concomitantly increased by the pro-patent policy. Value analysis of public sector patents is therefore quite important.

There are several prior studies concerning the Bayh-Dole Act in the United States. See, for example, Henderson et al. (1998), Mowery et al. (2001), Mowery and Ziedonis (2002), Thursby and Thursby (2002), Mowery and Sampat (2005), Hall (2005), among others. These studies provide, to a greater or lesser degree, a cautious view of pro-patent policy and of Bayh-Dole-like measures in particular.

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Concerning the Japanese Bayh-Dole, we suggest in a recent study that the value of patents by government research institutes began to increase since the introduction of the pro-patent policy in the late 1990s. On the other hand, there is no significant change in the value of university patents before and after the Japanese Bayh-Dole Act. Thus the Japanese pro-patent policy does not appear to dictate the patenting behavior of university researchers regarding their "important" inventions (Nakamura et al., 2007).

4. CLINICAL RESEARCH AND MEDICAL EVALUATION SCHEME

Inactive Translational Research in Japan

Basic biomedical research and clinical research have distinct features in terms of required knowledge, cost structure and stage-specific skills. As a result, pro-patent policy measures would not necessarily facilitate clinical research.

Translational research, in which basic and applied research are combined to produce clinically effective biomedical products or gene therapy/diagnoses, makes extensive use of post-genome technologies such as gene function, protein conformation, and protein function. However, the number of Japanese patents in these areas is not yet very impressive, and translational research may be one of the weakest areas in Japanese biomedical research.

On the other hand, basic research such as genetic engineering and gene analysis are the most active fields in patenting in Japan although these are rather upstream technologies in the long-term process of biomedical research and are, if anything, mature research fields.[17] The rapid growth of patenting in genetic engineering and gene analysis may be partly due to the enlargement of patentable subject matters in the early 1990s. Roughly speaking, the patentable subject matters in Japan is ranked somewhere between the broader scope of the United States and the narrower scope in EU.[18]

Hollowing Out of Domestic Clinical Trials

The reasons for the rapid decrease in clinical trials in the early 1990s was: (i) the 1998 adoption of a stricter standard for screening proceedings based on the International Conference on Harmonization of Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH); (ii) many last-minute applications in the early 1990s before the 1997 reforms of the Drug Legislation Act, which was expected to prolong examination periods at that time; and (iii) several drug lawsuits such as *the Sorivudine case* and *the HIV-contaminated blood products case*. As of 1997, ready and waiting notifications reached around 300.

[17]See Nakamura et al. (2007).
[18]See Japan Patent Office (2003) for more detail.

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According to the Office of Pharmaceutical Industry Research (2000), Japanese pharmaceutical companies increasingly start clinical trials overseas, particularly in the United States. In 1993, the ratio of clinical trials overseas to the total clinical trials for new chemical entities developed by Japanese pharmaceutical companies was 18.3 percent, but the ratio increased to 43.2 percent in 2000.

Binding institutional constraints on clinical trials slows the approvals for commercialization of biomedical products. There are two types of organizational structure of clinical trials. In the United Kingdom and the United States the main examiners are in-house experts. On the other hand, in EU and France, a large number of outside experts are nominated, and some of them are selected on case by case basis. In Japan, there were drastic reorganizations of the clinical trial system in 1997 and 2004. The organizational structure of the clinical trials is now shifting from the outside-oriented to inside-oriented expert panels, but the number of in-house experts remains quite small in Japan.[19]

The Ministry of Health, Labor and Welfare itself suggests that the main reason for the *hollowing out* would be a poor clinical trials infrastructure.[20] Implementation structure and incentives for clinical researchers and clinical study participants are not good enough in terms of funding as well as contracting system. The number of clinical research coordinators is also quite low in many national hospitals and national universities, which are the main implementing agencies in Japan. The hollowing out of clinical trials may cause slower access to new drug treatments and deterioration of the capability of clinical research by industry, medical doctors, and universities.

5. LOW MOBILITY OF RESEARCHERS

The inflexible career path of researchers is one of salient characteristics of the Japanese researchers' job market. It is quite infrequent for Japanese researchers to move across industry, government, and university employment during their careers. For example, only 1.1 percent of total researchers (8,800 of 790,900) switched their career path across the walls of industry, government, and universities in 2004. In addition, even when job switching occurs, the end point of the career path is likely to be a university. The moves within sectors are also quite infrequent. The shares of job-switching researchers are 3.1 percent for corporations (14,500 of 465,900), 2.3 percent for universities (6,600 of 291,100), and 6.6 percent for public research institutions (2,200 of 33,900).[21] Among the reasons for the low mobility of researchers in Japan are inflexible employment contracts,

[19]The number of in-house experts in Japan was gradually increased from 256 in 2004 to 341 in 2007. However the number of in-house examiners still remains much smaller than the U.S. See Pharmaceuticals and Medical Device Agency (2007).

[20]See Ministry of Health, Labor and Welfare (2002) for more detail.

[21]See Ministry of Economy, Trade and Industry (2006) for more detail.

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immobile pension schemes, and seniority-based wage systems, particularly in the public sector.

It is worth noting that the Japanese Bayh-Dole Act in 1999 further stipulates somewhat flexible dual-employment rules across private and public affiliations for the first time in Japan. Furthermore, *the Law on the Enhancement of Industrial Technologies*, which was enacted in 2000, made much further clarifications on the dual-employment rule. We think that the dual-employment provisions are no less important than the Bayh-Dole provisions in view of the inflexible job market for researchers in Japan.

The Law on the Enhancement of Industrial Technologies stipulates that the government should take into account the significance of dual employment of the public sector researchers (for example, as a board member of for-profit entities in terms of transferring academic research outcome) and that the government should introduce necessary policy measures to facilitate commercialization of the research results of the public sector.[22] However, these laws and other related ministerial ordinances has had only a limited effect, as yet, on the extent of researchers' mobility, not to mention dual employments.

Organizational Reforms for Public-Sector Research

The low mobility of researchers has possibly hindered mutual understanding regarding institutional missions, organizational cultures, and researchers' incentives among government, industry, and universities. Furthermore, Japanese public sector researchers are burdened with rigid office regulations and restrictive dual-employment rules. Unlike U.S. university researchers, Japanese university researchers have to abide by strict office regulations that are virtually identical to those for civil servants.

In fact, there have been several organizational reforms for the public sector since 2001. In April 2001, almost all public research institutes were reorganized into "independent administrative agencies" (IAAs), which seem to be independent of the government as literally interpreted. But they have been financially as well as managerially supervised tightly by vertically divided ministries and agencies.

As for Japanese national universities, they were reorganized to semi-private entities (so-called national university foundations) in April 2004. A national university foundation is an intermediate legal entity in between government agency and public foundation. In exchange for this reform, since 2004 Japanese national universities have to accept a 1 percent annual decrease in their government subsidy. Almost all universities, however, cannot obtain quid pro quo by competitive research grants.

[22]Kneller (2003) provides beneficial information about organizational and institutional differences between Japanese and the U.S. universities in more detail.

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These organizational reforms are called agencification (*houjin-ka*) and widely expected to improve organizational efficiency of universities (as well as government research institutes, perhaps, in slightly different ways). However, mainly due to weak financial bases and somewhat less expeditious responses by universities, the real effect of this reform still remains to be seen.

6. CONCLUDING REMARKS

The role of the public sector is possibly important in biomedical research. Biomedical research is characterized by the high importance of basic research done at universities and public research institutions. However, there are many steps before basic research leads to commercialization. Producing and transmitting scientific knowledge can take a wide variety of forms depending on research areas, organizations, participants, and other factors. Accordingly, there is no single answer with respect to methods of public support for biomedical research. Consequently, public support for research and pro-patent policy measures in particular must be designed with sufficient attention to the characteristics of institutional and organizational features of the public sector on a case-by-case basis.

We think that flexible funding schemes and higher mobility of researchers are keys to improve public-private linkage in Japan. The low mobility of researchers has possibly hindered mutual understanding regarding institutional as well as organizational features and researchers' incentives. This may make it all the more difficult for Japanese researchers to do public-private collaborative research in an expeditious way.

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IV

APPENDIXES

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Appendix A

Symposium Agenda

"21st Century Innovation Systems for the United States and Japan: Lessons from a Decade of Change"

International Symposium
Organized by

The National Institute of Science and Technology Policy (NISTEP)
Ministry of Education, Culture, Sports, Science & Technology, Japan

and

The Board of Science, Technology, and Economic Policy
U.S. National Academy of Sciences

in collaboration with

Institute of Innovation Research, Hitotsubashi University, Japan

January 10-11, 2006

Tokyo, Japan

Day 1: January 10, 2006

9:30 AM **Welcome**
Introduction: Takashi Inutsuka, Director Planning Division, NISTEP
Motohide Konaka, Director General, NISTEP, Japan

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9:45 AM **Opening Addresses**
Chair: Terutaka Kuwahara, Deputy Director General, NISTEP

Challenges in the U.S. Innovation System
Rep. Ronald Manzullo, Chairman, Committee on Small Business, United States House of Representatives

Evolution and Challenges to the Innovation System in Japan
Taizo Yakushiji, Member, Council for Science and Technology Policy, and Visiting Professor, Keio University

11:00 AM **Coffee Break**

11:15 AM **Panel I: Government's Evolving Role in Supporting Corporate R&D—U.S. and Japanese Models**
Moderator: Alice Amsden, Professor, Massachusetts Institute of Technology

Technology Policies in Japan: 1990-
Akira Goto, Professor, Research Center for Advanced Science and Technology, University of Tokyo, and Faculty Fellow, Research Institute of Economy, Trade and Industry
Kazuyuki Motohashi, Associate Professor, Research Center for Advanced Science and Technology, University of Tokyo, and Faculty Fellow, Research Institute of Economy, Trade and Industry

Government's Evolving Role in Supporting Corporate R&D—Theory and Practice in the Advanced Technology Program
Stephanie Shipp, Director, Economic Assessment Office, Advanced Technology Program, National Institute of Standards and Technology

Discussant
Ichiro Nakajima, Director and Professor, New Industry Creation Hatchery Center, Tohoku University

12:45 PM **Lunch**

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2:15 PM **Panel II: Government-Industry R&D Partnerships—U.S. and Japanese Experiments**
Moderator: Lonnie Edelheit, Retired Senior Vice President, Research & Development, General Electric, and National Academy of Engineering

Semiconductor Consortia in Japan: Experiences and Lessons
Shuzo Fujimura, Professor, Tokyo Institute of Technology, and Visiting Professor, Research Center for Advanced Science and Technology, University of Tokyo
Hiroyuki Chuma, Professor, Institute of Innovation Research, Hitotsubashi University, and Affiliated Senior Fellow, NISTEP

Economic Impacts of International R&D Coordination: SEMATECH, the International Technology Roadmap, and Innovation in Microprocessors
Kenneth Flamm, Professor and Dean Rusk Chair in International Affairs, Lyndon B. Johnson School of Public Affairs, University of Texas at Austin

Discussant
Kaoru Honjo, Executive Director, New Energy and Industrial Development Organization

3:45 PM **Coffee Break**

4:00 PM **Panel III: Government Programs to Encourage Innovation by Startups and SMEs**
Moderator: Bradley Knox, Committee on Small Business, U.S. House of Representatives

Government Programs to Encourage Innovation by Startups & SMEs: The Role of Innovation Awards
Charles Wessner, Board on Science, Technology and Economic Policy, National Research Council

Programs to Stimulate Startups and Entrepreneurship in Japan: Experiences and Lessons
Yasuhiko Yasuda, Professor, Toyo University

Discussant
Tetsuya Iizuka, President and CEO, THine Electronics

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Day 2: January 11, 2006

9:30 AM **Panel IV: Interaction between Intellectual Property and Innovation Systems**
Moderator: Shozo Uemura, Former Deputy Director General, World Intellectual Property Organization, and Visiting Professor, Research Center for Advanced Science and Technology, University of Tokyo

Issues and Possible Reforms in the U.S. Patent System
Bronwyn Hall, Professor, University of California at Berkeley

Reform of Patent System in Japan and Challenges
Sadao Nagaoka, Director and Professor, Institute of Innovation Research, Hitotsubashi University

Discussant
Mark Myers, Xerox, (retired) and Wharton Business School, University of Pennsylvania

11:00 AM **Coffee Break**

11:15 AM **Panel V: Industry and University Collaboration**
Moderator: Toshiya Watanabe, Professor, Research Center for Advanced Science and Technology, University of Tokyo

Industry-University Partnerships in the United States
Irwin Feller, Senior Visiting Scientist, American Association for the Advancement of Science, and Professor Emeritus of Economics, Pennsylvania State University

Industry-University Partnerships in Japan
Masayuki Kondo, Affiliated Senior Fellow, NISTEP, and Professor, Yokohama National University

Discussants
Gail Cassell, Vice President, Scientific Affairs, Distinguished Lilly Research Scholar for Infectious Diseases, Eli Lilly
James Turner, Chief Democratic Counsel, Committee on Science, United States House of Representatives

1:00 PM **Lunch**

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2:15 PM **Panel VI: Government Support for University Research**
Moderator: Hiroshi Nagano, Principal Fellow, Japan Science and Technology Agency

DARPA and the U.S. Connected Science Model for Innovation
William Bonvillian, Legislative Director and Chief Counsel, Office of Senator Joseph Lieberman, United States Senate

Government Support to University Research - Trends and Issues in Japan
Ryuji Shimoda, Professor, Integrated Research Institute, Tokyo Institute of Technology

Discussant
William Spencer, Board on Science, Technology and Economic Policy, National Research Council, and Chairman, SEMATECH (retired)

3:45 PM **Coffee Break**

4:00 PM **Panel VII: Industry-University-Government Cooperation: The Biotechnology Challenge**
Moderator: William Bonvillian, Legislative Director and Chief Counsel, Office of Senator Joseph Lieberman, United States Senate

Perspective on Current Trends in Drug Development in the United States
Gail Cassell, Vice President, Scientific Affairs, Distinguished Lilly Research Scholar for Infectious Diseases, Eli Lilly

Is There a Sgnificant Contribution of Public Sector in Biomedical Research in Japan?: A Detailed Analysis of Government/University Patenting, 1991-2001
Yosuke Okada, Associate Professor, Hitotsubashi University

Discussant
Shozo Nagai, Patent Attorney and Director, Intellectual Property Division, Japan Pharmaceutical Manufacturers Association

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21st Century Innovation Systems for Japan and the United States: Lessons from a Decade of Change: Report of a Symposium

5:30 PM **Closing Summary and Remarks**

Chair: Masayuki Kondo, Affiliated Senior Fellow, NISTEP, and Professor, Yokohama National University

William Spencer, Board on Science, Technology and Economic Policy, National Research Council, and Chairman, SEMATECH (retired)

Sadao Nagaoka, Director and Professor, Institute of Innovation Research, Hitotsubashi University

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"21st Century Innovation Systems for the United States and Japan: Lessons from a Decade of Change"

Symposium Planning Committee

Masayuki Kondo, *Co-chair*
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National Institute of Science and Technology Policy (NISTEP)
and Professor
Yokohama National University

Sadao Nagaoka, *Co-chair*
Director and Professor
Institute of Innovation Research
Hitotsubashi University

Akira Goto
Professor
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University of Tokyo

Hiroyuki Tomizawa
Senior Research Fellow
Second Theory-oriented Group
National Institute of Science and Technology Policy (NISTEP)

Masaru Yarime
Senior Research Fellow
Second Theory-oriented Group
National Institute of Science and Technology Policy (NISTEP)

William J. Spencer (NAE), *Co-chair*
Chairman Emeritus, *retired*
SEMATECH

Kenneth S. Flamm, *Co-chair*
Dean Rusk Chair in International Affairs
Lyndon B. Johnson School of Public Affairs
University of Texas at Austin

Alice H. Amsden
Professor of Political Economy
Massachusetts Institute of Technology

Gail H. Cassell (IOM)
Vice President, Scientific Affairs
and Distinguished Lilly Research Scholar for Infectious Diseases
Eli Lilly and Company

Lewis S. Edelheit
Senior Research and Technology Advisor, *retired*
General Electric

Bronwyn Hall
Professor of Economics
University of California at Berkeley

Mark B. Myers
Senior Vice President, *retired*
Xerox Corporation

Alan Wm. Wolff
Partner
Dewey & LeBoeuf LLP

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Appendix B

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