The U.S. National Innovation System:

Recent Developments in Structure and Knowledge Flows*

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*Prepared for the OECD meeting on "National Innovation Systems," October 3, 1996. Research for this paper was supported by the Alfred P. Sloan Foundation, the U.S.-Japan Industry and Technology Management Training Program, and the Canadian Institute for Advanced Research. Michael Barnes and Arvids Ziedonis provided invaluable assistance with data collection and analysis. Portions of this paper draw on research conducted jointly with Rose Marie Ham of the Haas School of Business.

I. Introduction

The foundations of the structure of the postwar U.S. "national innovation system" were largely put in place during the 1945-50 period, as demobilization for peace was replaced by Cold War rearmament. The federal government assumed a role as a financial supporter that dwarfed its pre-1940 presence, as the federal share of national R&D spending rose from roughly 20% in 1939 to more than 50% by 1962. Federal spending supported R&D activity in industry and universities, rather than being concentrated in federal government laboratories; as of 1980, 12.2% of R&D performance was located in the public sector, 13.2% took place in universities, and 71.1% was located in industry as of 1980.

Federal R&D spending was dominated by basic research (especially in the biomedical sciences), and research in defense-related technologies. During the late 1950s (see Figure 1), defense-related spending accounted for as much as 80% of federal R&D outlays. Federal and state governments invested little in programs designed to assist firms in adopting technology, which may have contributed to the relatively slow adoption by U.S. manufacturing firms of advanced manufacturing technologies (Mowery and Rosenberg, 1993; Edquist and Jacobsson, 1988). U.S. agriculture, of course, was a prominent exception to this characterization, with its elaborate network of federal and state-funded extension agents (See Evenson, 1982).

The dramatic transformation in the scope and sources of funding for R&D activity within the postwar U.S. economy aided the emergence of the United States as a leading source of basic scientific research, a characterization that could not have been applied to the U.S. innovation system of the 1930s. From a position of parity at best in some fields and considerable lags behind the scientific frontier in others during the interwar period, U.S. scientists during the postwar period dominated scientific publications and major awards, such as the Nobel Prize. The shift in the standing of U.S. scientific research was associated with the emergence of several other distinctive features of the U.S. national innovation system. Defense-related R&D and procurement programs provided a powerful impetus to the development and commercialization of new civilian technologies in commercial aerospace, semiconductors, computers, and computer software (such defense "spillovers" proved to be far less beneficial for civilian firms in nuclear power). In almost all of these industries other than commercial aerospace, new firms played a prominent, and in some cases, dominant role, in the commercialization of important technological advances. The important role of these new firms appears to be unique among the major postwar industrial economies, and reflected the unusual conjunction of defense procurement policies with U.S. antitrust policy and a domestic financial system that facilitated the capitalization of new enterprises in high-technology industries (Mowery, 1996 provides additional details).

This paper briefly surveys the evidence on trends in spending and evidence of structural change in the U.S. national innovation system. One of the key concerns of this meeting is the characterization of the ease with which technological knowledge diffuses within a national innovation system, and I will briefly consider this issue, although it is not easily addressed with publicly available data. More generally, however, the end of the Cold War is likely to produce fundamental changes in the structure of the U.S. innovation system, since it will reduce the role of defense-related R&D and the federal government share within national R&D spending. Combined with changes in other policies, such as intellectual property rights and competition policy, the intranational flow of knowledge within the U.S. innovation system could well shift considerably. Moreover, the combined effects of these structural changes may result in a U.S. innovation system that remains much larger than other industrial-economy systems but presents a less dramatic contrast in its structure.

II. Public and Private R&D Spending, 1980-1995

The most dramatic shift in spending trends within the U.S. innovation system during the past decade is the reduction in the rate of growth in R&D spending since the early 1980s. Total national R&D spending grew at nearly 7% annually in constant-dollar terms during 1980-85, but during 1985-94, the average annual rate of growth in total constant-dollar R&D spending declined to 1%. This sharp decline in growth in R&D spending reflects cuts in federal government R&D spending. Having grown by 6% per year in real terms during 1980-85, federal R&D spending has declined in real terms by 1% per year since 1985 (See Figure 2).[1]

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[1] The increases in R&D spending by "Other non-federal sources" in Figure 1 reflect growth in R&D funded by state and local governments, as well as universities and colleges. R&D spending from these sources grew by 2% in real terms during 1994-95.

The bulk of this sharp shift in spending growth is due to decreases in defense-related R&D spending, which grew from 50% of federal R&D spending in 1980 to almost 70% by 1986, a peak from which it has declined once again to approximately 52% of total federal R&D spending. The economic consequences of this sharp reduction in defense-related R&D spending are difficult to project. Technological "spillovers" from defense to civilian applications of this spending now appear to be less significant than was true of the 1950s and early 1960s, as the requirements for military and civilian applications in such technologies as aerospace and electronics have diverged. In addition, a considerable portion of federal defense-related R&D spending was directed to applied activities, such as weapons testing, that generated few civilian economic benefits. Nevertheless, the enormous defense-related R&D budget contained a substantial basic research component, and defense-related R&D accounted for a considerable share of federally funded research in U.S. universities in such areas as electronics. Reductions in spending in these areas could have negative consequences for civilian innovative performance.

The long-term outlook for growth in federal civilian R&D spending also is bleak. The possibilities for further reductions in the defense-related share of total federal R&D spending are limited. The events of 1995-96 suggest that political agreement on reductions in entitlement spending for the elderly and healthcare will be very difficult if not impossible to achieve. Yet the high projected rates of growth in spending on these items will severely constrain growth in discretionary spending, a category that includes federal R&D spending. The American Association for the Advancement of Science analysis of the seven-year budget projections developed by the Clinton Administration forecast sharp reductions in nondefense R&D budgets during 1996-2000, totaling as much as 18% in real terms over this period (Lawler, 1996). Such sharp reductions are unlikely, but they illustrate the severity of the constraints faced by federal R&D programs. For the near future, the share of federal spending within total U.S. R&D spending is likely to continue to decline still further below its 1994 level of 36%.

The other major source of R&D spending with the U.S. system is industry, which accounted for 59% of total R&D spending in 1994. Real growth in industry-financed R&D, however, also has experienced a slowdown since the early 1990s, and the 1993-94 change in such spending was negative (-1%). Interestingly, the flat trends in overall industry-financed R&D spending masked an increase in reported R&D spending in the nonmanufacturing sector, primarily in communications services, computer services (much of which involves software development), and engineering services. A portion of this measured increase reflects changes in the survey sample used by the National Science Foundation, which increased the reported R&D performed in the nonmanufacturing sector from $10 to $21 billion in 1991. Nevertheless, even without these changes in the NSF sample, R&D performance in the nonmanufacturing sector increased from 4% of total industry performance to 10-16% in 1992 (the bulk of this R&D performance is industry-financed).

As the data in Figure 2 show, total industry-financed R&D appears to move cyclically, and it is likely that growth in this category of R&D spending will resume within the next few years. But the likely future rates of real growth in industry-financed R&D spending (i.e., 2-4% annually) may well be insufficient to offset the consequences of real reductions in federal spending, and real U.S. national R&D spending therefore is likely to grow at very low levels, if at all.

III. Other policy-related changes

Despite their Administrations' rhetorical rejection of intervention in the market, significant technology policy initiatives were undertaken under Reagan and Bush.[2] Faced with more intense foreign competition from firms that had improved their abilities to exploit scientific advances made in U.S. and other foreign laboratories, federal policymakers began to experiment with programs that sought to strengthen civilian technological capabilities by subsidizing and promoting joint research, encouraging collaboration between U.S. universities and industry in technology development, and supporting collaboration between U.S. industry and the federal laboratories.

Programs such as the National Center for Manufacturing Sciences (NCMS), the semiconductor research consortium SEMATECH, the Advanced Technology Program (ATP) of the Department of Commerce, and even the National Science Foundation's Engineering Research Centers all represented significant departures from the postwar structure of federal science and technology policy. The SEMATECH and NCMS programs relied on expanded funding by the Defense Department for civilian technology development in so-called "dual-use" technologies,

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[2] The discussion in this section draws on Ham and Mowery (1995, 1997).

based on the premise that the economic benefits of "spinoffs" from military to civilian technology applications had declined.

Other U.S. initiatives in technology policy during the Reagan and Bush Administrations reduced antitrust restrictions on collaboration in research and improved enforcement of intellectual property protection. In antitrust policy, these Administrations adopted a substantially more lenient enforcement posture than their predecessors, arguing that international competition had reduced the ability of U.S. firms to increase their market power through domestic mergers and acquisitions. Justice Department guidelines and review procedures for mergers were relaxed somewhat, and major federal antitrust suits against high-technology firms were dropped or settled in the early 1980s. The Reagan Administration also supported the 1984 National Cooperative Research Act, which reduced the antitrust penalties for collaboration among firms in precommercial research. The NCRA has been credited with facilitating the early growth and operation of the Microelectronics and Computer Technology Corporation, a research consortium involving U.S. computer and electronics firms. In 1993, the NCRA was extended to cover joint production ventures.

Shifts in U.S. policy toward intellectual property rights began with the 1982 legislation that established the Court of Appeals for the Federal Circuit, which strengthened the protection granted to patentholders.[3] The U.S. government also pursued stronger international protection for intellectual property rights in the Uruguay Round trade negotiations and in other bilateral venues. The faith in intellectual property rights as a critical policy tool in improving U.S. competitiveness was exemplified in two other statutes of the 1980s that sought to transform the large system of federal laboratories into sources of innovations for U.S. firms. First, the Bayh-Dole Patent and Trademark Amendments Act of 1980 (sponsored by a leading Democratic and Republican senator) permitted federal agencies to grant licenses to small businesses and nonprofit institutions, including universities, for patents based on research funded by federal agencies at federal and contractor-operated laboratories. Second, the Federal Technology

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[3] According to Katz and Ordover (1990), at least 14 Congressional bills passed during the 1980s focused on strengthening domestic and international protection for intellectual property rights, and the Court of Appeals for the Federal Circuit created in 1982 has upheld patent rights in roughly 80% of the cases argued before it, a considerable increase from the pre-1982 rate of 30% for the Federal bench.

Transfer Act of 1986 and amendments passed in 1989 authorized federal laboratories to conduct cooperative research and development agreements (CRADAs)[4] with private firms.

These pre-Clinton initiatives expanded the federal role in supporting civilian technology development, especially in specific high-technology sectors that were believed to be important to both civilian economic competitiveness and national security. A small but growing share of the defense R&D budget began to flow to "dual-use" technology development projects, under the approving oversight of Congress. As Figure 1 shows, the sharp increase in the ratio of defense to nondefense outlays in the federal R&D budget from approximately 50% to nearly 70% that occurred during fiscal 1979-87 was reversed before the end of the Reagan Administration, and declined further under Bush, to approximately 58%. Both of these developments prefigured trends that would continue under President Clinton.

A. Change in Federal Technology Policy under Clinton

Although the Clinton Administration has not dramatically shifted the direction of post-1980 U.S. technology policy, several notable changes have occurred. The Clinton Administration has endorsed and supported policies for the support of civilian technology adoption, and has launched several new initiatives in support of ‘‘dual-use’’ technology development.

1. Commercial Technology Development and Adoption

The most dramatic shift in federal R&D spending under the Clinton Administration has occurred *within* civilian R&D spending.[5] In contrast to its role in previous Administrations, the Commerce Department has become a key agency in the management of jointly funded technology development and adoption programs with firms, and its R&D budget has more than

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[4] A CRADA specifies terms under which a private organization provides personnel, equipment, or financing for R&D activities that are consistent with a specific laboratory's broader mission. Most CRADAs include provisions that cover the sharing of intellectual property rights to any technologies resulting from the project.

[5] Despite its high profile within Clinton Administration goals, support for the National Information Infrastructure thus far has had little visible impact on reallocations of agency R&D budgets. The $1.3 billion requested for this program in fiscal 1995 is spread among a large number of programs within NIST, NSF, and the National Telecommunications and Information Administration (also a part of the Commerce Department), and represents less than 0.5% of the total federal R&D budget of $73 billion (American Association for the Advancement of Science, 1994).

doubled since fiscal 1993.[6] Much of this increase is linked to the Advanced Technologies Program (ATP), which provides matching funds for firms and consortia for the development of "precommercial" technologies. ATP's budget grew from $47 million in fiscal 1992 to $431 million and $491 million in fiscal 1995 and fiscal 1996 respectively (U.S. Office of Management and Budget, 1994, 1995).[7]

Another area in which the Clinton Administration shifted the rhetorical posture of U.S. technology policy was in its strong backing for federal programs supporting the adoption of advanced technologies, most of which began (at the behest of Congress) under the Bush Administration.[8] The Commerce Department has also received increases in budgets for industrial technology adoption, such as regional manufacturing extension programs that provide technological and management assistance to firms. For example, funding for the Manufacturing Extension Partnership program, which is administered by the National Institute for Standards and Technology (NIST) of the Commerce Department, has increased markedly under the Clinton Administration.[9]

2. "Dual-Use" Technology Development

The Clinton Administration also has launched several initiatives in the "dual-use" technology area that expand on efforts predating its accession to power. The first seeks to reform defense procurement policies to encourage greater use of commercially available components, by reducing the use of "military specification" requirements for such components and revising these specifications to better accommodate commercial components. The second

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[6] Growth in the Commerce Department's R&D budget occurred largely at the expense of the Department of Energy, which lost considerable funding with the termination of the superconducting supercollider.

[7] In April 1995, the 104th Congress rescinded $90 million from ATP's $431 appropriation for fiscal 1995 (Mervis, 1995)..

[8] Federal and state governments traditionally have invested little in programs designed to assist firms in adopting technology, which may have contributed to the relatively slow adoption by U.S. manufacturing firms of advanced manufacturing technologies (Mowery and Rosenberg, 1993; Edquist and Jacobsson, 1988). U.S. agriculture, of course, is a prominent exception to this characterization, with its elaborate network of federal and state-funded extension agents (See Evenson, 1982).

[9] The fiscal 1995 Presidential budget requested $61 million, more than twice the Congressional fiscal 1994 appropriation for this program. Congress further increased the fiscal 1995 appropriation to $91 million. For fiscal 1996, the Clinton Administration requested $147 million for this program, an increase of more than 60%.

initiative seeks to increase R&D and technology development in ‘‘dual-use’’ technologies through programs such as the Technology Reinvestment Program and others, many of which are managed by the Pentagon’s Advanced Research Projects Agency. The Pentagon estimated in February 1995 that total Defense Department investment in such R&D for fiscal 1995 was slightly more than $2 billion, 25% of the Pentagon’s total fiscal 1995 budget of $8.4 billion devoted to science and technology (U.S. Department of Defense, 1995, p. 10).[10]

The Department of Energy (DoE) has also played a prominent role in the dual-use R&D initiative. In order to sustain the weapons R&D capabilities of its huge defense-related laboratories (Los Alamos, Lawrence Livermore, and Sandia National Laboratories), DoE has expanded support for cooperative R&D agreements (CRADAs) in dual-use technologies. Energy Secretary O'Leary assigned a high priority to improving the laboratories' role in "...industrial competitiveness and job creation..." and argued that "...the department can and should help bring taxpayer-financed research into the marketplace" (New York Times, 11/14/94, p. F13). The number of CRADAs between DoE weapons laboratories and private firms that are supported by the Energy Department's nuclear weapons R&D budget increased from 122 in January 1993 to 326 in July 1994.

Among the most widely noted "dual-use" initiatives is a program to support (with over $580 million over the next 5 years) the development and production of flat-screen displays in the United States (Davis and Zachary, 1994). The flat-panel display initiative may be the first of several technology development programs in this area that seek to support the development of U.S. technological and manufacturing capabilities for products embodying these technologies for civilian and military markets.

IV. Structural change in the US innovation system

The changes in federal policy, along with change in the competitive and technological environment of many U.S. firms, have contributed to structural change in the U.S. innovation system. The speed and magnitude of change in the structure of the U.S. innovation system are

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[10] Illustrating the elastic character of current definitions of "dual-use" R&D spending, the February 1995 estimate omitted "dual-use S&T investments" in the Defense Nuclear Agency, the Ballistic Missile Defense Organization, and the three uniformed services that had been included in earlier tabulations, presumably by redefining them as "military-only" R&D programs (U.S. Department of Defense, 1995 p. 10).

difficult to ascertain with publicly available data, but the existence of such change seems inescapable. In addition, this structural change may have important implications for the flow of scientific and technological information within the United States and between the United States and other industrial economies. The major elements of structural change, many of which affect industrial R&D, are

1. Increased reliance by U.S. firms on sources of R&D outside their organizational boundaries, through such mechanisms as consortia, collaboration with U.S. universities and federal laboratories, and strategic alliances with other U.S. and foreign firms.

2. Expanded performance of R&D offshore by U.S. firms and increased performance by non-U.S. firms of industrial R&D within the United States.

3. Increased reliance by U.S. universities on U.S. and foreign industry for research funding and expanded efforts by U.S. universities to license and otherwise realize commercial returns from the results of research performed within them.

Space does not permit a detailed descriptive analysis of each of these trends. It may suffice to note that along with the reduced presence of federal funding within the U.S. innovation system, at least some of these elements of change are likely to result in a U.S. innovation system that more closely resembles those in other industrial economies, and one that in important respects more closely resembles the pre-1940 U.S. innovation system.

A. "Externalization" of industrial R&D

Beginning in the 1980s, a combination of severe competitive pressure, the perception of disappointing returns from their rapidly expanding investments in internal R&D, and a change in federal antitrust policy contributed to the decision by many U.S. firms to ''externalize'' a portion of their R&D operations. Large corporate research facilities in such pioneers of industrial R&D as General Electric, AT&T, and Du Pont were sharply reduced in size, and a number of alternative arrangements appeared. U.S. firms formed more than 450 ''research joint ventures,'' as reported by U.S. firms under the terms of the National Cooperative Research Act, during 1985-1994 (Link, 1995); Link's survey found that the majority of these research joint ventures focused on process R&D.

In addition to research joint ventures and consortia, U.S. firms entered into numerous ''strategic alliances'' with foreign and other U.S. firms during the 1980-1994 period. As Figure

3 shows, a majority of the international strategic alliances for which the National Science Foundation has data link U.S. and Western European firms. Alliances between U.S. and Japanese firms also were widespread. Nevertheless, U.S. firms have expanded their domestic alliance activities, and the formation of ‘‘intranational’’ strategic alliances involving U.S. firms has outstripped the formation of international alliances. Both intranational and international alliances involving U.S. firms appear to be most numerous in biotechnology and information technology. In contrast to the bulk of domestic research consortia, a large proportion of U.S. firms' alliances with foreign firms focused on joint development, manufacture, or marketing of products. In addition to the cost-sharing and technology-access motives that also underpinned the formation of many domestic research joint ventures, the international alliances of U.S. firms were motivated as well by concerns over access to foreign markets (Mowery, 1988).

B. "Internationalization" of U.S. industrial R&D

A second important characteristic of the structural change in the U.S. innovation system during the 1980s was the progressive ‘‘internationalization’’ of the U.S. industrial R&D system, as U.S. firms expanded offshore R&D operations and as foreign firms expanded their R&D activities within the United States. Figure 4 depicts a steady increase in the share of industrially financed R&D of U.S. firms performed in foreign countries during 1985-1992, with the most dramatic increases in share accounted for by chemicals (including pharmaceuticals), scientific instruments, and nonmanufacturing industry. Growth in the foreign share of U.S. industry-financed R&D was reversed during 1992-1993, however, and both electrical equipment (including electronics) and machinery display sharp drops in the offshore share of their industry-financed R&D spending. As with other National Science Foundation data on R&D spending, the meaning of these sharp shifts in spending trends is difficult to interpret, since the survey and sampling methods have changed during this period. Moreover, the small number of observations, especially within industry categories, make these time series very sensitive to omitted observations and other sources of error.

As Figure 5 shows, the share of industrial R&D performed within the United States that was financed from foreign sources also grew during this period, from slightly less than 5% in 1987 to nearly 10% in 1993. Despite this growth, in 1993 foreign sources financed a smaller share of industrial R&D performed within the United States than is true of Canada, the United Kingdom, or France. Data from another government survey indicate that current-dollar R&D

spending by affiliates of foreign firms within the United States rose from approximately $4 billion in 1982 to more than $14 billion in 1993 (Figure 6). Increased foreign financing of R&D activities in the United States was paralleled by an increase in the share of U.S. patents granted to foreign inventors (Figure 7). Foreign firms also participated in the formation of research joint ventures with U.S. firms--according to Link (1995), 32% of the research joint ventures filing under the terms of the National Cooperative Research Act during 1985-1994 enlisted foreign firms among their members. Finally, a number of foreign firms operating R&D facilities in the United States pursued collaboration with U.S. universities. According to Florida (1995), more than 50% of Japanese R&D laboratories in the United States, more than 80% of French R&D laboratories, and almost 75% of German corporate R&D laboratories in the United States were involved in such collaborative agreements.

C. A changing role for university research?

A defining characteristic of the postwar U.S. innovation system is the central role of research universities in R&D performance. Data on the prewar importance of U.S. universities as R&D performers and on the sources of funds for this R&D are not available, but anecdotal evidence strongly suggests that universities depended more heavily on state governments, rather than the federal government, for their research budgets. In addition, close ties between public universities, motivated by a desire to maintain political support for their operating budgets, and industry, appear to have been relatively common (Rosenberg and Nelson, 1992).

Increased federal R&D spending during the postwar period transformed the position of U.S. universities within the domestic innovation system. Universities' share of total U.S. R&D performance grew from 7.4% in 1960 to nearly 16% in 1995, and universities accounted for nearly 60% of the basic research performed within the United States throughout the 1970-95 period (National Science Board, 1996). The federal government's contribution to university research has declined since the early 1970s, however, when federal funds accounted for more than 65% of university-performed research. By 1994, federal funds accounted for roughly 60% of total university research, and industry's contribution had nearly doubled to nearly 7% of total university research. The major growth in industry's share of university research, however, occurred during the 1980s, and since 1990 this industry share has remained constant. The data in

Figure 8 suggest that another significant source of growth in support for university research since the late 1980s is expanded self-financing of research by universities themselves.

The increased importance of industry in funding university research is reflected in growth in the number of research institutes at U.S. universities seeking to support research on issues of direct interest to industry. Data from Cohen, Florida, and Goe (1994) on university-industry research centers in the United States indicate that more than 57% of all university-industry research institutes in existence as of 1992 were established during the 1980s. Nearly 45% of these institutes involve 1-5 firms as members, and more than 46% of them rely on government funds for support, in addition to (or in some cases, in lieu of) support from industry.

Of particular interest for the broader concerns of this OECD working group is the apparent willingness of U.S. universities to accept significant restrictions on the publication of the results of research undertaken with industry sponsorship. The survey of university-industry research centers by Cohen et al. (1994) found that 35% of these centers allow participating firms to require that information be deleted from research papers before submission for publication, 52.5% of the centers allow participating firms to delay the publication of research findings, and 31.1% of the centers allow participating companies to require both the deletion of information and delays in publication. As these researchers note, their data indicate only the fraction of centers that allow participating firms to impose such restrictions; these data do not capture the frequency with which sponsor firms actually request publication delays or deletion of information. The study also provides no information about the prevalence of publication restrictions at the leading U.S. research universities that account for the bulk of the publicly financed research performed within the United States. Moreover, restrictions on the publication of university research results are not new within the United States--during the 1950s and 1960s, defense-related research funding occasionally included restrictions on publication. Nevertheless, the apparent willingness of a large number of U.S. universities to accept restrictions on the dissemination of research findings should be a cause for some concern, and may represent a major shift from the relatively ‘‘open’’ norms of university research that typified U.S. universities during the 1970s and early 1980s.

Another policy development with significant implications for the role of universities within the U.S. innovation system is the growth of university patent licensing and ‘‘technology transfer’’ offices. The Bayh-Dole Act of 1980 and its 1986 amendments made it possible for universities to establish title to the intellectual property resulting from federally funded research performed on their campuses. The Bayh-Dole Act sought to accelerate the transfer and commercial exploitation of university research findings by clarifying their ownership, thereby facilitating the sale of licenses by universities to industry for the commercial development of these research results. During the 1980s, many universities created licensing offices and other programs to seek patent protection for the research advances of their faculty and to market licenses for these advances to industry. During 1980-83, the number of patents issued to academic institutions grew by roughly 10%; for the top 50 research universities, the number of patents granted during this period grew by more than 17%. Henderson, Jaffe, and Trajtenberg (1994) found that university patenting grew even more rapidly after 1984, and Trajtenberg, Henderson, and Jaffe (1994) noted that the share of all U.S. patents accounted for by universities grew from less than 1% in 1975 to almost 2.5% in 1990.

Even more interesting is the finding by Trajtenberg et al. of a significant increase in the ‘‘propensity to patent’’ of universities, as the ratio of patents to R&D spending within universities almost doubled during 1975-90 (from 57 patents per $1 billion in constant-dollar R&D spending in 1975 to 96 in 1990), while the same indicator for all U.S. patenting displayed a sharp decline (decreasing from 780 in 1975 to 429 in 1990). In other words, universities increased their patenting per R&D dollar during a period in which overall patenting per R&D dollar was declining significantly.

Data on the magnitude of the license fees and royalty income generated by universities' patenting and licensing activities are not reliable, because of changes in the coverage of most surveys. Nevertheless, the most reliable estimates indicate that these income flows have grown significantly since the late 1980s. The U.S. General Accounting Office (1995) reported that university licensing income in 1989-90 amounted to $82 million. Estimates from the Association of University Technology Managers for fiscal years 1991-1994 indicate that university royalty and licensing income increased from nearly $130 million in fiscal 1991 to slightly more than $244 million in fiscal 1994, although the rate of growth slowed during the fiscal 1993-94 period (Association of University Technology Managers, 1994; Blumenstyk, 1996). Data for the largest single institutional recipient of licensing income, the University of California, indicate that total income grew from $22.5 million in fiscal 1991 to more than $63 million in fiscal 1995 (Office of Technology Transfer, 1996).

There are few rigorous evaluations of the implications of greater university licensing of research results. Federal policymakers' faith in the power of intellectual property rights alone to accelerate the commercialization of research advances from universities or the federal laboratories almost certainly is overstated. Moreover, the flow of licensing and royalty income that U.S. universities have reaped since 1980 is dominated by a very small number of innovations--the ‘‘top 5’’ patents within the University of California’s portfolio (four of which are based on inventions created at the San Francisco campus, and all of which are based on biomedical research) accounted for 73% of the University’s 1994 licensing income, and the distribution of profits from other universities’ patent portfolios is likely to be equally skewed. Nevertheless, like the spread of publication restrictions within university-industry research institutes, the possibility exists that aggressive university licensing programs, many of which involve restrictions on publication before patent applications are filed, could limit the diffusion of important scientific and technical knowledge within the U.S. innovation system. U.S. universities’ use of federal funds to ‘‘privatize’’ research results for profit also could erode the relatively robust postwar political consensus in favor of federal support for basic research.

A more detailed assessment of the University of California’s patent licensing activities does not provide compelling evidence that the Bayh-Dole Act has increased the share of major scientific and technological advances of this major U.S. research university that is being ‘‘privatized.’’ Figures 9 displays trends in the disclosure of ‘‘inventions’’ by faculty (which is mandated by state law) for the 1974-88 period, one that includes a substantial period before the Bayh-Dole Act. The average annual number of disclosures during 1984-88 (293.2) is well above this number for the 1975-79 period (73.2); but the major increase in invention disclosures appears to predate the passage of the Bayh-Dole Act. This may reflect the important advances in biotechnology that occurred at U.C. San Francisco during the 1970s, or other changes in the structure and activities of the U.C. patent licensing office that were unrelated to Bayh-Dole. The data in Figure 10 suggest that the sharp increase in the shares of biomedical and pharmaceutical inventions within all university invention disclosures may be partially responsible for this increase in overall disclosures.

But the share of the much larger number of disclosures occurring each year during 1984-88 that yield patent applications, granted patents, or licenses is smaller than is true of the 1974-79 disclosures (See Table 1). Moreover, the share of patent applications that yield patent grants and the share of licenses that yield revenues are smaller for 1984-88 than for 1975-79. An interesting exception to this tendency concerns the share of granted patents that are licensed, which increases between the 1975-79 and 1984-88 periods--this may reflect more aggressive marketing by the University of California staff. Although additional analysis is needed to examine these trends, they appear to indicate that the average ‘‘quality’’ of invention disclosures in fact declined during the 1980s, as universities created greater incentives for faculty and research staff to disclose and patent the results of their research. Rather than increasing the barriers to dissemination of major scientific advances, these data appear to indicate that within the University of California, coverage of such advances by formal intellectual property protection in fact may have declined. In general, these data from the leading licensor of university research advances are consistent with Henderson et al. (1994), whose analysis of university patents obtained during the 1980s concluded that the average ‘‘quality’’ of these patents was declining.

V. Conclusion

Virtually all of the central components of the innovation system that emerged in the postwar U.S. economy now are undergoing change. The future U.S. innovation system is likely to be characterized by:

- lower levels of overall federal R&D funding.
- lower levels of defense-related R&D funding and procurement activity.
- reduced military-civilian technological spillovers.
- a higher level of internationalization, both in terms of U.S. R&D investment in foreign economies and in terms of higher levels of non-U.S. R&D investment within the domestic U.S. economy.
- more stringent domestic and international protection of intellectual property rights.
- less stringent domestic antitrust policy.
- higher levels of interfirm collaboration, university-industry collaboration, and collaboration between U.S. and foreign firms in R&D.
- greater efforts by U.S. universities to seek to protect and license the results of publicly and privately funded research.

The implications of these changes for the performance of the U.S. innovation system, and for the role of this system within the global science and technology system, are unclear. The effects of some of these changes, such as the efforts by U.S. universities to protect and market the results of their research, may be modest, because of the lower quality of much of these recent patents. In addition, the sporadic efforts by federal policymakers to limit the international dissemination of the results of publicly funded basic research and technology development programs have in many cases been frustrated by the ineffectiveness of these restrictions and by the actions of private firms in the United States and other industrial economies. But other structural changes, especially those affecting defense-related procurement, the role of universities, and intellectual property rights and antitrust policies, could reduce the importance of new firms in the commercialization of new technologies and in the creation of new industries. The effects of these changes are mediated and possibly offset, however, by the abundance of venture capital for the foundation of new technology-intensive firms within the United States, as well as the relatively modest entry barriers in segments of such rapidly growing "new industries" as computer software and multimedia.

Structural change in the U.S. innovation system, of course, is not occurring in isolation from change in the structure of other industrial economies' innovation systems. Indeed, one of the defining characteristics of such structural change in the United States is increased links with non-U.S. firms and government-supported programs. Structural change in the U.S. and foreign nations' innovation systems nevertheless may well result in some "convergence" in structure, as competition policy in the European Union becomes more stringent and venture capital becomes more abundant in the EU and elsewhere. In the long run, these tendencies toward convergence may reduce some of the "structural frictions" in trade and technology policy that have pervaded recent bilateral and multilateral negotiations (Ostry, 1989; Mowery and Rosenberg, 1989). But the pace of such "convergence" will be slow and frictions will continue to arise regularly and quickly, making for a crowded policy agenda for the foreseeable future.

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Table 1: University of California Invention Disclosures, Patents, and Licenses, 1975-79 & 1984-88

	Patent applications/invention disclosures	Patents issued/invention disclosures	Licenses/invention disclosures	Licenses with revenues>0/invention disclosures	Patents issued/patent applications	Licenses/patents issued	Licenses with revenues>0/licenses
1975-79	47.3%	42.9%	19.1%	14.5%	90.7%	44.6%	75.7%
1984-88	33.1	21.4	13.3	3.9	64.7	62.1	29.2

FIG. 1: tHE CONDUCT OF FEDERAL R&D: DEFENSE AND NON-DEFENSE SHARES

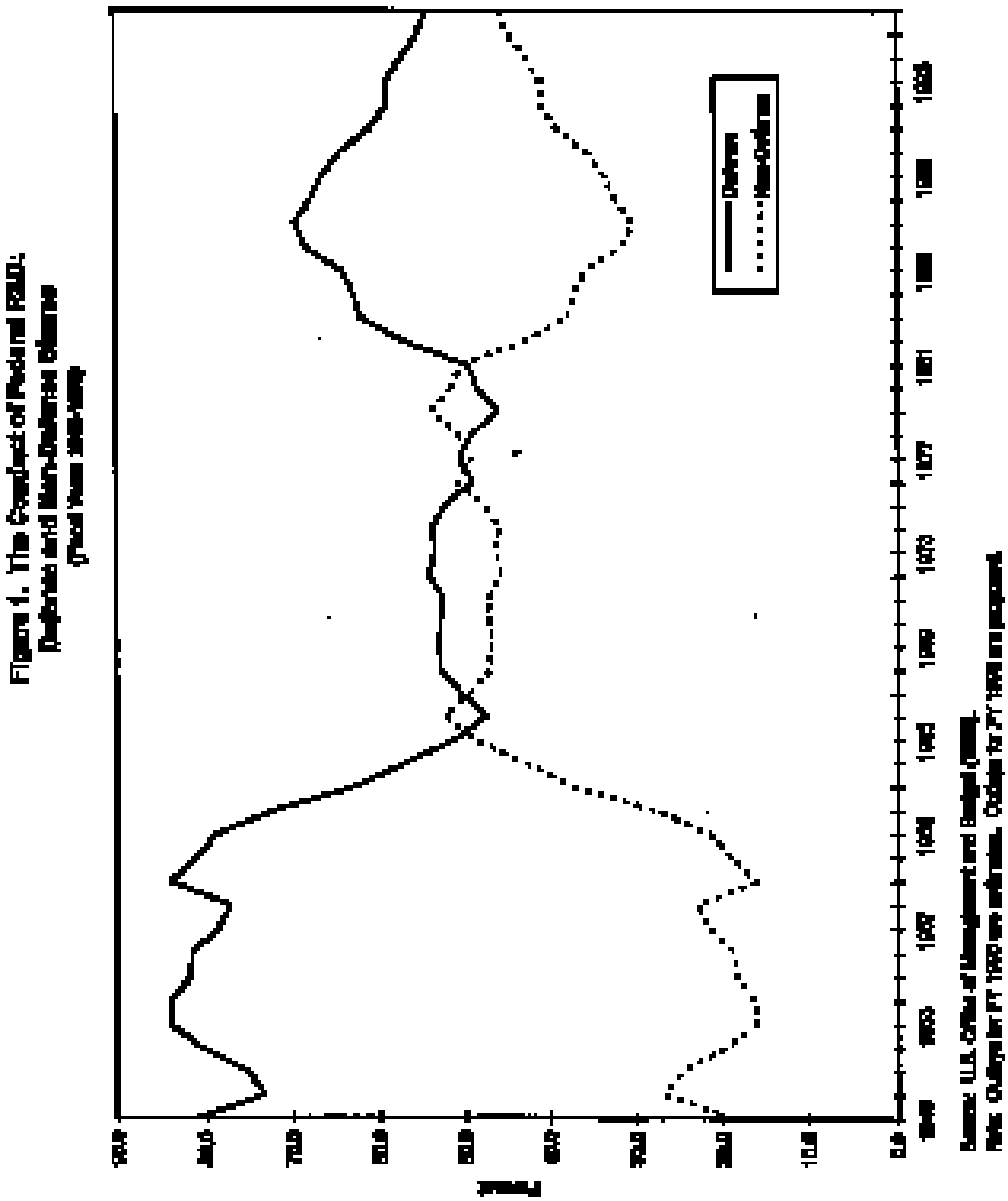

FIG. 2: NATIONAL PATTERNS OF R&D RESOURCES: 1994: Changes in R&D spending by source of funds [LINK TO: HTTP://WWW.NSF.GOV/SBE/SRS/S2194/S2194044.HTM]

FIG.3: DISTRIBUTION OF STRATEGIC TECHNOLOGY ALLIANCES BETWEEN ECONOMIC BLOCS, BY TECHNOLOGY: 1980-94 taken from Science&Engineering Indicators 1996 [http://www.nsf.gov/sbe/srs/seind96/start.htm] APPENDIX table 4-38 p.158

FIG.4: U.S. OVERSEAS R&D AS A SHARE OF COMPANY-FINANCED DOMESTIC R&D, BY INDUSTRY taken from Science&Engineering Indicators 1996 [http://www.nsf.gov/sbe/srs/seind96/start.htm] APPENDIX FIG 4-24

FIG.5: SHARE OF INDUSTRY DOMESTIC R&D PERFORMANCE FINANCED FROM FOREIGN SOURCES, BY COUNTRY, from Science&Engineering Indicators 1996 [http://www.nsf.gov/sbe/srs/seind96/start.htm] APPENDIX FIG 4-26

FIG. 6:

R&D Spending by Foreign Affiliates in the United States
1982-1993

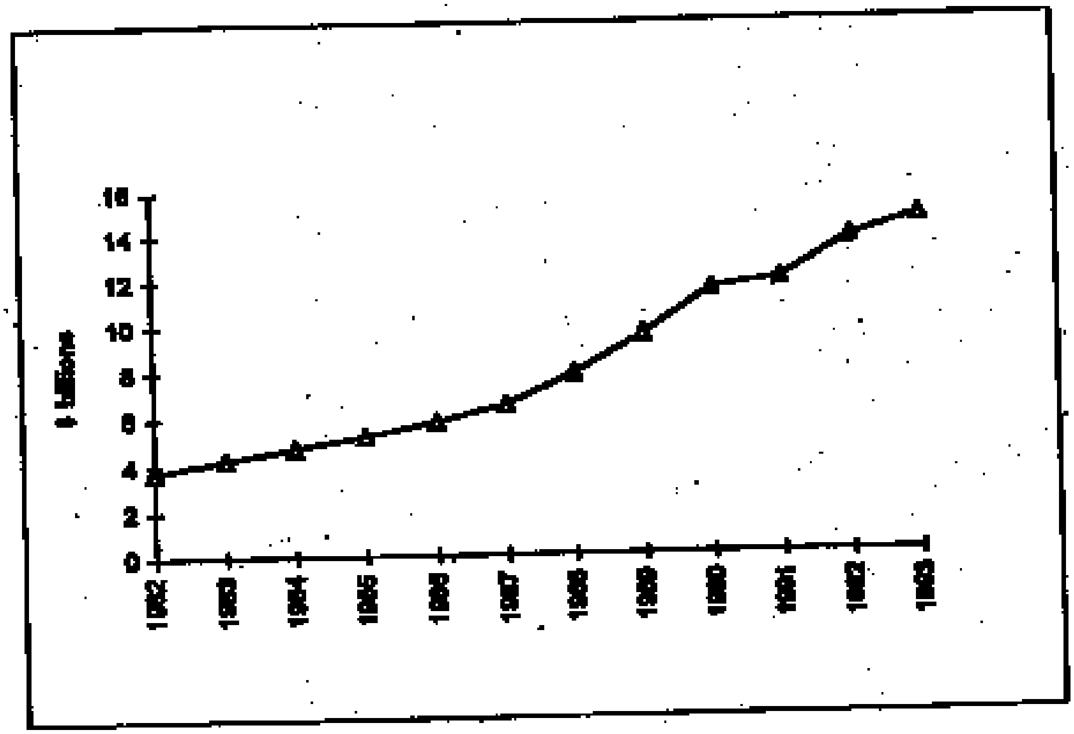

FIG. 7: SHARE OF US PATENTS GRANTED TO FOREIGN INVENTORS (1973-93)

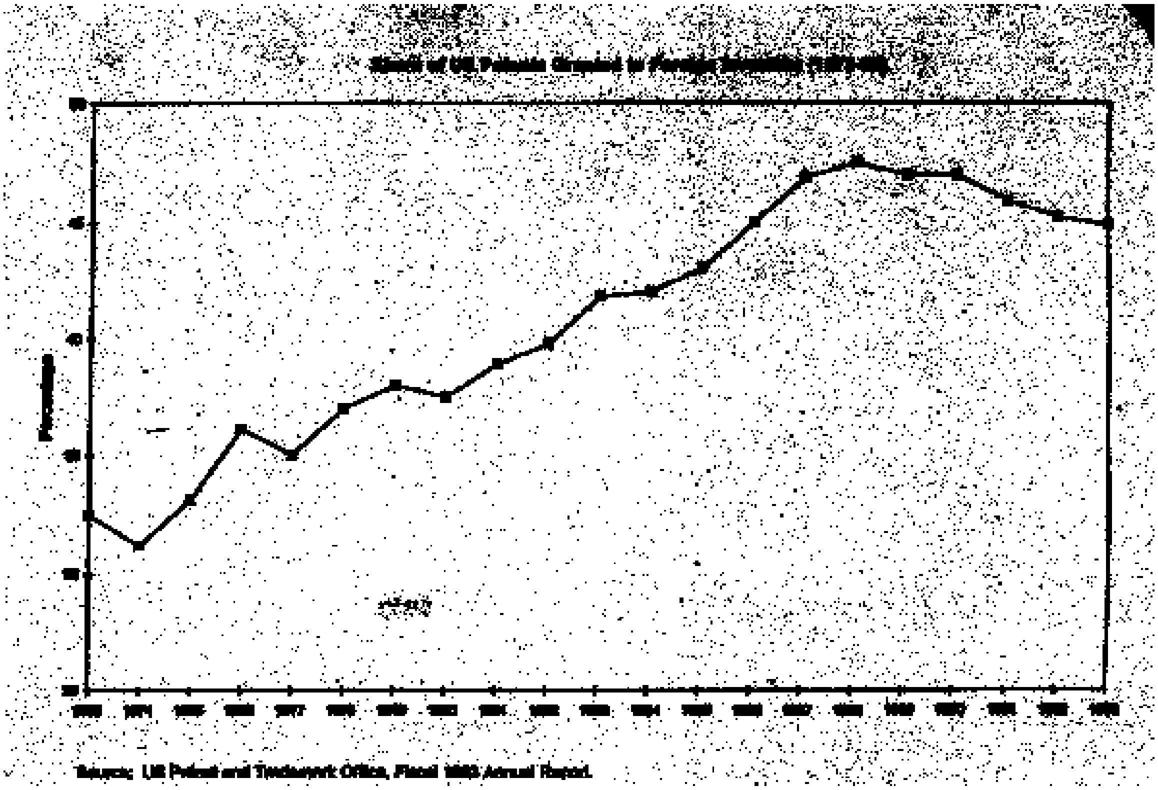

FIG. 8: NATIONAL PATTERNS OF R&D RESOURCES: 1994: Source of funds for university and college R&D performance [LINK TO: HTTP://WWW.NSF.GOV/SBE/SRS/S2194/S2194051.HTM]

FIG. 9: INVENTION DISCLOSURES, PATENT APPLICATIONS, GRANTS, AND LICENCES. UNIVERSITY OF CALIFORNIA 1975-88

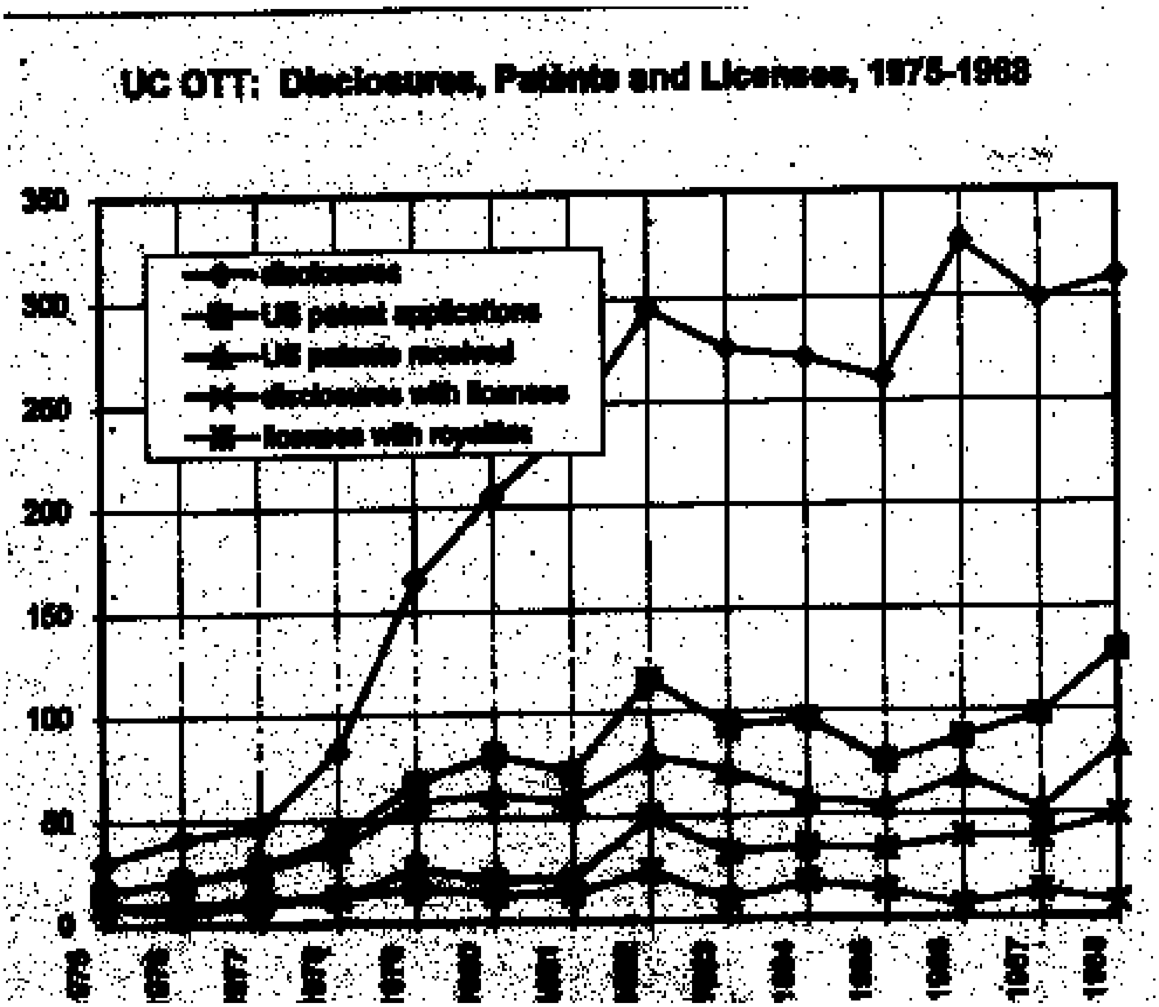

FIG. 10: INVENTION DISCLOSURES BY TECHNOLOGY CLASS, UNIVERSITY OF CALIFORNIA. 1975-88