Securing Australia's Future - Project 9
Translating research for economic and social benefit: country comparisons

United States of America

Selected U.S. Measures to Promote the Transfer and Commercialisation of Public Sector Research

Dr David Roessner
Senior Fellow, Center for Science, Technology, and Economic Development, SRI International
Professor Emeritus of Public Policy, Georgia Institute of Technology

Suggested Citation
Roessner, D (2015). *Selected U.S. Measures to Promote the Transfer and Commercialisation of Public Sector Research.* Report for Securing Australia's Future Project *"Translating research for economic and social benefit: country comparisons"* on behalf of the Australian Council of Learned Academies, www.acola.org.au.

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Foreword

This report is one of a number of country-specific studies prepared as input to Project 9 of the Securing Australia's Future Program. The report describes and analyses five measures, initiated and implemented successfully in the United States, that have contributed significantly to the transfer and commercialisation of the results of publicly funded research. The measures I selected, in consultation with the Australian Council of Learned Academies, include both federal government programs and state-supported organisations, whose primary goals include the transfer and commercialisation of publicly funded research. I had several criteria in mind in selecting candidate measures:

- the measure's longevity and size of scale or impact;
- my personal knowledge of the measure's history, features, and the literature describing and assessing its effectiveness;
- existence of sufficient publicly accessible documentation on the measure to ensure that ACOLA experts could address with some confidence its applicability to the Australian context.

The five measures chosen are:

1. The Bayh-Dole Act of 1980,
2. The National Science Foundation's Engineering Research Centers Program,
3. Cooperative Research and Development Agreements between federal research laboratories and industry,
4. The Small Business Technology Transfer Program,
5. Technology Based Economic Development organisations in the U.S. states.

Following an overview of U.S. efforts to promote the transfer and commercialisation of federally funded R&D (Chapter I), are five chapters, each devoted to one of the measures listed above. Included in each chapter are the origins of the measure; its provisions or features; empirical evidence of its activities, outputs, and impacts, and descriptions of how its effectiveness and impact have been measured. Each chapter identifies key issues involving the measure's rationale, goals, implementation, and barriers or problems encountered.

A final chapter summarises key issues that are for the most part shared by all five measures, and thus continue to be the target of efforts to improve their effectiveness. I would guess that in most cases, applicability of similar measures to the Australian context would, in general, encounter similar key issues. I am not sufficiently familiar with Australian government rules and regulations, legislation, or the specifics of university and business cultures to offer much guidance beyond identifying some of these likely issues. So I leave the truly difficult role of assessing in detail the applicability of "foreign" measures to Project 9's Expert Working Group.

David Roessner
July 2015

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1 Overview of U.S. efforts to promote utilisation of federally-funded R&D

1.1 Prehistory: 1914–1958

In the United States, government policies related to technology transfer of federally funded R&D fall roughly into four historical eras that this author has labelled *prehistory* (1914–1958), *technology push* (1958–1980), *demand pull* (1980–1986), and *collaboration* (1986–present). The beginning of significant governmental concern with technology transfer and use of publicly funded research was marked by passage of the Smith-Lever Act of 1914, which created the Cooperative Extension Service (CES) in the U.S. Department of Agriculture. The Act provided federal grants to states for a growing "extension" system that provided more effective means of transmitting research results originating in state land-grant colleges (research supported largely by the Agriculture Department) via county extension agents to individual farmers (Rogers, Eveland, and Bean, 1976). The cooperative aspect of the Service involved cooperation, and financial support, from all three levels of government in the federal system. The most important aspect of the extension system was that it involved two-way exchange of information among numerous participants who were closely associated both geographically and culturally. Problems requiring research were identified by farmers and passed through the system to research managers; the managers established priorities and funded research whose results were translated into the language of farmers by county agents. Agents not only translated research results into practical guidelines, they also demonstrated the payoffs from the new seeds, techniques, and fertilizers by using them in their own fields.

The extension system in agriculture was extremely labour-intensive, and thus expensive, but it was also highly effective. Agricultural productivity shot upward through the first half of the twentieth century, largely as a consequence of the CES. As noted later in this chapter, the language of extension and various of its elements have been injected into numerous government efforts to disseminate research-based knowledge and technology, yet none has succeeded to a degree approaching that of the CES. An analysis of the CES and of federal government efforts (primarily in the 1960s and 1970s) to replicate its success in other fields such as education, vocational rehabilitation, family planning in developing nations, and space research identified eight main elements of the extension model:

- a critical mass of new technology
- a research sub-system oriented to utilisation
- a high degree of user control over the research utilisation system
- structural linkages among the research utilisation system's components
- a high degree of client contact by the linking sub-system
- a "spannable" social distance across each interface between components in the system
- evolution as a complete system
- a high degree of control by the system over its environment (Rogers, Eveland, and Bean, 1976: 122–3).

In every case, the inability to replicate the success of agricultural extension can be attributed largely to the failure to replicate one or more of these eight key features in the new setting. Until the Soviet Union launched sputnik in 1957, however, agricultural extension remained virtually the sole example of significant government activity to promote technology transfer.

1.2 Technology push: 1958–1980

The National Aeronautics and Space Act of 1958 created NASA and charged the agency to "provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."[1] In 1962, in partial response to this legislative mandate, NASA created a Technology Utilisation Office whose specific objectives were to encourage additional uses of the knowledge gained from NASA-supported R&D, shorten the time required for new knowledge to be used in the marketplace, and facilitate the movement of new knowledge across organisational and other boundaries. In the roughly 20 years following initiation of NASA's technology utilisation activities, nearly all the major federal R&D agencies created at least one significant technology transfer or knowledge utilisation program.

As the size of the federal investment in research and technology became more visible, programs were created to ensure that maximum benefits would be derived, and studies and evaluations sought to determine how these programs should be designed and operated. The programs and their related literatures were variously labelled as technology transfer, research utilisation, knowledge utilisation, and Scientific and Technical Information (STI) dissemination. Information dissemination and technology transfer programs were created in the fields representing the primary missions of virtually all major federal agencies that supported or conducted research. Some of these programs emphasised "spinoff," the transfer of technology and research results to users other than those for whom the research was originally conducted (e.g., NASA and the Department of Defense), whereas others emphasized "research utilisation," the transfer of research results to the agency's primary constituents or clients (e.g., the National Science Foundation, the National Institutes of Health, the Department of Transportation, the Department of Justice). In the mid-1970s, perhaps the apex of the "technology-push" era, several annual editions of the *Directory of Federal Technology Transfer* described the organisation and operations of scores of these programs. These directories were catalogues of technology transfer, alerting readers to the kinds of information available from federal agencies and informing them about how to gain access to the information.

During the technology push era, federal R&D agencies were considered by Congress and most administrators to be the repositories of vast amounts of information and technology that could, if matched to appropriate problems or users, help justify the public investment in R&D. The federal government was assumed to be holding thousands of valuable patents or patentable ideas in its research laboratories. Following the landing on the moon in 1969, members of Congress asked, "If we can go to the moon, why can't we . . .," substituting their favourite social or economic problem in the second phrase. The 1960s and 1970s were the decades of the Defense Documentation Center; NASA Technology Briefs; the National Technical Information Service; the Educational Resources Information Center; National Clearinghouses for Alcohol Information, Drug Abuse Information, and Mental Health Information; and other huge, centralized, computerised research data bases.

The State Technical Services program (STS), initiated in 1965 in the U.S. Department of Commerce, exemplified many of the assumptions that characterised the technology push era.[2]

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[1] NASA legislative history can be found at http://www.hq.nasa.gov/pao/History/aeronaut.html

[2] This description on the State Technical Services program draws heavily upon Roessner, 1989.

The program's objective was to upgrade "lagging" industries by increasing their use of advanced technology, thereby increasing employment in these industries and enhancing their competitive position internationally. Designated state agencies, usually land-grant colleges, would submit proposals to the Commerce Department, which would approve and fund them on a 50-50 matching basis. Projects would include teaching, technical assistance, and information dissemination, with the primary clients intended to be small business.[3] The underlying assumption was that there was plenty of existing technology that could be used to promote economic development, and the government's proper role was to help make these available to industry. Despite a favourable program evaluation conducted in 1969, in the following year the Commerce Department eliminated the program as part of a departmental reorganisation. At this time, Congress held a series of hearings on the technology transfer activities of the Commerce Department. Among the points raised at the hearings was that STS, constrained to an information and technical assistance role, could not offer the kind of help its clients needed. Efforts by state and university officials to save STS or revive it were overwhelmed by resistance from other bureaus within the Commerce Department, lack of support from the Office of Management and Budget, and opposition of a powerful, well-placed member of Congress.

As it turns out, the findings of the literatures evaluating the technology transfer/knowledge utilisation programs of the 1960s and 1970s are largely convergent or complementary, rendering them all the more compelling (Ballard, et al., 1989; Doctors, 1969; Doctors, 1971; Gruber and Marquis, 1969; Havelock, 1969; Hough, 1975; Rogers and Shoemaker, 1971; U.S. Department of HEW, 1971; U.S. National Science Foundation, 1975). Among the several lessons learned from this literature is that passive/reactive technology transfer mechanisms and programs are generally less effective than active/collaborative ones. Successful transfer of knowledge and technology is based on relationships between suppliers and users characterised by trust and personal relations developed over time. Further, technology transfer is expensive and time-consuming, because it tends to require considerable adaptation and/or further development by the user. In addition, because of the need for users to further develop or adapt technology, successful transfer is more likely when the user possesses substantial technical capabilities. If the transfer of information and technology is to be effective, clients and users should be involved early in the process of research or technology development activity by helping to select and package information to be transferred, to set research objectives and priorities, and even to be involved in the knowledge or technology development process itself. Effective information and technology transfer occurs when users are closely involved with producers in an ongoing personal relationship; in other words, knowledge use and production are inherently linked. That these lessons closely match the elements of the agricultural extension model is obviously not a coincidence.

The frustrations and difficulties experienced by federal technology transfer programs during the technology-push era paved the way for more collaborative arrangements between sources of knowledge and technology and potential users. The decade of the 1980s saw a series of legislative steps that created the legal bases for such arrangements. But before significant improvements in technology transfer from governmental agencies to other institutional settings

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[3] It is interesting to note that the program carefully avoided research projects that were in any way related to product development, and the federal government's role, beyond funding support, was intended to be a minor one. In both these design features, STS sought to avoid the criticisms from both industry and Congress that sank its predecessor, the Civilian Industrial Technology Program.

could occur, major changes were required in the way intellectual property (IP) rights were assigned to the results of government-supported R&D.

1.3 Intellectual property rights and the shift from technology push to demand pull

Until 1980 the prevailing federal policy toward ownership of intellectual property, whether based in legislative mandate or in practice, was that the government should retain ownership of intellectual property if the taxpayer had paid for the research that underlay it. Private firms could obtain nonexclusive licenses to federal patents, but few chose to do so. However, some individual agencies had flexibility. In the 1958 Space Act, for example, inventions made under contract to NASA were the exclusive property of the government, but the NASA Administrator could waive all or part of these rights as long as the government retained a nonexclusive, royalty-free license to use the invention for government purposes. The Energy Research and Development Administration, created following the 1973 energy crisis, like NASA was authorized to grant exclusive licenses "Where a determination has been made that exclusive licensing is a reasonable and necessary incentive to call forth risk capital to bring an invention to the point of commercial application and the desired commercial application is not likely to be achieved expeditiously under a nonexclusive license." (*Directory of Federal Technology Transfer,* 1977: 41).

But these were exceptions. Typically agencies could market and license government inventions on a nonexclusive basis only. The prevailing solution to lagging demand was not greater flexibility, but admonitions to try harder. In his 1972 Science and Technology Message to Congress, President Nixon directed his science advisor and the Secretary of Commerce to "develop plans for a new, systematic effort to promote actively the licensing of Government-owned patents and to obtain domestic and foreign patent protection for technology owned by the United States Government in order to promote its transfer into the civilian economy." (*Directory*, 1977: 22). Shortly thereafter the National Technical Information Service's Patent Program was charged with promoting the licensing of all government-owned inventions, which proved to be a formidable challenge indeed. By 1980 it was clear that a major shift in government intellectual property policy was required if any significant transfer of government-owned patents to organisations capable of commercialising them was to take place.

1.4 Demand pull: 1980–1986[4]

Although six years is rather short to be termed an "era," the legislative initiatives that bounded this period represented remarkable departures from the assumptions that underlay the technology transfer policies and practices that preceded them. The year 1980 was a milestone in the changing public policies toward technology transfer because it marked passage by Congress of two significant laws: the Stevenson-Wydler Technology Innovation Act and the University and Small Business Patent Procedure Act (the Bayh-Dole Act). Among the Stevenson-Wydler Act's several provisions was a mandate for the National Bureau of Standards (now the National Institute of Standards and Technology, or NIST) to create a set of Centres for Industrial Technology. These centres would have been established at universities and other non-profit institutions, with financial support from government funds. There was no provision for

[4] The descriptions and discussion of technology transfer legislation in this section draw heavily on Hill and Roessner, 1998.

industrial cost-sharing, but the act expressed the intention that the centres should eventually become self-sufficient as an explicit goal. This program was not acceptable to the new Reagan Administration that took office in 1981, however, and this provision was never implemented.

The most important provision of Stevenson-Wydler gave permission to all federal laboratories owned and operated by the government to engage in technology transfer to industry. It required the larger agencies to create Offices of Research and Technology Applications that would facilitate the transfer of technology to industry and the states. Prior to the adoption of this act and despite the flexibility available to agency administrators, many federal laboratories operated under the presumption that it was illegal for them to assist industry or to transfer government-owned technology to private companies.

The Stevenson-Wydler Act also provided the legislative authority for the National Science Foundation's (NSF) Industry-University Cooperative Research Centers Program (IUCRC).[5] For these centres, funds were awarded to universities by NSF on a competitive, peer-reviewed basis, provided that centres raised additional funds from industry. NSF built on the IUCRC experience in establishing its more ambitious program of Engineering Research Centers (ERCs) in 1985. Both of these programs are discussed in greater detail later in this chapter, and Chapter III of this report is devoted to the ERC program.

By the early 1980s, it began to be more widely realised that in commercial terms, “that which belongs to everyone creates value for no-one.” Proponents of change pointed out that fewer than 5% of all government-owned patents were ever licensed for commercial purposes, with the implication being that potentially valuable government-owned technology was not being exploited in such as way as to maximize the return to society for its investment in producing that technology. Senior officials in the Department of Commerce and various private interest groups proposed changing the fundamental patent law to make it possible to give exclusive licenses for use of government patents to private interests and to give government employees[6] and contractors the right to hold title to inventions made with public funding.

As a consequence of this campaign, a series of changes were made in U.S. patent law during the 1980s. The first major change came with passage in 1980 of the Bayh-Dole Act, discussed in detail in the next chapter. This law permitted patent titles to be held by government R&D contractors if the contractor was a university, small business, or not-for-profit institution. The government retained the right to a royalty-free license to such patents for its own use, with title reverting to the government if the contractor did not commercialize the patent within a reasonable time. In 1983, President Reagan issued an order extending the terms of Bayh-Dole to all government contractors except for those specifically prohibited from its provisions by existing law.

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[5] NSF had begun the IUCRC program in the early 1970s under its own broad authority, but the Act provided specific legislative approval for this initiative.

[6] In the United States, employers have typically required all their employees to agree as a condition of employment that they transfer ownership of inventions they make to their employers, usually for a nominal payment of one dollar or so. When Congress was considering changing the patent law to allow government employees to retain title, a number of employer groups opposed this provision because they were concerned it would create a precedent for private sector employees to demand the same rights.

Amendments to the Patent and Trademark Laws in 1983 allowed government-owned, contractor-operated laboratories (GOCOs), except certain of those controlled by the Department of Energy (DOE), to decide on their own how to award licenses for the transfer of technology they developed internally. The Act also allowed GOCO labs to retain certain royalties earned on their patents to use in funding further R&D and rewarding employee-inventors, and for education. It also allowed private firms, regardless of size, to obtain exclusive licenses to exploit government-owned patents for the full seventeen year life of the patent, rather than for the much shorter period of time specified under Bayh-Dole.

These legislative changes reflected increased understanding that at least part of the problem in federal technology transfer was insufficient incentive for private firms to commercialize technology or patented concepts owned by government. Although the laws changed the legal environment for technology transfer from government to industry, in some quarters prevailing practice was slow to change. Compared with government labs, universities moved rapidly to take advantage of the new situation by creating offices of technology transfer or intellectual property that sought to identify commercially promising ideas generated in academic research labs. But most of the huge laboratories of the Energy Department were not covered by the provisions of the new laws. Other government-owned labs found that, even with the new legal setting, private firms were reluctant to negotiate with government over intellectual property rights. One major impediment, real or imagined, was the Freedom of Information Act, which allowed private parties access to virtually all unclassified government documents, thus potentially undermining a firm's ability to keep information about the licensed technology proprietary. Also, all parties to technology transfer negotiations learned what NASA learned from its Technology Utilisation program: ideas and technologies generated by government-supported research typically were a long way from being ripe for commercial development. These realisations led to yet another series of laws governing technology transfer, laws that sought to promote a more collaborative mode of interaction between government-supported research institutions and private firms.

1.5 Collaboration: 1986–present[7]

The Federal Technology Transfer Act of 1986 (FTTA), an amendment to the Stevenson-Wydler Act of 1980, made it a formal mission of all federal laboratories to transfer technology to industry. It also established the legislative authority for the Cooperative Research and Development Agreement, or "CRADA," to be used by all federal R&D agencies to conduct R&D of mutual interest jointly with firms and consortia of firms. In the original CRADA, no funds were to be exchanged between the federal laboratory and industry; instead, both were to support their own efforts, but they could engage in joint agenda setting, could divide the specific research tasks among themselves, and could share the results with each other. CRADAs were intended to be real partnerships, including an expectation that all the industrial partners would contribute not just money but also technical effort to the collaboration.

The FTTA also made several important changes in the law affecting disposition of patents developed under federal R&D funding. The Act permitted firms to retain title to inventions resulting from R&D conducted under CRADAs pursuant to the Act, with the government

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[7] Once again, this section draws upon Hill and Roessner, 1997.

maintaining its usual right to a royalty-free license. Under the Act, federal laboratories (with the exception of DOE GOCOs) were permitted to retain royalty income at the lab when they license patents they own to the private sector, up to certain specified limits. For technology transferred to the private sector that results in royalty payments to a federal laboratory, the Act required that 15% of the royalties go to the individual employee-inventor. FTTA also enabled federal agencies to share any royalties that might accrue to licensed federal technologies with the laboratory employees who were the inventors of the licensed technology. It also allowed federal laboratory employees to retain title to inventions that the government did not seek to patent and to exploit them for private gain outside the laboratory. Under a new law passed in 1989, the National Competitiveness Technology Transfer Act, the GOCOs of DOE were also authorized to participate in CRADAs.

In 1987 President Reagan issued Executive Order 12591, which directed all federal agencies to extend the provisions of the patent laws described above, as well as those of the Federal Technology Transfer Act, to all contractors and to allow all of them, regardless of size or form of organisation, to retain title to federally-funded inventions except where expressly prohibited by existing law to do so. Thus, with the exception of certain DOE laboratory activities, by the end of the 1980s U.S. policy on the disposition of federally-funded intellectual property had undergone a complete change in philosophy, from the view that all publicly-funded technology should belong to the people at large, to the view that the public interest was best served by transferring ownership of such property to private individuals who would be better placed to exploit its benefits for all.

In the current era, collaborations or other forms of cooperative research arrangements are regarded as the most productive and effective forms of interaction between sources and potential users of knowledge and technology. “Technology transfer” has given way to “knowledge exchange” or “information exchange” as more inclusive phrases that portray more accurately the most effective interactions between research institutions (Bozeman, 2000). Technology transfer and technical assistance increasingly are applied to interactions between institutions with greater disparities in their technical capabilities, such as between federal laboratories, universities, and state industrial modernisation programs on the one hand, and small manufacturers on the other. The following sections provide an overview of collaborative and cooperative arrangements between, first, federal laboratories and industry and, second, universities and industry.

1.6 Federal laboratory-industry interaction

The "federal laboratories" consist of approximately 700 intramural and contractor-operated R&D institutions operated by, or for, federal agencies. In 2011 they spent nearly $18 billion of the total federal R&D budget of $50 billion and employ approximately 100,000 scientists and engineers (National Science Board, 2014). They range in size from the giant labs of the National Institutes of Health, NASA, and DOE to tiny defense and agriculture stations with no more than a dozen employees. There are two basic classifications of federal laboratories: Government-owned, government-operated labs (GOGOs) owned and operated primarily by the Department of Defense, NIST, NASA, and the National Institutes of Health; and GOCOs owned primarily by the Department of Energy. GOCOs are operated in some cases by universities (e.g., Argonne, Lawrence Berkeley, Jet Propulsion Laboratory) and in others by private firms (Oak Ridge, Sandia). As noted in the previous section, GOGOs and GOCOs now operate under the same set of rules concerning technology transfer. About half the $18 billion expended at all federal labs is military-related, and a comparable proportion of the DOE labs' total budget is military-related. Although these numbers are the subject of some disagreement, a large segment of the United States' scientific and technological capability is, in the view of some policymakers, potentially available to serve different goals—that is, “dual use” (Branscomb, 1993; Roessner, 1993).

Federal laboratories are under extreme pressure to contribute to U.S. industrial competitiveness via technology transfer. The CRADA has become the most visible instrument of transfer as well as the metric by which many labs’ success is measured. (CRADAs are detailed in Chapter IV of this report.) Congressional legislation and executive orders, budget setasides for CRADAs, and threats to survival owing to reductions in the strategic military threat to the U.S. are all manifestations of this pressure. The labs thus seek to maximize the use of their publicly-funded R&D as part of a strategy for surviving in a rapidly changing environment. They, like the universities, set up offices devoted specifically to industrial relations, intellectual property negotiations, and technology transfer. It is beyond the scope of this chapter to describe these laboratory-specific organisations, but a number of other organisations with larger responsibilities have been created to faciliate the technology transfer process. Some are agency-specific, such as NASA’s Regional Technology Transfer Centers, whereas others are national in scope, such as the National Technology Transfer Center (NTTC) in Wheeling, West Virginia and the Federal Laboratory Consortium for Technology Transfer (FLC).

The National Technology Transfer Center was established by Congress in 1990 with primary funding from NASA, but with additional support from the Ballistic Missile Defense Organisation, the U.S. Navy, and other federal agencies. It resembles a high-tech version of the technology transfer agencies of the 1960s and 1970s in that people seeking technological solutions to problems can call an 800 number and, through “technology access agents,” obtain contact information about the specific laboratories and people most likely to provide assistance. Via the Internet, interested parties can also browse through listings of new technologies available for licensing and commercialisation (www.nttc.edu).

NTTC is linked to NASA's Regional Technology Transfer Centers (RTTCs), which are funded by NASA and aligned with the six Federal Laboratory Consortium regions (http://www.ctech.org/rttc.html). Since their inception in 1992, the RTTCs have established regional ties to more than 70 state and local organisations, creating a national web intended to enable U.S. companies to learn of, evaluate, and acquire NASA and other federally-funded technologies for commercial exploitation.

The Federal Laboratory Consortium for Technology Transfer (FLC) was organized in 1974 and formally chartered by the FTTA to promote and to strengthen technology transfer nationwide (http://www.fedlabs.org/). More than 600 federal laboratories and centres and their parent departments and agencies are FLC members. The FLC serves as a point of entry to federal laboratory expertise and technology. Various networks have been established to facilitate the transfer of technology to state and local governments. The goal of these networks is to assist and expedite the use of federal science and technology in addressing state and local government needs. The FLC works to keep its members aware of these and other networks that seek to increase the use of federally developed technologies.

Studies of federal lab-industry interaction have yielded a number of interesting results useful for both policy and practice. Although there have been numerous studies of the process from the laboratory perspective and many case studies, only a few relatively large-scale studies have been done that attempt to assess the consequences, costs, and benefits for industrial participants of federal lab-industry interactions (Berman, 1994; Bozeman, 2000; Bozeman, 2013; Bozeman, Papadakis, and Coker, 1995; Geisler and Clements, 1995; Kassicieh and Radosevich, 1994; Roessner and Bean, 1990 and 1994; Roessner, 1993). Among the more significant results of these studies are the following:

- Large, research-intensive firms consider “idea” transfer from federal labs to have greater payoff than more tangible interactions such as those involving licensed technology. Instead, they seek access to lab expertise and facilities. They want to share research risks and leverage their investment in research (Roessner and Bean, 1994: Bozeman, Papadakis and Coker, 1995; Geisler and Clements, 1995).

- Effective interactions are wide-ranging, company-initiated, and tend to originate from day-to-day professional communication. Fruitful collaborative work comes only after considerable personal interaction. Companies report that the factors critical to success or failure of lab-industry interactions are personal contact, management support (especially middle management), and clarification of rights to intellectual property (Roessner and Bean, 1994; Geisler and Clements, 1995).

- Most interactions do not result in commercial products. The benefits reported from interactions that do not result in products are highly skewed, with a few resulting in very large benefit:cost ratios, but the typical interaction does not yield significant net benefits. For interactions that result in products, the benefits are uniformly modest but positive: about $40,000 in a typical case (Bozeman, Papadakis, and Coker, 1995).

- What makes labs and companies interact may not be the factors that influence the success of the interaction in the form of technology transfer and commercialisation. Companies may join labs to gain access to resources and to enhance their R&D, but the success of the interaction does not depend on accomplishing these objectives. Rather, it depends on individual and organisational variables such as management support and attributes and attitudes that favor industrially-oriented objectives (Geisler and Clements, 1995).

Supplementing these results, a carefully-done study of five CRADAs (Ham and Mowery, 1998) also found that the primary benefits from CRADAs were generic and longer-term, such as design principles, engineering techniques, and testing methods that enhanced their overall technical capabilities. The study also concluded that CRADAs, with their emphasis on intellectual property rights, may be the wrong mechanism for most laboratory-industry collaborations, for which property rights are of secondary importance. Finally, consistent with numerous results from other studies of research collaboration, the authors of these CRADA case studies concluded that firms without inhouse technical expertise, or the willingness to devote inhouse resources to the collaboration; are unlikely to benefit commercially from such collaborations. A more detailed treatment of CRADAs appears in Chapter IV of this report.

1.7 University-industry technology transfer

Industrial funding of university research in the U.S. rose from $61 million in 1970, to $235 million in 1980, and to $3.2 billion currently. During the same period, the federal government's share of support for total university research dropped from two-thirds to 63% currently. Thus, industry's relative contribution to university research has risen dramatically, although it still accounts for just 5% of the total.[8] The number of university-industry linkages is increasing dramatically. There are now well over 1000 university-industry research centers (UIRC), more than half of which were established since 1980 (Cohen, Florida, and Goe, 1992). A mix of factors has influenced this trend: legislative initiatives such as the Bayh-Dole Act, federal cutbacks in nondefense, university research in the 1980s, financial constraints in private corporate R&D (leading firms to outsource some R&D or seek leverage for R&D expenditures), and competitive pressures from abroad. This change has been characterised as a new institutional stance: "active technology transfer," according to which universities search their laboratories for commercialisable ideas and then seek to license technology so identified to a appropriate business entities. Universities are encouraging faculty members to identify potentially commercialisable ideas and file invention disclosures with their Office of Technology Licensing or other appropriate unit, and to undertake research that might produce something patentable. They seek to license patents already owned by the university; and in some cases take equity positions with new firms formed by members of the research faculty. Although several of the forces that stimulated these changes have eased in the past few years (e.g., partial restoration of federal cutbacks in university research; easing of competitive pressures from abroad), the question is not whether research universities will retreat from their newly-acquired, aggressive stance toward technology transfer, but how much further they will go.

Although the intellectual property aspects of university-industry relationships have assumed salience recently in policy debates about the appropriate role of universities in technology commercialisation, university interest in applied research in areas of interest to industry is not new. During the latter part of the 19th century and well into the 20th, much university research was actually oriented toward the economic interests of the states in which they resided (and from which they drew their primary support). A small number of elite, private institutions struggled to increase the amount of basic research done on campus, as their counterparts in Europe had been doing for some time. But it was not until the period following World War II that American research universities assumed the role as the primary performers of the nation's basic research (Geiger, 1986; Rosenberg and Nelson, 1994; Mowery and Rosenberg, 1989).

The UIRC has become the dominant organisational arrangement though which industry-university research interaction occurs, but within and beyond that form there is a wide variety of mechanisms through which ideas and technology are exchanged. Some of them are oriented toward accomplishing the one-way, hardware focused relationships characteristic of traditional technology transfer, whereas others are highly collaborative in nature, more closely resembling a partnership. Tornatsky has identified five types of university-industry linkage mechanisms (Tornatsky: 1997):

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[8] In 1972, business support for academic R&D amounted to less that 3% of total support. This grew to a maximum of about 7 percent during the late 1980s through 2000, but has declined since that time to about 5% (US National Science Board, 2014).

- Industry-sponsored contract research, in which a single company contracts with a university for the performance of research. Usually such contracts are limited to no more than a year or two and include formal arrangements for the assignment of intellectual property rights.

- Company-sponsored research consortia, in which a group of companies enters into a formal arrangement with a university (a UIRC, by definition) for the conduct of research in an area of interest to all involved. Companies contribute membership fees that are pooled and used for research and/or the support of students, and as a consequence have some degree of influence over research project selection. In some consortia the research is sufficiently fundamental that issues of intellectual property ownership do not arise; in others, patents resulting from the research are licensed to consortium members on a non-exclusive basis; in still others, unique provisions are drawn up at the time the consortium is formed.

- Consulting arrangements. Companies engage faculty as consultants to address specific, often proprietary technical problems. Such faculty may or may not be a part of a UIRC with which the company is involved, but working within such a centre is an obvious way in which faculty and companies can be come mutually acquainted and agree to consultantships "on the side." Many research universities encourage consulting by allowing faculty members up to one day a week to do so.

- Licensing university-developed technology. University offices of technology licensing and transfer usually have multiple roles: encouraging research faculty to file invention disclosures, working with faculty to patent promising ideas and market them to potential licensees, and marketing existing, university-owned patents to potential licensees. The latter is sometimes referred to as "off-the-shelf" technology transfer.

- Joint development and commercialisation of technology. Although relatively rare, active university encouragement of, and participation in, new start-up companies formed by faculty members is increasing. In some cases this occurs because intellectual property rights cannot easily be established, in others the university decides that greater payoff in licensing fees or in regional economic development warrants the increased overhead costs and risks involved.

The following two sections of this chapter summarise briefly the results of selected studies covering two of these transfer mechanisms, consortia and licensing via university technology transfer offices. Very little systematic evaluation has been done on contract research or consulting, although some of the findings and issues relevant to consortia and licensing are pertinent to these as well.

1.8 University-based industry consortia

Because their formation has been the objective of federal programs, particularly those of the National Science Foundation, university-based research consortia have been the subject of a number of empirical investigations. Two programs stand out, at least with respect to the subject of this chapter: the Industry-University Cooperative Research Centers program (IUCRC) and the Engineering Research Centers (ERC).[9] The IUCRC program was initiated on an experimental

[9] Information about the ERCs and the IUCRCs can be found at http://www.eng.nsf.gov/eec/erc.htm and

basis in the early 1970s, and its apparent success led to full implementation and expansion of the program in the 1980s (Gray, et al., 1986). The goals of the IUCRC program are to promote research of mutual interest to industry, universities, and government; contribute to the U.S. research infrastructure base, and enhance the intellectual capacity of the engineering workforce through the integration of research and education. There are now approximately 55 IUCRCs in universities all around the country. Seven hundred firms are members of these consortia (including a small number of government agencies and nonprofit organisations), with full members contributing $25,000 annually to a centre. NSF provides seed money to help establish these centres, then supports the administrative and other costs with annual payments of $50,000 for a period of five years. Centres can apply for a second five-year award, after which centres are supposed to be self-sustaining. Centres are required to obtain at least $300,000 annually in cash from membership fees. With the host university contributing required cost-sharing, and with additional grants and contracts run through the centre, a typical IUCRC's annual budget is in the range of $1-2 million. Total budgets of all IUCRCs is about $75 million, with NSF contributing 7%, other federal sources 28%, industry 45%, states 13%, and universities the remaining 8% (Gray and Walters, 1997).

The Engineering Research Centers program represents a more ambitious effort to stimulate the formation of university-based industrial consortia while at the same time seeking to change the context of engineering research and education. Although one of the key initial political rationales for creation of ERCs, increased U.S. industrial competitiveness, currently is of lesser concern, other objectives remain salient: promote interdisciplinary research and teaching, foster a team approach to research, and introduce students to industry needs and perspectives. To encourage the conduct of longer-term, high-risk research and the formation of an enduring change in the institutional setting of engineering research and education, NSF supports each ERC for eleven years (subject to intensive reviews every three years) at a level averaging $2 million annually for each centre. As with IUCRC's, ERCs are supported by a combination of NSF core support, other federal agency research grants and contracts, state and/or university money, and industry membership fees, contracts, and in-kind contributions. A typical ERC has 30 industrial members, with full members contributing an average of $20,000 in membership fees. But the average annual budget of an ERC is $10 million, representing support from other parties as well.

Because existing ERCs and IUCRCs are the winners of a highly competitive peer review process and, in the case of ERCs, enjoy the stability that up to 11 years of government support offers, arguably their technical work is more likely to be at the cutting edge of knowledge and, potentially, to be of higher-than-average quality. NSF centres are located at the country's major research universities, and together their more than 700 industrial members include many of the nation's largest research-intensive corporations. The annual budgets of centres representing both programs total more than $300 million. The NSF-sponsored consortia likely represent the cutting edge, technically and organisationally, of this form of university-industry research collaboration. Still, they differ in some ways from the larger group of UIRCs studied by Cohen, Florida and Goe (1992). NSF guidelines require that UICRC and ERC research be interdisciplinary and that ERCs bring a "systems approach" to engineering education. Companies involved in other types of UIRCs may not enjoy some of the benefits that NSF

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http://www.eng.nsf.gov/eec/i-ucrc.htm, respectively. A full treatment of the ERC program appears in Chapter III of this report.

centre participants acknowledge, such as the opportunity to interact with suppliers, customers, and competitors on neutral ground, and to hire graduates with exceptional sensitivity to industry needs. Despite these differences, the results of research on ERCs and IUCRCs reveal a number of important lessons for centre management and industry R&D directors (Bozeman, 2000; Gray, et al., 1986; Feller and Roessner, 1995; Roessner, et al., 1998; U.S. General Accounting Office, 1988; Ailes, et al. 1997):

- Firms are motivated to join university-based consortia primarily because they seek access to new ideas, access to technical know-how, exposure to new technologies, opportunities to keep abreast of university-based research, and access to expertise. Outcomes of this sort most frequently occur as a result of a firm's participation, and, generally speaking, outcomes of this sort are relatively highly valued when they occur. Although "hard" outcomes such as new products or technology licenses occur only rarely, they too are highly valued.

- Student hires are the outcome most highly valued by firms that are members of research consortia. There is considerable evidence supporting the view that the most effective method of technology transfer from university to industry is in the knowledge, training, and experience of graduating students.

- Payoffs to member companies from consortium membership are largely a function of the resources the companies expend, beyond the membership fees, in the form of staff time. The more intensive and extensive company participation in university research and training, the greater the benefit.

- The organisational penetration of the direct consequences for firms of consortium membership appears to be quite shallow. Typically, it is restricted one division, and even then only a handful of individuals typically have any direct knowledge of the firm's connection to the consortium or of the impacts of Centre activity on the firm.

- Company participation in university-based industry consortia is fragile. Not only is direct knowledge of centre activities and their direct consequences for the firm restricted in scope, but the "champions" of the university centre within the firm are vulnerable to changing divisional priorities, reorganisations, and budget stringencies, and personal career changes or reassignments can sever existing firm-Centre relationships.

1.9 Issues involving intellectual property rights

In both relative and absolute terms, university patenting has increased dramatically during the past 35 years, attesting to the likely influence of the Bayh-Dole Act (see Chapter II of this report) and to the changed climate in both universities and industry favoring closer interactions. In the late 1960s universities were granted an average of 200–300 US patents annually. By the early 1980s this had increased to 350–400 annually, rising rapidly to more than 1600 patents in 1993. Since that time, the number of patents granted continued to grow until 1998, flattened out for ten years, and then grew again rapidly until the present. About 5000 U.S. patents were awarded in 2012. Universities received 3% of total U.S. patents granted in 1993 compared with 1% in 1980. The number of universities granted patents grew equally rapidly during this period—30 universities received patents in 1965, 80 in 1980, and 165 in 1993. Although the number of universities receiving patents has continued to increase, most universities receive only a few annually, whereas the proportion of patents granted to the 100 universities with the largest R&D

expenditures grew from 80% in 1980 to 90% in 1993 (Henderson, Jaffe, and Trajtenberg, 1995; Geiger and Feller, 1995; Feller, 1997).

Prior to the changed climate in university patenting wrought by Bayh-Dole, an organisation known as the University Research Corporation contracted with most universities to handle patenting. The corporation, for a percentage of the royalties and fees paid by licensees, decided which ideas were worth patenting, prepared the filing, and marketed the patents. During the 1980s, most research universities established their own patenting and technology transfer offices. A key development in the formation and professionalisation of university technology transfer activities was the founding of the Association of University Technology Managers (AUTM).[10] In addition to serving as the professional association for university technology officers, providing them with professional identity, a journal, workshops, training programs, and other important infrastructure support resources, since 1991 AUTM has conducted annual surveys of U.S. universities, hospitals and research institutions. Although not necessarily fully representative of total licensing activity in these institutions, the data collected by AUTM provide valuable information on university licensing activity, costs and returns. The FY2013 survey, for example, yielded data from 170 U.S. universities. These universities reported that they expended $17 billion in sponsored research, filed 14,995 U.S. patents (mostly the result of previous research expenditures, of course), executed 5,198 licenses, and received over $2 billion in gross royalties (AUTM, 2007 and 2013).

Royalty payments as a proportion of total university research expenditures vary enormously across these institutions. The distribution is highly skewed, with only a few universities receiving significant income from royalties, especially if the overhead associated with operating a technology licensing office is taken into account. At individual universities with relatively large royalty incomes such as MIT, Berkeley, and Stanford, only a few patents account for the majority of royalty income (Feller, 1997). “Old hands” at university technology transfer such as Niels Reimers of Stanford and Lita Nelsen of MIT (former and current Directors, respectively, of technology licensing offices) argue that the primary purpose of their offices is not to maximize royalty income, but to develop productive research relationships with private firms that will lead to subsequent research contracts with them. These statements notwithstanding, many university technology transfer offices are evaluated by metrics such as the number of sponsored research dollars required to generate one dollar of royalty income (Tornatzky, Waugaman, and Bauman, 1997).

Most university technology transfer offices barely break even financially (Nelsen, 1998). Under pressure from their administrations and state legislatures to maximize payback to the university from the public investment in research, staff members attempt to negotiate the most financially favourable deal possible without causing the industry partner to withdraw from the negotiations. But universities seeking to maximize royalty income from their research can alienate the industry “customers” they wish to serve. Small firms can have difficulty obtaining bank financing or venture capital if the university insists upon retaining ownership of IP. Squeezing maximum dollars from university IP obviously can impair university-industry relations. This is another of the challenges facing university administrators as they struggle to respond constructively to a

[10] For details on AUTM and a wealth of information about university-based technology transfer, see http://www.crpc.rice.edu/autm/index.html.

myriad of internal and external changes, while preserving and nurturing two primary roles of the university in national life—education and knowledge creation.

1.10 Transfer and commercialisation of federally-funded R&D: a continuing challenge

The recent recession rekindled many public policy fires in federal and state governments, and stimulating innovative activity throughout the economy returned to the top of Presidential and Congressional agendas, at least to the extent that there was agreement on the job-creating effects of new technology. Some of these policy initiatives specifically targeted the transfer and commercialisation of federally-funded R&D. In early 2011, President Obama announced "Startup America," a White House initiative "to celebrate, inspire, and accelerate high-growth entrepreneurship throughout the nation."[11] One of the five objectives was to "Strengthen commercialisation of the about $148 billion in annual federally-funded research and development, which can generate innovative startups and entirely new industries." However, among the numerous activities and programs described in the Initiative, none specifically mentioned the commercialisation of federally-funded R&D. This apparent omission was corrected later in the year by a Presidential Memorandum: Accelerating Technology Transfer and Commercialisation of Federal Research in Support of High-Growth Businesses.[12] In this three-page Memorandum, the President directed that a number of actions be taken to "accelerate technology transfer and support private sector commercialisation." Excerpts from these directives follow:

- Agencies with Federal laboratories shall develop plans that establish performance goals to increase the number and pace of effective technology transfer and commercialisation activities in partnership with non federal entities, including private firms, research organisations, and nonprofit entities.
- The Interagency Workgroup on Technology Transfer, established pursuant to Executive Order 12591 of April 10, 1987, shall recommend to the Department of Commerce opportunities for improving technology transfer from Federal laboratories, including: (i) current technology transfer programs and standards for assessing the effectiveness of these programs; (ii) new or creative approaches to technology transfer that might serve as model programs for Federal laboratories; (iii) criteria to assess the effectiveness and impact on the Nation's economy of planned or future technology transfer efforts; and (iv) an assessment of cooperative research and development venture programs.
- Streamlining licensing procedures, improving public availability of federally owned inventions from across the Federal Government, and improving the executive branch's Small Business Innovation Research (SBIR) and Small Business Technology Transfer (SBTT) programs based on best practices will accelerate technology transfer from Federal laboratories and other facilities and spur entrepreneurship.
- Agencies must take steps to enhance successful technology innovation networks by fostering increased Federal laboratory engagement with external partners, including

[11] https://www.whitehouse.gov/startup-america-fact-sheet
[12] http://www.gpo.gov/fdsys/pkg/DCPD-201100803/content-detail.html

universities, industry consortia, economic development entities, and State and local governments.

The Memorandum also directs that agency plans for establishing performance goals for their efforts to increase the number and pace of their transfer and commercialisation activities by submitted to the Office of Management and Budget within 180 days (or by about mid-2013). OMB is charged with reviewing and monitoring implementation of the plans, in consultation with the Office of Science and Technology Policy in the White House and with the Department of Commerce. As of this writing, a number of agencies have prepared and submitted the required reports, but to this author's knowledge no comprehensive overview of these plans has been prepared by OSTP or the Commerce Department and made public. Clearly, the challenge of commercialising publicly funded R&D continues.

2 Commercialising university research: the Bayh-Dole Act and its effects

2.1 University contributions to the U.S. economy

The direct commercial value of knowledge generated from university research is only one of a wide range of outputs that have economic significance. In a recent review of methods for assessing the economic impacts of universities, Drucker and Goldstein (2007) note that, since their origins in the Middle Ages, universities' primary reason for existence has been the formulation and dissemination of knowledge and wisdom. Research-intensive universities have recognized that development of human capital has been an accompanying objective, difficult to separate from the research function itself. "The development of human capital is intrinsic in the process of establishing new knowledge as faculty, students, and researchers develop their own intellectual and technical skills; [it] also occurs through activities such as distance learning, industrial extension, and community education programs." (p. 22) Knowledge and technology transfer focus on application of existing knowledge to solve problems and improvement of products and processes, functions that initially (in the U.S.) were central to land grant universities but are now recognized as highly important for all research universities, public and private. The creation of technological innovations at the university frequently leads to patenting, licensing, and the formation of start-up companies by faculty and students.

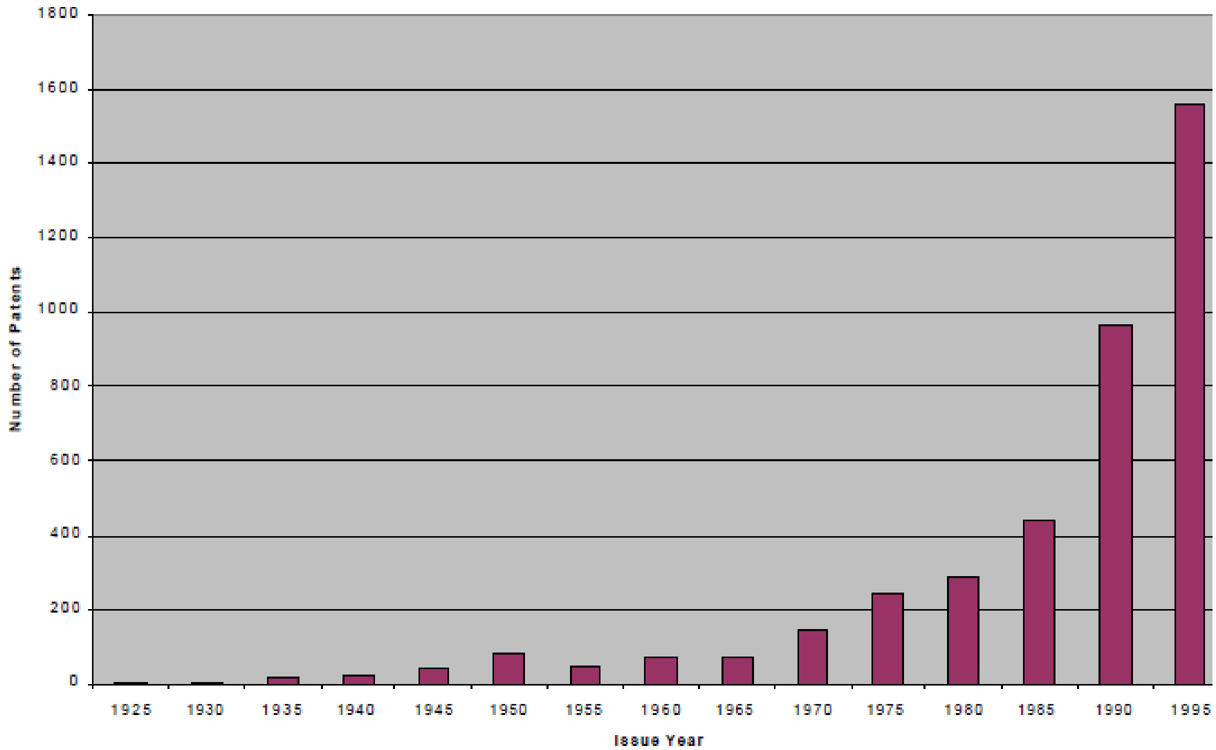
Sampat (2003) makes several points relevant to the purposes of this report. He notes that the relative importance of the different channels through which university outputs diffuse (or are "transferred") to industry has varied by industry and over time. Such channels include hiring of students and faculty, consulting relationships between faculty and firms, publications, conference presentations, informal interactions with industry researchers, university start-up companies, and licensing of university patents. Recent studies show that both faculty and private firms in most industries consider the primary channels through which learning occurs to be publications, conferences, and informal information exchange (Cohen, Nelson, and Walsh, 2002; Agrawal and Henderson, 2002). Also, several studies of the benefits that companies derive from membership in National Science Foundation-funded university-industry research centres (e.g., Engineering Research Centers, Industry/University Cooperative Research Centers) show that access to students and faculty and to new ideas and research results, rather than technology *per se*, are consistently the most frequently cited benefits of centre membership (Feller, Ailes, and Roessner, 2002; Roessner, 2000). So, although the focus of this chapter is clearly on the economic impact of university licensing, this represents only one of many outputs from university research that are highly valued in the economy.

2.2 Emergence of the entrepreneurial university: licensing and patenting activity

Despite the "ivory tower" label sometimes attached to U.S. universities, this is now a gross misrepresentation of reality. "Most economic historians agree that the rise of American technological and economic leadership in the postwar era was based in large part on the strength of the American university system" (Sampat, 2003: 56). Many other countries viewed the university-industry collaborations found in the United States as a competitive advantage and sought to duplicate the underlying conditions supporting these trends (Neal, Smith and McCormick, 2008). Patenting of university research outputs is by no means a phenomenon of the past few decades only. Although growth in university patenting accelerated dramatically beginning in the 1980s, the history of university patenting extends back to the 1920s (see

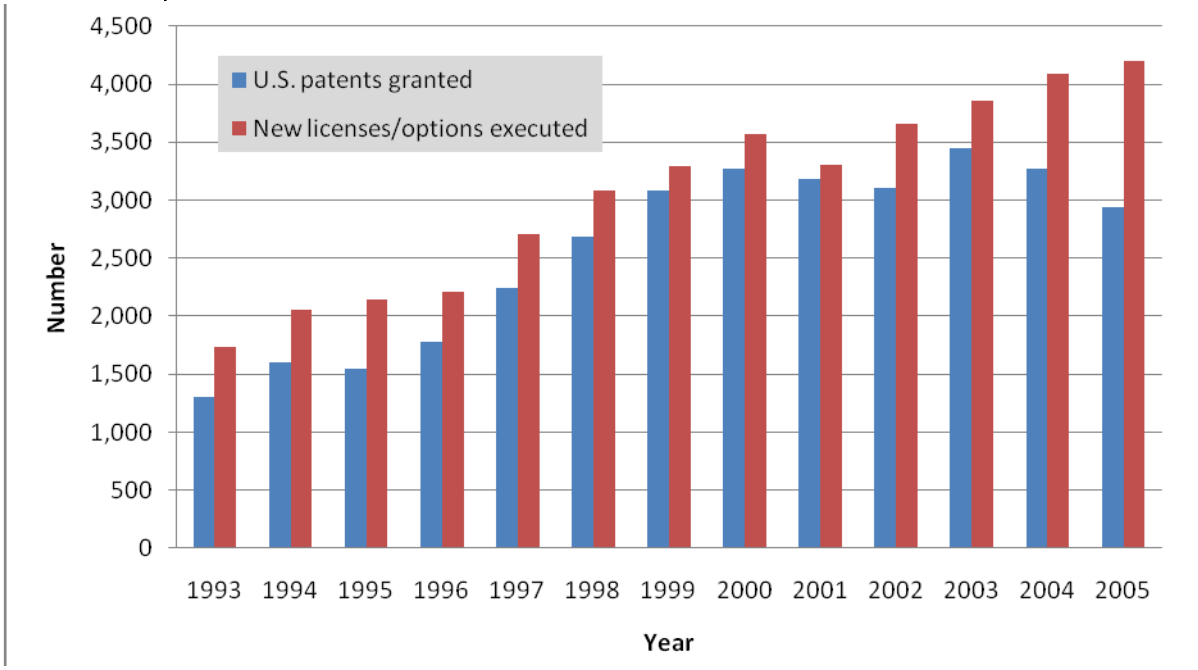
Figures II-1 and II-2). Indicators of academic patenting are mixed in recent years. The U.S. Patent and Trademark Office reports that patent grants to universities have declined since 2002, but other indicators suggest continued expansion of activities related to patents and patent/licensing revenues, such as invention disclosures, patent applications, and revenue-generating licenses. For example, Figure 2.2 shows that the number of new university license agreements/options have grown steadily in recent years from 1,079 in 1991 to 4,201 in 2005.

Figure 2.1: Patents issued to U.S. research universities, 1925–1995



Source: Sampat (2003), page 60.

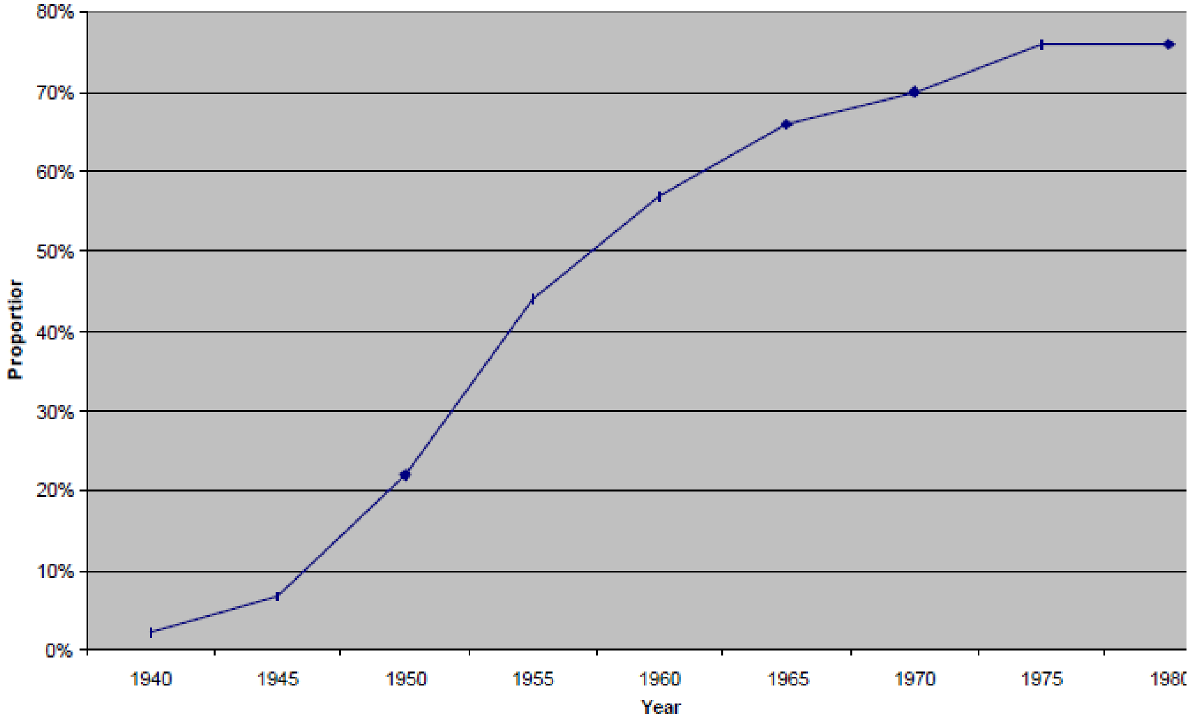
Figure 2.2: U.S. patents granted and new licences/option executed at U.U. academic institutions, 1993–2005



Source: AUTM annual surveys, various years, and National Science Board, 2008.

Until the latter part of the twentieth century, however, universities generally did not wish to engage directly in the patenting and licensing process, largely because they viewed such activities as possibly compromising their commitments to openness and knowledge dissemination. In these early years, most universities avoided intellectual property issues, and the few that did become involved either contracted out their patent management activities to third party organisations such as the Research Corporation (founded in 1912), or set up separate, non-profit foundations such as the Wisconsin Alumni Research Foundation (created in 1924). Beginning with MIT in 1937 and continuing into the post WWII period, universities signed "invention administration agreements" (IAA) with Research Corporation, specifying that all necessary services would be provided by Research Corporation, for which the Corporation would retain a portion of royalty income, with the remainder going to the university. Figure 2.3, below, shows the proportion of Carnegie research universities that had such agreements between 1940 and 1980.

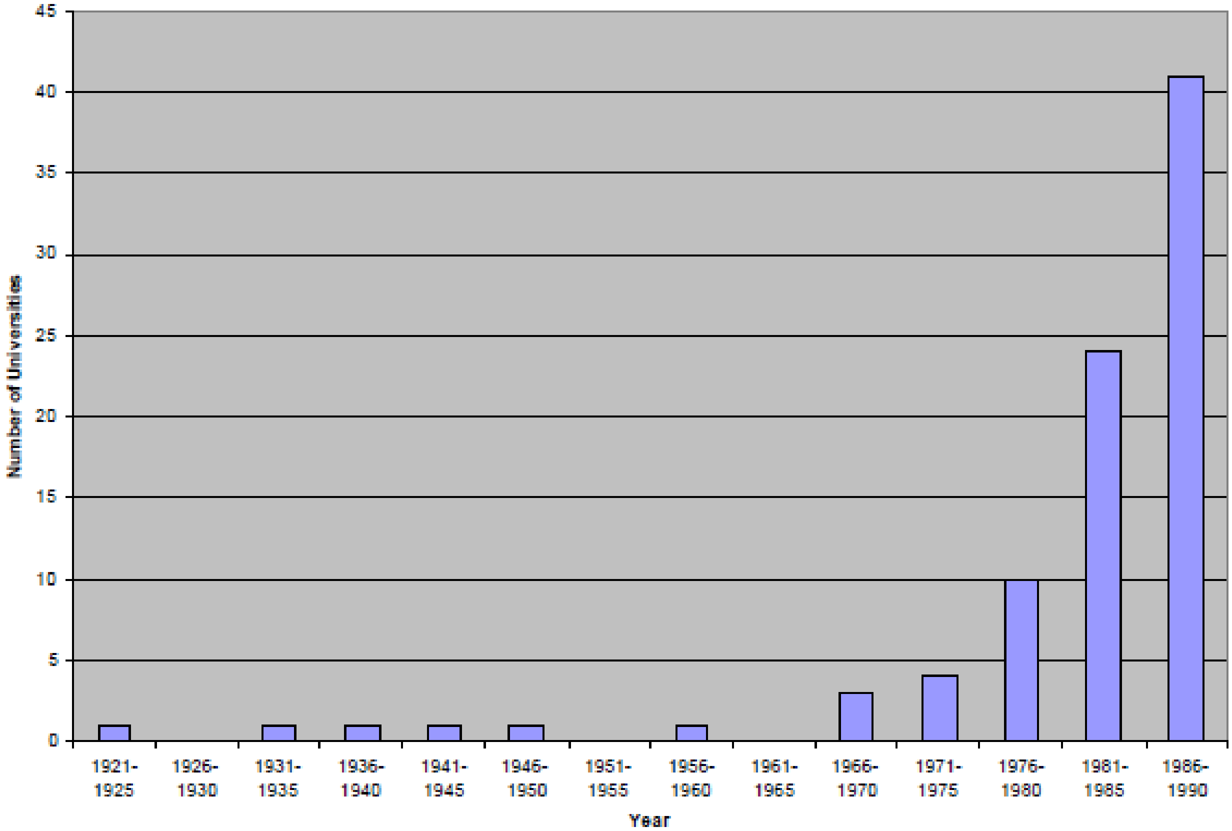
Figure 2.3: Proportion of Carnegie research universities with IAAs with Research Corporation, 1940–1980



Source: Sampat (2003): page 58.

A number of forces beginning in the 1970s brought about significant changes in university patent policies, manifested most obviously in the decision by many research universities to establish internal technology transfer offices, thus internalising the functions previously performed by the Research Corporation. Figure 2.4 shows the number of additional universities “entering into” internal technology transfer activities during each five-year period between 1921 and 1990, with “entering into” defined by AUTM as having a minimum of 0.5 Full Time Equivalents (FTEs) devoted to such activities. Research Corporation noted in its Annual Report that by the mid-1970s most major research universities were considering establishing internal technology transfer offices (Sampat 2003, p. 59).

Figure 2.4: Year of "entry" into technology transfer activities, 1921–1990



Source: Sampat (2003), page 60.

Among the several forces at work during the 1960s and 1970s, prior to passage of the Bayh-Dole Act in 1980, were:

- Commercial applications resulting from the growth of "use oriented" basic research in fields such as molecular biology;
- A decline in federal and other funding for university research;
- University frustration with Research Corporation's failure to return licensing revenues as called for in the IAAs;
- Court rulings and shifts in federal policy that made it easier to patent research results in biomedicine. (Mowery, et al., 2001; Mowery and Sampat, 2001).

According to Mowery, et al. (2001), beginning in the 1960s important federal research agencies began to allow universities to patent and license results from federally-funded research. The Department of Defense allowed universities to retain title to patents resulting from DOD research, provided that DOD retained control of the patents for military application. Both the Department of Health, Education, and Welfare (parent agency of the National Institutes of Health) and NSF negotiated Institutional Patent Agreements (IPA) with individual universities, which eliminated the need for case-by-case reviews of the disposition of individual academic inventions. The universities whose patent filings were increasing during this period were participants in these IPA agreements (J. Allen, personal communication to the author, March 23, 2009). In addition, the Court of Appeals for the Federal Circuit (CAFC) was established in 1982 to “serve as the court of final appeal for patent cases throughout the federal judiciary . . . the CAFC soon emerged as a strong champion of patentholder rights” (p. 103). The IPAs were, in a sense, an administrative form of many of the agency-wide provisions of the Bayh-Dole Act, enacted in 1980 and implemented in 1981. In any event, as Mowery et al. (2002) noted, “growth during the 1970s in patenting, licensing, licensing income, or in the establishment of independent technology transfer offices, was dwarfed by the surge in all of these activities after 1981.” (p. 104)

2.3 Passage, provisions, and aftermath of the Bayh-Dole Act

As noted in Chapter I of this report, 1980 marked a series of major departures from the assumptions that underlay previously longstanding federal policies and practices regarding technology transfer. What gave birth to these changes were a series of legislative debates in the US Congress over ways to promote private sector development and utilisation of federally funded R&D. Public Law 96–517, the Bayh-Dole Act of 1980, was one of the first of these new initiatives.[13] Prior to 1980, only 5% of government-owned patents were ever used in the private sector, although a portion of the intellectual policy portfolio had the potential for further development and commercialisation. The Act was in part intended to address this apparently low utilisation rate of federal patents. At the time the bill was passed, 26 different agency policies existed regarding the use of the results of federally funded R&D. In general, the government retained title to inventions made with government support for research performed in federal labs, universities, and individual companies. Licenses were then negotiated with firms either on a non-exclusive basis or, occasionally, for exclusive use. At the time, many in Congress believed that, despite this, applications would be pursued by private firms if they were provided with proper incentives. According to the House Committee Report accompanying the bill, the new law intended to replace this situation with a “single, uniform national policy designed to cut down on bureaucracy and encourage private industry to utilize government financed inventions through the commitment of the risk capital necessary to develop such inventions to the point of commercial application.” Commercialisation was to be accomplished by using the patent system to augment collaboration between universities, other nonprofit institutions, and the business community to bring inventions to market. Under the law, universities and small businesses could, within a reasonable time, choose to retain title to an invention made under federally funded R&D. Thus the institution must commit to commercialisation within a predetermined, agreed upon, time frame. The government retains a nonexclusive, nontransferable, paid-up license to practice any such invention, and retains “march-in” rights enabling the funding agency to require the contractor grant a nonexclusive or exclusive license in any field of use “to a responsible applicant or applicants” with due compensation.

The following authoritative description of the provisions of the Bayh-Dole Act is taken directly from the 2012 report by the Congressional Research Service (Schacht, 2012):

[13] This discussion of the context of its passage by Congress draws upon Schacht, 2012.

Provisions of the Bayh-Dole Act of 1980

In enacting P.L. 96–517, the Congress accepted the proposition that vesting title to the contractor will encourage commercialisation and that this should be used to support innovation in certain identified sectors. The law states:

> It is the policy and objective of the Congress to use the patent system to promote the utilisation of inventions arising from federally-supported research or development; ... to promote collaboration between commercial concerns and nonprofit organisations, including universities; ... to promote the commercialisation and public availability of inventions made in the United States by United States industry and labor; [and] to ensure that the Government obtains sufficient rights in federally-supported inventions to meet the needs of the Government and protect the public against nonuse or unreasonable use of inventions.[14]

Each nonprofit organisation (including universities) or small business is permitted to elect (within a reasonable time) to retain title to any "subject invention" made under federally funded R&D; except under "exceptional circumstances when it is determined by the agency that restriction or elimination of the right to retain title to any subject invention will better promote the policy and objectives of this chapter."[15] The institution must commit to commercialisation within a predetermined, agreed upon, time frame. As stated in the House report to accompany the bill, "the legislation establishes a **presumption** [emphasis added] that ownership of all patent rights in government funded research will vest in any contractor who is a nonprofit research institution or a small business."[16]

Certain rights are reserved for the government to protect the public's interests. The government retains "a nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the United States any subject invention throughout the world...." The government also retains "march-in rights" which enable the federal agency to require the contractor (whether he owns the title or has an exclusive license) to "grant a nonexclusive, partially exclusive, or exclusive license in any field of use to a responsible applicant or applicants...." (with due compensation) or to grant a license itself under certain circumstances. The special situation necessary to trigger march-in rights involves a determination that the contractor has not made efforts to commercialize within an agreed upon time frame or that the "action is necessary to alleviate health or safety needs which are not reasonably satisfied by the contractor...."[17]

The government is "authorized" to withhold public disclosure of information for a "reasonable time" until a patent application can be made. Licensing by any contractor retaining title under

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[14] P.L. 96-517, sec. 200.
[15] *Ibid*.
[16] *Report to Accompany H.R. 6933*, 5.
[17] P.L. 96-517, sec. 203.

this act is restricted to companies which will manufacture substantially within the United States. Initially, universities were limited in the time they could grant exclusive licenses for patents derived from government sponsored R&D to large companies (5 of the *then* 17 years of the patent). This restriction, however, was voided by P.L. 98–620, the Trademark Clarification Act of 1984. According to S.Rept. 98–662, extending the time frame for licensing to large firms "is particularly important with technologies such as pharmaceuticals, where long development times and major investments are usually required prior to commercialisation."[18]

Time-series data on a variety of indicators of the level of activities related to commercialisation of university research consistently show that, whereas universities engaged in such actions as early as the 1920s, an enormous surge in the rate of activity took place after the Bayh-Dole Act became law. Although the trend data may suggest, *prima facie,* that Bayh-Dole is to a significant extent responsible for the economic consequences of university-based technology transfer and commercialisation activities during the past thirty-five years, there is currently considerable debate about this. Mowery and his colleagues, for example, are skeptical of the causal links, arguing that there is little empirical evidence that Bayh-Dole substantially increased the contributions of university research to the U.S. economy. Based on national university patenting data and detailed historical data from Columbia, Stanford, and Berkeley, they argue that commercialisation activity would have grown in the absence of Bayh-Dole, that the evidence on rates of commercialisation before passage of Bayh-Dole is weak, and that patenting and licensing frequently are not necessary for the development and commercialisation of publicly funded, university-based inventions (Mowery, et al., 2004, pp. 183-184). However, these conclusions and those of other skeptics concerning the apparent economic significance of Bayh-Dole have been challenged strongly in a published article by Bremer, Allen, and Latker (2009). They concluded that "Reams of objective data exist supporting the conclusion that the Bayh-Dole Act greatly improved the commercialisation of federally-funded research . . . and that the public sector-private sector partnerships which were generated under the Act are essential both to the well being and the competitive position of the United States" (p. 2).[19]

Debate on the causal relationship between the provisions of the Bayh-Dole Act and observed trends in rates of commercialisation of university-based inventions continues to the present,[20] and in the absence of credible evidence of the counterfactual (what would have happened in the absence of the Act) is unlikely to be resolved to the satisfaction of both sides of the argument. Nonetheless, several reports by the General Accounting Office (1987; 1998) provide evidence that university administrators and small business representatives agreed that Bayh-Dole "had a significant impact on their research and innovation efforts," and that the increase in industry support for university research was directly attributable to the patent changes in Bayh-Dole and subsequent amendments. More recent data from the National Science Foundation support the conclusion that Bayh-Dole has significantly stimulated industry support for academic research: industry support for academic research grew faster than any other funding source until FY 2002;

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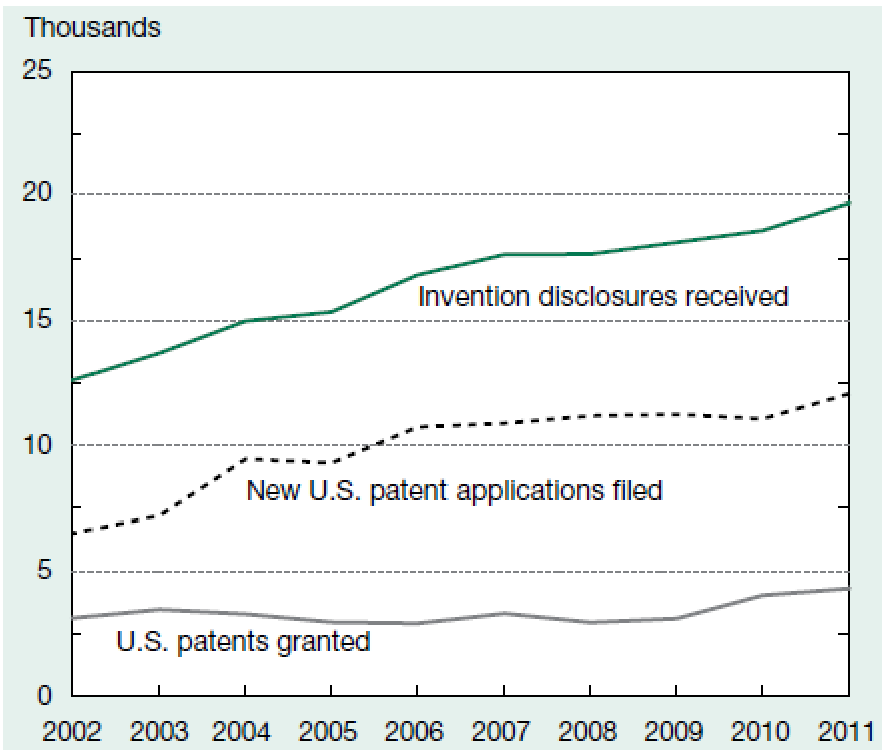
[18] Senate Committee on the Judiciary, *Report to Accompany S. 2171*, 98th Cong., 2d Sess. S.Rept. 98-662, 1984, 3.

[19] It is not coincidental that Joseph Allen was one of the architects of the Bayh-Dole Act.
[20] For example, see Shane (2004), Mowery (2005), Sampat (2006),

industry financing expanded from 3.9% of university R&D in 1980 to 7.2% in 2000; in 1980, federal financing represented 67%% of total academic research funding, but by 2000 federal support had declined to 58.2% of academic research support. Other indicators suggest continued expansion of activities related to patents and patent/licensing revenues, such as invention disclosures, patent applications, and revenue-generating licenses. For example, Figure 2.5 shows that the number of new university invention disclosures, patent applications, and patent awarded grew steadily in recent years; Table 2.1 shows the substantial increase in the number of university licensing/options income and licensing income over a similar period.

Figure 2.5: U.S. university patenting activities, 2002–2011



Source: National Science Board, 2014

Table 2.1
Total license income and licenses/options yielding income by U.S. respondents, FY2003–FY2012

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Number of U.S. Respondents	194	196	188	187	188	188	180	182	186	194
Total License Income ($ Millions)	$1,419	$1,474	$2,130	$2,173	$2,383	$3,444	$2,326	$2,396	$2,458	$2,625
Running Royalties ($ Millions)	$1,126	$1,122	$1,139	$1,173	$1,938	$2,303	$1,618	$1,382	$1,451	$1,889
Cashed-In Equity ($ Millions)	$39	$29	$43	$53	$46	$44	$24	$63	$65	$64
License Income Paid to Other Institutions ($ Millions)	$108	$89	$85	$103	$97	$134	$173	$186	$209	$128
Licenses/Options Yielding Income	**10,682**	**11,414**	**12,254**	**12,684**	**14,387**	**15,498**	**16,331**	**16,205**	**17,103**	**18,295**
Number of U.S. Respondents	**195**	**196**	**189**	**187**	**188**	**189**	**178**	**178**	**182**	**192**

Source: AUTM, U.S. Licensing Activity Survey, FY 2012

Although direct evidence of the economic and other impacts of Bayh-Dole remain elusive, there is no doubt that the decades following passage of the act showed dramatic changes in the role and culture of US academic institutions. Creation of Technology Licensing Offices (TLOs) in virtually all U.S. research universities and the founding of the Association of University Technology Managers in 1974[21] marked the beginning of the rapid growth and professionalisation of these offices' management and staff. But at the same time, concerns arose about increased potential for conflict of interest by faculty members involved in commercialising research results, diversion of faculty attention from traditional teaching and research functions to more applied research, restrictions placed on publishing research results, and emphasis on maximising university income from licensing at the expense of the university's traditional mission--diffusing new knowledge as quickly and widely as possible.[22] Indeed, as more and more universities initiated TLOs, observers of their functions and incentive systems began to recognize three alternative models, each of which had inherent strengths and weaknesses: the legal model, the business model, and the administrative model. Although in practice TLOs are a mixture of these three models, as extreme cases the models bring into sharp focus the conflicting incentives that managers may be required to juggle: maximising retention of intellectual property (IP) rights for the university, maximising licensing income in an attempt to make the TLO self-supporting, and maximising the number of "deals" with private firms in pursuit of the knowledge/technology dissemination mission. Overemphasis on generating licensing income comes at the expense of knowledge and technology dissemination; as does overemphasis on protecting university intellectual property (by patenting virtually all potentially commercialisable research results). Insistence on retaining patent ownership with the

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[21] The Society of University Patent Administrators was formed in 1974. The name was changed to AUTM in the late 1980s.

[22] Schacht's report to the Congressional Research Service (2012) provides a balanced review of the literature on the issues raised in the decades following the passage of Bayh-Dole, the positions on these issues taken by a variety of stakeholders and scholars, and a summary of the available evidence supporting these positions. .

university (rather than granting an exclusive license) can prevent businesses, especially small businesses and startups, from obtaining the venture financing necessary to develop the idea into a marketable product.

Over time, many of these issues have eased as both universities and private firms have learned through sometimes bitter and frustrating experience to reach accommodation and resist making unrealistic or unacceptable demands on the other party. (See further discussion in this report's Chapter V on the STTR program.) Reasonable limitations on publication of research results required by industry research collaborators generally have been accepted by university researchers and administrators as not significantly impeding dissemination of new knowledge. There is little evidence that faculty involvement in technology commercialisation comes at the expense of good teaching or of publication quantity or quality. As the history and performance of the National Science Foundation's Engineering Research Centers Program shows (detailed in Chapter III of this report), students and faculty alike find working in teams on industry-relevant research problems stimulating, exciting, and rewarding for career advancement, professional recognition—and occasionally lucrative as well.

3 Fostering industry-university research collaboration: Engineering Research Centers

3.1 Background

The National Science Foundation (NSF) established the Engineering Research Centers (ERC) program in 1985 at least partly on the basis of a widely held perception that U.S. industrial competitiveness was declining in the face of the emerging global economy. One major thrust of the program was designed to increase patterns of interaction between universities and industry.[23] Overall, the program's objectives included strengthening academic engineering research and encouraging the development of a cross-disciplinary engineering systems approach as one way of addressing the competitiveness problem. The program was designed as a three-way partnership: universities, in addition to receiving government support from NSF for the establishment of the Centres, were to recruit industrial firms as ERC members that would provide additional financial support and maintain close ties with ERC activities.

Engineering Research Centers are the flagship centres program of the National Science Foundation. The first generation of ERCs (classes of 1985–1990), all one- or two-institution centres, were focused on a cross-disciplinary, next-generation "engineered system" approach deemed important to U.S. national competitiveness. All these ERCs have since graduated from the program. The second-generation ERCs (classes of 1994–2006) were mostly multi-institution centres, each focusing on a transformative engineered system and with a stronger emphasis on innovations in education, including pre-college education, and on increasing the diversity of the engineering workforce. "Gen-3" ERCs, the first of which were funded in 2007, were intended to position ERCs in the current globally competitive economy by extending the ERC research scope to include "translational" research in partnership with small firms to speed the translation of discoveries into innovations, while also providing entrepreneurial training and cross-cultural and global research experiences for both faculty and students.

To encourage the conduct of longer-term, high-risk research and the formation of an enduring change in the institutional setting of engineering research and education, NSF supports each ERC for ten years (subject to intensive reviews every three years) at a level averaging $2 million annually for each centre. ERCs are supported by a combination of NSF core support, other federal agency research grants and contracts, state and/or university money, and industry membership fees, contracts, and in-kind contributions. Roughly 30% of an ERC's annual budget comes from NSF and another 30% from industry; the remainder comes from other Federal agencies (20%), the host university (10%), and state and local and other sources (10%). A typical ERC has 30 industrial members, with full members contributing an average of $20,000 in membership fees. The average annual budget of an ERC is on the order of $10 million, representing support from other parties as well.

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[23] Background material on the history and features of the ERC Program are drawn from Roessner, Cheney, and Coward (2004), Ailes, Roessner, and Feller (1997), National Science Foundation (2008), and a number of ERC program announcement.

3.2 ERC objectives and requirements

ERCs are complex organisations. They seek to achieve multiple objectives, account to multiple stakeholders, depend on multiple funding streams, and produce multiple outputs. To quote or paraphrase a variety of NSF officials and documents such as ERC program announcements and other reports, the ERCs were to pursue the following objectives:

- pursue cross-cutting interdisciplinary research and education using an engineering systems approach;
- conduct research that relates to "next-generation advances," the results of which are to be "useful to industry without being too near-term in focus";
- have as explicit economic and practical goals the enhancement of the international competitiveness of U.S. industry -- "their novel features" in terms of a 1986 National Research Council report;
- provide a new means of fostering the transfer of knowledge and technology developed at the Centres into the marketplace;
- establish liaison programs with industry that would lead to continuous and mutually beneficial interactions; and
- inculcate students with a broad understanding of what is needed to bring sophisticated products all the way from the laboratory to the market.

These objectives, however, had certain limitations. ERCs were not expected to take on short-term applied projects as part of core Centre work, or to take on some of the more activist roles that characterised the contemporaneous state-sponsored efforts to establish university-based technological innovation centres. It was not anticipated that the ERCs would become directly involved in commercialising new technologies or take equity positions in spin-off companies intended to commercialize new technologies.

Following the initial cycle of the ERC program solicitation and evaluation of proposals, six "generation one" ERCs were funded. Subsequent annual cycles of awards and review resulted in the funding of twenty-three additional centres, but several of them were phased out of the program prior to completion of the available award cycle of a total of eleven years.[24] (By the end of the award cycle, ERCs are expected to "graduate" from the program and become self-sustaining entities, unless they choose to compete for a brand-new ERC award with a significantly different focus and are successful in that competition.) By 1995, eighteen centres were being funded by the program, and a total of more than 700 industrial partnerships, involving approximately 550 different firms, were in effect.[25] By 2001, 18 second generation centres were being supported. The US economic climate had changed considerably since the first ERCs were funded ten years earlier, such that the ability of the US to compete internationally was no longer in serious doubt. Also, R&D activities in private firms had shifted in organisational locus and in emphasis, and both universities and private firms had learned a great deal about how to collaborate effectively in research.

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[24] The award cycle was reduced to ten years for the second generation of ERCs.

[25] Some firms had partnerships with more than one ERC.

All of these changes, plus others reflecting some changes in the program announcements for second-generation ERCs, meant that ERCs initiated in the mid- and late 1990s began operating in a very different context from that of their earlier counterparts. First, the education component of ERCs was expanded in the second generation centres, with pre-college outreach and impact on university curriculum becoming explicit objectives. Evidence of this change included new degree programs, certification programs, and pre-college outreach that was not explicitly expected or developed by first generation ERCs. Second, whereas the criteria for industrial collaboration had remained constant, such involvement had become more standardized through centre-specific, formal membership agreements between each centre and its member firms. Industrial liaison officers (ILO) had become more activist and more effective in building firm membership bases and expanding to user organisations not previously involved in ERCs, e.g., hospitals and similar practitioner organisations. Third, centre management had become less hierarchical, reflecting a more horizontal and participatory mode of leadership. Fourth, university start-ups had become more important in research-intensive universities as vehicles for commercialising technology, and ERC-derived start-ups were a relatively new phenomenon when the second generation ERCs began. Finally, although companies appeared to be substituting university research for their own research, the amounts that companies were willing to pay for membership in ERCs had declined, and the location of membership approval within member firms had shifted from R&D units to product line business divisions, which were increasingly the users of ERC results.

By 2007, 22 years after the program was launched, 49 ERCs had received roughly $1 billion in funding from the ERC program. They had established formal collaborative relationships with more than 700 companies and, in terms of commercially relevant activities, ERC produced 1,430 invention disclosures, had 524 patents awarded, granted 1,886 patent and software licenses, and spun off 113 firms with (at that time) 1,303 employees. Industrial partnerships had educated thousands of ERC graduates who were in great demand by industrial firms.

3.3 Evaluations of the ERC Program, 1995–2007.

During the two “generations” of ERCs, NSF had supported a number of evaluations of the ERC program, seeking not only to document the degree to which the program met its multiple objectives, but also to understand better how the program might be improved. These evaluations yielded a wealth of important information for both NSF management and for ERC practices and procedures. This section summarises some of the most significant of these results.

During 1994–1997, NSF contracted with SRI International to study the effects on industry of membership in the first 18 ERCs. This study examined patterns of interaction that had emerged between the centres and industry as a consequence of the program and the overall impact of the interactions on industry. More specifically, the study identified the types of results or outcomes of ERC-industry interactions, the frequency with which those results occur, and the relative value or benefit of reported interactions and results of interaction from the perspective of the companies involved. “Value” was defined more broadly than just financial terms.

Even as the data were being collected for the first ERC industry impact study, a new cohort of ERCs began operation: four were funded during 1994–1995 and four more in 1996. As noted in the previous section, ERCs initiated in the mid- and late 1990s began operating in a very different context from that of their earlier counterparts. Accordingly, in 2001 NSF again contracted with SRI to conduct a new study that would address many of the same questions posed in the first study, anticipating that at least some of the results would differ from those that reflected the experiences of industry members of the first cohort of ERCs. The newer study repeated the original study in modified form. The primary objectives of this study were to:

- Determine the extent to which industrial ERC members use different ERC activities and resources, including fundamental research, enabling technology research, and research equipment/facilities (including testbeds) and technical advice/consulting with faculty;

- Determine the specific benefits members receive from their use of these ERC activities and resources;

- Compare the value to members of the various kinds of benefits they receive from ERC membership;

- Identify the capabilities and value to member firms of ERC student/graduate hires compared with other student/graduate hires who were not exposed to ERC research or education programs; and

- Provide measures of the overall impact on firms of their ERC membership.

These objectives were met via a 2002 survey of the 182 primary representatives of private sector firms with membership during 1999-2000 in the eight ERCs included in the study. In addition, a set of secondary objectives for the study were to:

- Identify ways in which ERCs work with small, non-member companies that seek assistance from the centres and with firms that are start-ups based on ERC technology; and

- Determine the extent to which the nature of the involvement of such start-ups and other small companies with the ERCs and the benefits they receive are similar to or different from what is the case with larger firms.

To address these latter objectives, SRI conducted interviews with Industrial Liaison Officers (ILOs) in each ERC, and, in selected cases, with representatives of those businesses as well. SRI compared selected results from the earlier study with those from the newer study to identify how the changing context in which the second generation of ERCs operated had affected their interactions with, and impact on, industry members.

***Reasons for Participating in an ERC*.** The relative importance to member firms of alternative reasons for deciding to participate in a centre did not change drastically for the second cohort of ERCs compared to members of the first cohort. In both cases, access to new ideas and know-how were by far the most important and the ability to license ERC inventions and software least important. However, a much wider range of benefits was identified as “very or extremely important” by a majority or near majority of member firms in the second cohort, possibly suggesting that industry generally was becoming more aware of the myriad benefits that can result from participation in university-based industrial research consortia (Table 3.1).

Table 3.1: Importance of alternative reasons for deciding to participate in Centre, 1994/5 and 2001/2

	Percent Responding							
	Not at All or Somewhat Important		Quite Important		Very Important or Extremely Important		Mean Rating*	
Reason for Participating	1994/5	2001/2	1994/5	2001/2	1994/5	2001/2	1994/5	2001/2
Access to new ideas and know-how	7.2	6.1	10.9	14.7	80.2	77.6	4.1	4.1
Technological/research focus at ERC matched our interests	8.6	6.8	16.7	23.1	73.0	67.5	4.0	3.9
Access to ERC technology		19.0		22.4		55.2		3.5
Access to specific ERC faculty	17.6	20.7	23.7	21.6	56.1	55.2	3.5	3.4
Opportunity for joint projects	32.1	22.4	24.9	27.6	39.1	48.3	3.1	3.3
Opportunity for cross-disciplinary research	43.5	24.8	24.5	26.5	27.4	46.2	2.7	3.3
Prior connections/ relationships with individuals at the ERC	43.5	23.3	19.8	20.7	32.7	52.6	2.7	3.3
Opportunity to interact with other companies affiliated with the ERC	46.7	26.1	22.6	29.6	27.5	42.6	2.7	3.2
Access to ERC students as prospective new hires	43.7	38.8	25.3	25.0	27.6	33.6	2.8	2.9
Ability to leverage our research investment with money from other ERC sponsors	44.0	41.9	20.1	19.7	30.8	35.9	2.7	2.9
The ERC's engineered system goals		26.5		31.6		33.4		2.9
The ERC's integration of research and education		38.8		24.1		35.3		2.9
Access to equipment, facilities, and/or testbeds at the ERC**	44.9	46.1	23.5	16.2	28.7	34.2	2.8	2.7
Ability to license inventions and/or software development by the ERC	62.4	53.5	19.4	19.0	14.5	25.9	2.2	2.6

*Items were rated on a 5-point scale, with 1=not at all important, 2=somewhat important 3=quite important (moderately important in 1994-5 scale), 4=very important, 5=extremely important. The midpoint is 3.0.

Benefits Experienced from Participation. When data on the benefits actually realised by centre member firms from the two cohorts were compared, the relative ranking of benefits was quite consistent across time. Generally speaking, in both surveys member firms tended to obtain the benefits they expected, with approximately the same degree of relative importance (value) associated with each specific benefit. One important difference between the benefits reported by the two cohorts was the much larger percentage of firms in the 2001/2 survey reporting that they improved a product or process, and developed a new product or process. It is also notable that the proportion of member firms reporting every specific benefit increased, in most cases significantly, suggesting that the second cohort centre members were either more aware of the full range of benefits they receive, or actually do receive a wider range of benefits than members of first cohort ERCs (Table 3.2).

Table 3.2: Benefits experienced from participation in an ERC, 1994/5 and 2001/2

	Companies Reporting Benefit (percent)		Mean Rating**	
Type of Benefit	**1994/5**	**2001/2**	**1994/5**	**2001/2**
Hired an ERC student or graduate	39.9	41.0	3.4	3.4
We obtained access to new ideas or know-how.*	**84.0**	**91.2**	2.9	2.9
Our R&D agenda was influenced.	**54.1**	**67.0**	2.8	2.7
We improved a product(s) or process(es).	**42.5**	**58.2**	2.9	2.7
We developed a new product(s) or process(es).	**23.6**	**42.9**	2.9	2.7
We had more interaction than in the past with other ERC firms.	50.1	50.5	2.7	2.6
We were able to provide our customers/suppliers with improved technical information.	**44.1**	**56.0**	2.9	2.5
We made unexpected operational changes (e.g., equipment or project additions or cancellations).		18.7		2.4
We patented or copyrighted technology or software we developed as a result of interacting with the ERC.	**8.4**	**14.3**	2.8	2.3
We licensed technology or software developed by the ERC.	11.8	15.4	2.8	2.2

*Wording in 1994/5 survey was "Obtained access to new ideas, know-how, or technologies through ERC interaction."
**Items were rated on a 4-point scale, with 1=little or none, 2=some, 3=moderate amount, 4=a great deal. The midpoint was 2.5
Notes: Missing data indicate that this item was not a choice in the 1994/5 survey.
Entries in bold face indicate that the differences are statistically significant, $p < 0.05$.
Mean ratings could not be compared statistically because they were obtained in different ways, and standard deviation data were not available for the 1994/5 data.

ERC Student/Graduate Performance in Industry**.** Centre member firms hired ERC students or graduates in similar proportions: among survey respondents who knew whether their company unit had hired students or graduates, 30% of the 1994/5 member firms surveyed reported hiring centre students or graduates as regular employees, and 41% of the firms surveyed in 2001/2 reported hiring ERC students or graduates as either regular or summer employees. The earlier survey did not include summer hires, so it is likely that the proportion of member firms hiring ERC students or graduates on a permanent basis did not change significantly. In both surveys, ERC students were rated as "somewhat better or much better" than comparable non-centre hires by more than a majority of centre representatives on all of the ten dimensions of employee performance.

Factors Contributing to ERC-Derived Benefits**.** In both the 1994/5 and 2001/2 surveys, member representatives were asked to rate nearly comparable lists of factors in terms of their relative contribution to the realisation of benefits for the firm. Data from the more recent survey showed that a wide range of factors contributed to member benefits, some associated with the ERC, some with the member firm, and some with their interaction. A comparison of these results with those obtained in the earlier survey shows a similar pattern (Table _). Nearly all the factors listed showed an increase in the proportion of representatives who considered the factors to be very important or extremely important to the realisation of benefits, with the increases somewhat greater for those factors rated less highly in the earlier survey.

Interviews with member representatives of the factors that contribute to the realisation of benefits by their firms complemented the results of the statistical analyses. They suggested that a very wide range of diverse factors work together in complex ways to generate benefits for the firm, with characteristics of both ERC and the firm involved, as well as the nature of their interaction. Over time, the number of factors considered to contribute in important ways to the realisation of benefits appeared to have increased. Existence of a strong ERC champion in the firm, management support of the ERC, and the close match between ERC and member firm research foci all mattered a great deal, as did the ERC's responsiveness to member needs and efforts to communicate and stay in contact. This further supports the observation that a very wide range of influences are regarded as important to the realisation of ERC-derived benefits for members, and, if anything, the range has widened over time (Table 3.3).

Table 3.3: Factors contributing to ERC-derived benefits, 1994/5 and 2001/2

	Percent Responding							
	Not at All or Somewhat Important		Quite Important		Very Important or Extremely Important		Mean Rating*	
Factor	1994/5	2001/2	1994/5	2001/2	1994/5	2001/2	1994/5	2001/2
Continuous existence of a strong ERC "champion" in the company unit	35.3	22.1	18.1	25.0	43.1	52.9	3.3	3.5
Management support of the ERC within our company	34.8	25.7	25.0	25.7	38.1	48.6	3.2	3.4
The closeness between the ERC's specific technical focus and ours	23.4	21.1	16.9	31.2	58.3	47.7	3.6	3.4
Responsiveness of ERC faculty/researchers to our needs	26.7	24.3	21.4	24.3	49.2	51.4	3.4	3.3
The ERC's efforts to communicate and stay in contact with sponsors	25.7	25.2	24.8	27.0	48.1	47.8	3.4	3.3
The ERC's emphasis on cross-disciplinary research	40.4	27.8	22.2	30.6	35.1	41.7	3.0	3.2
Receptivity of company technical staff to ERC ideas and/or results	31.9	30.6	24.6	33.3	41.7	36.1	3.2	3.1
Our ability to influence the ERC's research agenda	48.4	36.5	23.9	30.8	25.1	32.7	2.7	2.9
The ERC's engineered systems goals**	50.8	43.1	19.8	23.5	24.5	33.3	2.6	2.8
Integration of research and education		46.1		24.5		29.4		2.8
The commercialisation potential of ERC research	55.4	43.3	19.0	26.0	21.9	30.8	2.6	2.8
Our ability to establish proprietary rights	64.1	51.6	11.7	17.2	20.5	31.2	2.5	2.7

*Items were rated on a 5-point scale, with 1=not at all important, 2=somewhat important 3=quite important (moderately important in 1994-5 scale), 4=very important, 5=extremely important. The midpoint is 3.0.
**The wording of this factor was "The ERC's engineered systems approach to education" in the 1994/5 survey.

Notes: Some percentages do not add to 100 owing to a small number of respondents who reported "don't know/don't remember."
Missing data indicate that this item was not a choice in the 1994/5 survey.

ERC Interactions with Small Businesses. Interviews with CEOs and COOs of small businesses that interacted with ERCs revealed as much about the differences among the eight second-cohort ERCs as their similarities. Many interactions with ERC-based start-ups and small, non-member firms were heavily influenced by factors over which centre managers had little or no control. These include state laws, university policies, university culture, the resources available to the university Technology Licensing Office, tensions inherent in the long-term research focus of centres and the short-term needs of start-ups, the centre's technical focus, and the dynamism of the industry served by the centre. Yet it is clear that the second generation ERCs are interacting with small firms in a variety of ways that mutually benefit the centres and their host universities, the small firms involved, and the centre's full members.

The importance of research universities for regional economic growth became widely recognized over the first two decades of the ERC program, and new government programs at all levels reflected this change. Successful, innovative, research-based businesses are now accepted as one of the keys to sustainable regional growth, and university-based start-ups are an important ingredient in the recipe. Industrial liaison officers of the second cohort of ERCs were well aware of this and acted knowledgeably and aggressively to help create, develop, and nurture centre relationships with small, research-based firms in their regions. They also worked closely with university technology licensing offices to foster the creation and growth of start-up forms based in ERC research. Although probably more a matter of degree than of kind, this emphasis represented a significant change in ERC-industry relationships since the late 1980s and early 1990s.

***Implications for Third Generation Centres*.** The basic patterns of benefits realised from participation in ERCs and their impacts on industry did not appear to have changed dramatically. Access to ideas, know-how, and the ability to hire centre students and graduates continued to top the list of most frequently experienced benefits, whereas licensing ERC software and technology continued to be least important to member firms. A significantly higher proportion of member firms from the more recent study reported receiving a number of important benefits, notably product and process improvements and new products or processes. Maintenance of frequent and close communications with member firms was important to the retention of members, as was responsiveness of ERC researchers to member needs. Highly favourablesa assessments by member representatives of the net benefits of participation in ERCs continued, as did the match between expectations of benefits from membership and the benefits actually experienced. Barriers to the realisation of benefits by member firms were not serious, and they continued to relate mostly to firm policies and environments, not ERC activities.

Generations Three and Four ERCs*.* As the flagship centres program of the NSF, there has been continuous attention paid to identifying the strengths and weaknesses of program features and practices, with an eye toward spawning future, improved "generations" of ERCs. Attendees at the 2007 annual meeting of ERC program (these meetings include ERC faculty, staff, and students) participated in a detailed analysis and assessment of the key features of Gen-2 and Gen-3 ERCs. The primary outcome of this effort was that "the existing set of ERC key features is generally excellent and should be retained, with some modifications to the characteristics of a few features." There was a call for flexibility in the ways ERCs met the program's goals, and for exploring ways to reduce the substantial annual reporting burden. Regarding industrial collaboration, "a substantial number of participants identified this key feature as the single most significant strength of the ERC program. Industrial collaboration provides industrial/practitioner relevance, generates best practices, prepares students, supports company hiring and innovation. . . all things that are extremely important for a successful ERC." Without offering a solution, participants pointed out that it was difficult to establish a centre-wide intellectual property policy for multi-university ERCs.

Just as this questioning, and general reaffirmation, of current ERC policies and practices was occurring, an important study by the Science and Technology Policy Institute, commissioned by NSF, was released. This study was intended to inform "ERC management, organisation, and practice regarding the formulation of the next generation of ERCs." Because the ERC program was acknowledged to be one of the preeminent university research centres programs in the U.S., the focus of the study was on research centres abroad, specifically on centres in China, South Korea, Japan, England, Ireland, Germany, and Belgium. The "overarching finding" of the report was that the ERC program, when compared to the centres visited abroad, "is unique in its numerous missions and in the relative 'rigidity' of its approaches to these missions. These approaches include funding strategy, requirements and benchmarks, and life-span." (Science and Technology Policy Institute, 2007).[26]

3.4 The ERC best practices manual

After 15 years of experience with ERC management, seasoned ERC managers (including Directors, Industrial Liaison Officers, Education Directors, and Administrative Directors) prepared a "Best Practices Manual." Since its origin in about 2000, it has been updated regularly to reflect changing conditions, additional experiences, and particularly the changes attributable to Generation 3 revisions in ERC policies and practices. Although not an official NSF publication, it was, and remains, an authoritative guide to those interested in knowing how ERC's actually work, what lessons were learned during more than 25 years of experience with scores of ERCs, and what constitutes current effective practice.[27]

The following excerpt from the current version of the Best Practices Manual describes a key portion of the current objectives of Third Generation ERCs regarding the transfer and commercialisation results from ERC research.

"The major objectives of the ERC program include both developing and commercialising technologies to bolster the competitiveness of U.S. industry. To successfully bridge the gap between technology development and commercialisation, ERCs must take a holistic, integrated approach to technology (creation, experimentation, development, and implementation) that is unique among NSF-funded organisations. The involvement of industry representatives in goal

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[26] This study and other program evaluations and studies of ERC program impact are available at http://erc-assoc.org/content/erc-program-evaluations-and-case-studies-program-impact

[27] The Best Practices Manual is available at www.erc-assoc.org.

setting, project review, technology evaluation, and technology implementation is vital to the success of this effort. In addition, if they are to be successful at commercialisation, they must have ways to ensure the equitable treatment and ownership of intellectual property (IP) resulting from research by individual researchers, the ERC, the university, and industry sponsors.

“Technology commercialisation at ERCs is an ever-expanding art. The process is significantly more complex than it is where technology is developed and commercialized wholly within a single company or at a small business spin-off based on a university invention that is not licensed by ERC members. The challenge lies in melding a commercially promising research agenda with the often disparate goals of individual industrial sponsors, guiding the resulting work to a point at which industry can use the product, and supporting the commercialisation effort through continued close contact between ERC researchers and industry representatives. Both university investigators and industry scientists must understand that their roles will change from advisor to project director as a commercialisation effort moves forward.

“These challenges are significant, but ERCs are well positioned to take advantage of the considerable experience of industry in generating value from new ideas. The ERC model has a built-in mechanism for maintaining industrial relevance, in the form of periodic project reviews and direction by industry representatives. Technology transfer takes the forms of directly commercializable technologies as well as the transfer of ideas, which industry can refine and cultivate into saleable products.”[28]

3.5 ERC commercialisation and economic impact data

As of 2012, over the entire history of the ERC program, centres have generated an impressive number of commercially relevant outputs. These are summarised in the following table.

[28] http://erc-assoc.org/best_practices/53-building-innovation-ecosystem

Table 3.4: ERC products of innovation, FY 1985–2012

	FY 2012 (17 ERCs)		FY 2007–2011 Annualized		FY 1985–2012 (34 ERCs)
Intellectual Property Transaction	*Total*	*Per Center*	*Total*	*Per Center*	*Total*
Inventions Disclosed	105	6	98	6	1,554
Patent Applications Filed	46	3	93	6	1,190
Patents Awarded	16	1	32	2	382
Licenses Issued	5	< 1	64	4	669
Economic Development	*Total*	*Per Center*	*Total*	*Per Center*	*Total*
Spinoff Companies	15	1	9	1	117
Spinoff Employees	49	3	32	2	1,015

** Does not include centers from the Earthquake Technology Sector*

Source: http://erc-assoc.org/about/erc_data/erc-products-innovation-fy-985%E2%80%932012

Recently NSF supported a pilot study to examine the feasibility of quantifying the national and regional economic impacts of ERCs. This pilot study developed detailed quantitative estimates of such impact for five ERCs nearing the ends of their ten-year funding cycle. The following summary of the study's findings is excerpted (in slightly modified form) from Roessner, Manrique, and Park (2012).

For regional impacts, the authors combined estimates of the direct plus indirect and induced economic impacts of ERC expenditures generated from a regional input-output model with estimates of the additional impact on each ERC host state owing to centre-based start-up companies, licensing income from intellectual property produced by the centre, the cost savings enjoyed by local firms that had hired centre graduates, and advice and consulting to local firms by centre faculty. For national economic impact, a suitably modified version of the regional approach was employed, supplemented by use of a consumer surplus model to estimate the net public benefits of newly commercialized technologies based in centre research. As the project proceeded, it became clear that efforts to focus solely on economic impacts that could be quantified relatively easily would greatly underestimate the actual economic impact of ERCs. The types of impacts included and the kinds of data collected from centres and their collaborating companies were therefore expanded in the last two of the five case studies.

Quantifiable regional impacts vary widely, from about $90 million to just over $250 million. Almost all of this variation is attributable to differing amounts of external income to the centres and the indirect and induced effects of that income. External income itself varied from about $25 million to $125 million across the five ERCs, so ignoring the indirect and induced effects makes the disparities a bit less drastic. In the case of one centre, the considerable income to the centre from sponsored research, which typically amounts to at least as much as the amount of NSF Program support, could not be included because the centre's accounting system does not distinguish ERC-related sponsored research projects from projects attracted by other units of the Institute. In addition, although this centre emphasized start-ups as the most effective way to transfer knowledge and technology, and has been quite successful in this, data on the amount of venture capital generated by the centre's nine start-ups—obtained for another centre's eight start-ups and was sizeable ($42M)—were not available. To complicate comparison further, even if venture capital figures for the first centre had been available, they would probably not have "counted" in the calculations of regional impact because presumably most of the funding would have been invested by regional venture capital firms, and thus would not represent external funding entering the state.

The total quantifiable national economic impact of the five ERCs and the composition of the impact for each centre varied enormously, from more than $170 million for one centre to just $3 million for another. These disparities in both total impact and composition are much greater than was the case for regional impacts. But they are highly misleading because of variations in the availability of data, not because of actual differences in economic impact. Because two companies associated with the centre with apparently highest impact, one a start-up and one a centre industrial member, were willing and able to provide estimates of the profits and cost savings to their customers for products attributable to centre technology, the total national impact dwarfed that of the other four ERCs studied. But interview data showed that even this probably underestimates the economic impact of the centre on industry. There is a very strong possibility that the other ERCs studied had this much or more national economic impact, which could not be estimated reliably using the consumer surplus approach to measuring the impact of industrial innovation. Interviews with other centre member firms indicated that one centre's concept of modular integrated power systems appears to have had a multi-billion dollar impact on the national economy, that the impact of another centre's technology on the survival of numerous small businesses in the medical devices business, and that another centre's knowledge and technology had major influence on moving what was a barely extant industry in 1997 to a $2.4 billion industry worldwide today, with about 55% of it in the United States.

Only some of these variations could be attributed to ERC characteristics; most were the result of variations in the amount and type of data that could be obtained from the centres involved and the companies with which they worked. Even the most conscientious and costly data collection efforts would be unlikely to yield comparable data across centres because the accessibility of key data, especially proprietary data, will differ unpredictably from centre to centre. Further, focusing on narrowly-conceived, quantifiable economic data alone should be avoided in these kinds of impact studies; that is, studies that seek to estimate the economic impact of university-based cooperative research centres with multiple objectives such as major advances in research; interdisciplinary, team-based educational experiences for students; and knowledge exchange with industry. Emphasis on quantifiable impacts will underestimate the range and value of the actual impact of ERC-like centres, masking the much broader and, based on our findings, larger and more significant impacts on the economy and society.

4 Cooperative R&D agreements between federal laboratories and industry

4.1 CRADA origins and provisions

In Chapter 1 it was noted that in 1986 and 1989 amendments to the 1980 Stevenson-Wydler Technology Innovation Act created the CRADA and formalized the process by which federal laboratories could enter into cooperative research agreements with commercial firms and other institutions such as universities and state and local governments. Subsequently, additional legislation was enacted to help reduce the time and effort required to develop CRADAs with the federal laboratories and confirm that private firms had the option to obtain an exclusive license for an invention created under a CRADA.

According to Title 15 of the *U.S. Code of Laws*, a Cooperative R&D Agreement (CRADA) is an

"…agreement between one or more federal laboratories and one or more non-federal parties under which the Government, through its laboratories, provides personnel, services, facilities, equipment, intellectual property, or other resources with or without reimbursement (but not funds to non-federal parties) and the non-federal parties provide funds, personnel, services, facilities, equipment, intellectual property, or other resources toward the conduct of specified research or development efforts which are consistent with the missions of the laboratory."

CRADAs are one of a number of mechanisms available to the federal labs for engaging in technology transfer and commercialisation. In addition to CRADAs, labs may:

- Employ a Material Transfer Agreement to convey tangible research materials such as reagents, cell lines, or chemical compounds to outside entities, for use in basic research, testing, or feasibility studies;
- Grant an exclusive license to a government-held patent;
- Engage in a Work-for-Others agreement, a contract for performance of research, but the research or technical assistance is performed entirely by the federal lab, but paid for fully by the partner;
- Enter into a User Facilities Agreement, which allows outside parties to gain access to unique research equipment and facilities at the lab.

Both government owned, government operated (GOGO) labs and government owned, contractor operated (GOCO) labs, including weapons production facilities of the Department of Energy, are authorized to use CRADAs. Partners can be business firms, universities, and nonprofit organisations, but preference should be extended to small business and to firms that agree to manufacture any resulting products in the U.S. Labs may grant, or grant in advance, licenses or assignments to inventions made by lab employees during the course of the agreement. Also, the lab must agree that the partner organisation will be granted an exclusive license for a pre-negotiated field of use for such an invention. However, the lab can waive its claim of ownership to any invention made by the partner. Almost always, the lab retains its option to claim a royalty-free license to practice on its behalf. Finally, information developed under a CRADA is protected from public disclosure under the Freedom of Information Act (Institute for Defense Analysis, 2011).

CRADAs had a number of advantages over other types of cooperative R&D agreements used previously.[29] Most significant among the features listed above was the authority permitting participating laboratories to protect intellectual property created under the agreement from disclosure under the Freedom of Information Act. CRADAs also permitted labs to contribute staff and equipment to a CRADA project involving a private sector partner. Further, CRADAs constituted the only mechanism by which the federal government could specify the disposition of intellectual property rights in advance--ownership of any intellectual property developed during the research is agreed upon during the negotiations preceding establishment of a CRADA. Through CRADAs, companies or groups of companies can work with one or more federal laboratories to pool resources and share risks in developing technologies. Both the federal laboratories and the nonfederal partners can provide personnel, services, facilities, equipment, or other resources. The nonfederal partner is permitted to transfer funds to a federal laboratory under a CRADA, but to avoid conflict with the Federal Procurement Regulations, the federal partner cannot transfer any funds to the industrial partner. Abstracts of two CRADAs are presented below in Box 4. 1.

Box 4.1

Abstracts of two CRADAs between federal laboratories and private firms.

Example 1—Under a one-year CRADA, the Centers for Disease Control (a government-owned and operated laboratory) will collaborate with Chemicon, Inc. to develop monoclonal antibodies to the most common adenoviruses. The development of such a battery of reagents may result in the ability to detect as many adenovirus types as possible. Through this CRADA, reagents and/or methods for detection of adenovirus will be made commercially available to clinical laboratories.

CDC will provide their expertise in planning the specific strategies for developing and evaluating the antibody reagents and any related assays, carry out laboratory studies directed toward the evaluation of the monoclonal antibodies using various assay techniques, and make suggestions on product uses in clinical laboratories. Chemicon will provide the technical expertise to immunize the mice, produce the fusions and resulting monoclonal antibodies, and carry out all screening tests. Chemicon will also provide the expertise for scaleup to commercial production of the reagents. (Information courtesy of CDC.)

Example 2—NASA's Ames Research Center and Learjet, Inc. will work together on technologies and design methods for developing and testing a new high-performance business jet. The first year of the program will cost about $2 million for development and testing of a wind tunnel model. NASA will contribute wind tunnel time totaling 480 hours. Learjet will build the model and will cover the cost of developing and flight testing a prototype aircraft if the test results are commercially viable. Tunnel tests were scheduled to begin in January 1994. NASA and Learjet will share test data, computer programs and design methods developed during the cooperative effort. Any new design methods that result will be offered to all U.S. aerospace companies. (From an article in *The FLC Network*, May 1993.)

The legislation creating CRADAs envisioned that both partners to an agreement would benefit from cooperative research, and that the joint activities would advance the research interests of both parties. Industry and state and local governments could gain from access to information

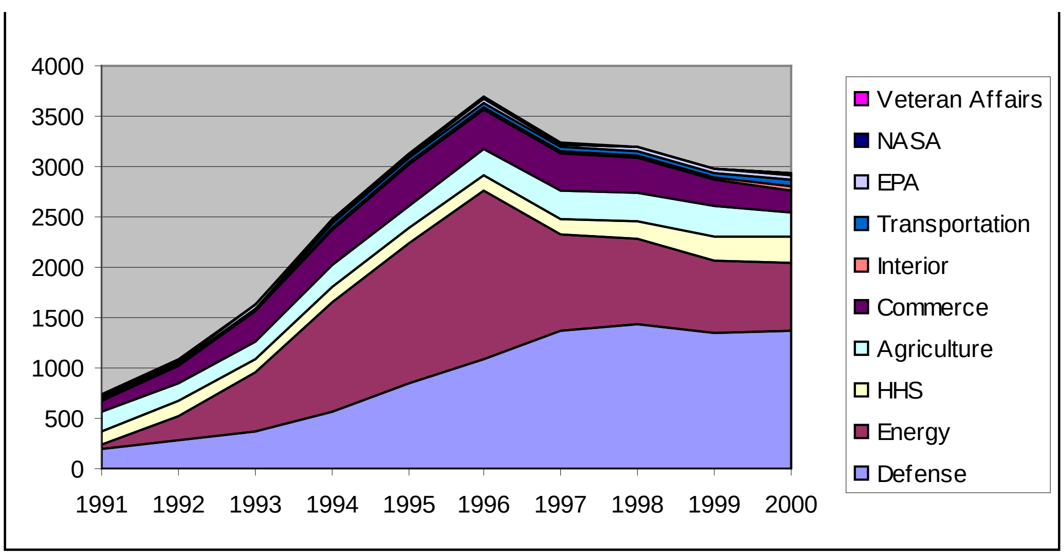
[29] This and the following paragraphs draw extensively from Carr, et al., 2003.

and expertise by working with federal laboratory scientists and research facilities. The federal labs, in turn, could benefit from both lower costs and research expertise not available from their own internal staff. Despite the "cooperative" label, in actuality little shoulder-to-shoulder research activity takes place between lab and partner technical staff. Much more common is coordinated research in the facilities of each party, with approaches coordinated and results shared during formal and informal communication and meetings.

4.2 Historical data on use of CRADAS

Following passage of the CRADA legislation, the number of CRADAs executed between federal labs and industry grew rapidly, from 34 in 1987 to 3,688 in 1996, an average growth rate of more than 68% per year. After reaching a peak of 3,688 in Fiscal Year 1996, the number of federal-wide active CRADAs dropped nearly 20% to 2,926 by Fiscal Year 2000 (Figure 4.1, below). As this decline in CRADAs suggests, some changes occurred in the mid-1990s that affected the reward system related to federal lab-industry research collaboration. The primary agencies responsible for this decline in the number of active CRADAs were the Department of Energy and Department of Commerce. The reasons were twofold: first, in the mid-1990s, owing to Congressional action, laboratory budgets ceased having funds earmarked specifically for CRADAs. Second, toward the end of the 1990s and into the following decade, national priorities shifted from concern with the competitiveness of U.S. industry, at least as far as the missions of federal laboratories were concerned, to national defense. During this period, the vast majority of CRADA activity was centreed in five federal agencies: the Department of Defense, the Department of Energy, the Department of Health and Human Services, the Department of Agriculture, and the Department of Commerce. Between Fiscal Years 1998 and 2000, the Department of Defense was responsible for nearly half of all active CRADAs and the Department of Energy for roughly another quarter. The Department of Agriculture, the Department of Commerce, and the Department of Health and Human Services accounted for about 10% each.

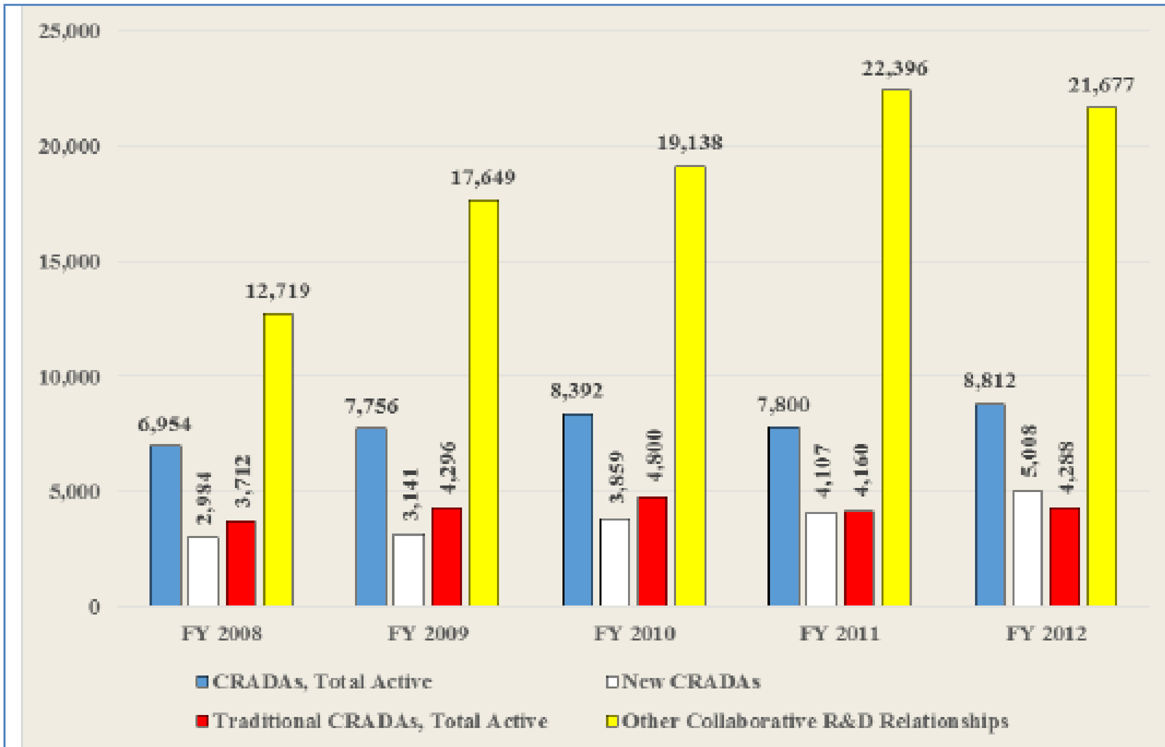
Figure 4.1: Number of active CRADAs, all federal agencies, 1990–2000



Source: U.S. Department of Commerce, 2002

Toward the end of the first decade of this century, CRADA activity had increased and then surpassed its previous levels (Figure 4.2). By FY 2008 the total number of active CRADAs had reached nearly 7000, and by FY2012 numbered more than 8800. However, CRADAs continued to represent a declining proportion of all federal lab collaborative research relationships—from nearly 55% in FY2008 to just over 40% in FY2012.

Figure 4.2: Federal collaborative R&D relationships, including CRADAs, FY2008-2012



	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012
CRADAs, Total Active	6,954	7,756	8,392	7,800	8,812
New CRADAs	2,984	3,141	3,859	4,107	5,008
Traditional CRADAs, Total Active	3,712	4,296	4,800	4,160	4,288
Other Collaborative R&D Relationships	12,719	17,649	19,138	22,396	21,677

Source: U.S Department of Commerce, 2014

4.3 Problems with CRADAS

The early years of experience with CRADAs revealed a number of problems, particularly concerning negotiations over intellectual property, foreign company participation, resolution of losses owing to damage or other unexpected events, and accounting for cost sharing and advanced payment requirements. Regarding intellectual property, early CRADA negotiations featured very complex clauses that covered the disposition of potential intellectual property developed during the research. As the process evolved, however, experience with actual intellectual property development led to more general language covering intellectual property disposition, thereby reducing the complexity of these crucial early negotiations.

CRADA regulations required that preference be given to firms that have “business units in the U.S.” In the case of foreign firms, reciprocity and the governmental policies of the home country government had to be considered during the licensing negotiations. Current regulations stated that a license for a government-owned invention “shall normally be granted only to a licensee who agrees that any products embodying the invention or produced through the use of the invention will be manufactured substantially in the United States.” As uncertainties arose among potential manufacturers about just where a product might be produced, the apparent rigidity of this language was eased, allowing a licensee to show that an equivalent economic benefit would flow to the United States. Many U.S. CRADA partners planning to manufacture products abroad used this alternate approach to demonstrating economic benefits to the U.S.

CRADA agreements require that the licensee of a resulting invention must agree to hold the U.S. Government harmless from any liability arising from the invention. This obviously proved to be a barrier to CRADAs for many companies whose own internal policies were not to indemnify anyone, and as such slowed negotiations on many CRADAs.

Finally, private firms worried about whether they would be audited by Federal auditors regarding their contributions to CRADAs. They were concerned about the cost of conforming to Federal accounting standards, or that a Federal audit of their cost sharing would lead to bad publicity and possibly outweigh the benefits of the CRADAs. As a consequence, Federal agencies have successfully resisted pressures to audit industrial cost sharing .

Many of these problems resulted in protracted negotiations before a CRADA agreement could be signed. In reaction, most federal agencies developed model CRADA agreements that incorporate language that most private sector partners can agree to. Simplified model agreements were also developed for use with small businesses.

4.4 Research on and evaluations of CRADAs

The short review of industry-federal lab research collaborations in Chapter 1 of this report included a short summary of the results of the limited research available on such collaborations, few of which focus on or include analyses of CRADA-specific based collaborations. As Barry Bozeman points out in his recent review of the literature on federal laboratory technology transfer (Bozeman, 2013), very little research on these collaborations, much less on CRADAs themselves, has been published since 2000.[30] At about this time, Bozeman and Wittmer (2001) conducted a survey-based study of 229 federal lab-industry joint R&D projects, most of which were based on CRADAs. Their primary objectives were to learn if certain combinations of technical roles (basic vs. applied research) and performer (federal lab, company, or both) were more effective at transferring knowledge and technology; and whether the number of technical roles involved was related to transfer effectiveness. They found that “increased technical range on the part of industry (not the federal laboratories) is associated with both increased product development and net economic benefit,” and that “the highest marginal benefit (as estimated by the company officials responding) occurred when the company’s technical role involved pre-commercial research (but not development) and the federal laboratories involved basic

[30] The following sections draw from Bozeman’s review, focusing primarily on studies involving CRADA-based collaborations.

research." Perhaps not surprisingly, in the least fruitful combinations, both the federal lab and the firm viewed pre-commercial research as its primary contribution. The results of this study and a followup analysis using the same data suggests that "although partnership effectiveness requires distinctive roles, partner roles should not be so different as to undermine possibilities for coordination and integration."

The results of Ham and Mowery's (1998) detailed case studies of five CRADAs issues from the Lawrence Livermore National Lab, some of which were referred to earlier in this report in Chapter 1, are worth expanding upon here. These projects included quite diverse technologies, ranged widely in size ($250,000 to more than $20 million), and varied from just over a year to four years in length. Using market impact as the criterion for success, Ham and Mowery found that key features of successful agreements were the degree of budgetary and managerial flexibility of the project, the quality of relationships among the partners, federal lab researchers' knowledge of the firm's needs and requirements, and the firm's ability to absorb and apply the results of the collaboration.

In research by Adams, Chian, and Jenson (2003), data were collected from 115 industrial research labs in a variety of industries on technology transfer from federal labs using a number of collaborative mechanisms, including CRADAs. The researchers assessed the effectiveness of these interactions using qualitative reports by the firms' R&D managers on the importance to the firms of these projects. They found that, at the time of the study, CRADAs were the most common transfer mechanism from federal labs to firms, and that such agreements had a near monopoly on transfer activities. Compared with firms working with federal labs but not via CRADAs, firms with CRADAs subsequently spent more on their internal R&D, devoted a larger share to the partnerships, and developed more patents.

Although not focusing specifically on CRADAs, in 2010 the U.S. Department of Commerce asked the Institute for Defense Analysis' Science and Technology Policy Institute (STPI) to "study the landscape of technology transfer and commercialisation at the federal laboratories to serve as a baseline for further action" (Institute for Defense Analysis, 2011). STPI held numerous discussions with technology transfer staff at federal agencies and labs (the primary source of data for the study). The discussions "provided an understanding of technology transfer and commercialisation activities at the laboratories, identified perceived barriers to technology transfer, and uncovered strategies with potential for overcoming these barriers. They also revealed factors that affect the speed and dissemination of technologies from the laboratories."

The discussions led to identification of nine factors that affect the speed and extent of dissemination of technologies transferred from federal labs to the private sector:

- The laboratory mission. The scope, size, and mission of even the major federal laboratories varies widely, and this affects the lab's emphasis on technology transfer. If transfer and commercialisation clearly helps achieve the primary mission of the lab, then that activity attracts more attention and resources than in other labs.

- Lab management. It does make a difference if a lab is government operated (GOGO) or contractor operated (GOCO). GOCO lab managers are often explicitly tasked to perform technology transfer and commercialisation, whereas GOGOs must comply with government regulations that do not affect GOCOs.

- Congressional support and oversight. Congressional action and oversight can have unintended consequences such as encouraging a risk-averse culture towards technology transfer. Sometimes lab transfer activities can be undermined when congressional priorities shift, weakening the long-terms support that transfer activities require.

- Agency leadership and lab director support. Lab directors who support transfer provide resources, flexibility, and creative freedoms to their Offices of Research and Technology Applications (ORTAs). Othewise, ORTAs are severely constrained in what they can accomplish.

- Organisation and coordination of technology and commercialisation activities. Whether transfer and commercialisation activities are centralized or decentralized at the lab or agency levels affects the speed with which transfer actions can be implemented, the consistency of policies across labs and within an agency, and the ability to share best practices. Also, the location of the ORTA can affect the visibility of the technology transfer function.

- ORTAs. The responsibilities assigned to the office, the technical and business experience of the staff, the office's processes, and the legal authorities available to the lab (and how ORTA staff interpret them) all have substantial effect on ORTA effectiveness.

- Researchers. The degree of participation in transfer activities by lab staff varies widely across labs. Researchers may lack the knowledge, ability, and incentives to undertake administrative and business development activities required for successful transfer.

- Government-industry interactions. Generally, federal labs are not visible to, or easily accessible to, private firms. Partnership intermediaries, groups designed to broker partnerships between the labs and industry, report that industry is largely unaware of opportunities to collaborate with federal labs.

- Resources. Not only do internal resources devoted to transfer and commercialisation vary across labs and agencies, but so does the extent to which labs and agencies leverage programs at all levels of government that support technology-based economic development.

4.5 Measuring the value and impact of CRADAs

Barry Bozeman probably has contributed more to the literature on technology transfer than any other U.S. based scholar. His extensive 2000 review of the literature covers both research and theory in the field, and includes very useful definitions and models of the transfer process in general. In addition, he developed classifications of the literature itself, including thoughtful considerations of the meanings associated with transfer effectiveness and how effectiveness might be measured under various conditions and assumptions. Table 4.3 below, taken from Bozeman (2013), provides a useful classification scheme for alternative criteria on which measures of effectiveness can be based, and the advantages and disadvantages of each.

Table 4.3: Effectiveness criteria for technology transfer

Effectiveness criterion	Key question	Theory base	Major advantage and disadvantage
"Out-the-Door"	Was technology transferred?	A-theoretical or classical organisation theory	Advantage: Does not hold transfer agent accountable for factors that may be beyond control. Disadvantage: Encourages cynicism and focuses on activity rather than outcome
Market impact	Did the transferred technology have an impact on the firm's sales or profitability?	Microeconomics of the firm	Advantage: Focuses on a key feature of technology transfer. Disadvantage: Ignores important public sector and nonprofit transfer; must accommodate market failure issues.
Economic development	Did technology transfer efforts lead to regional economic development?	Regional science and public finance theory.	Advantage: Appropriate to public sponsorship, focuses on results to taxpayer. Disadvantage: Evaluation almost always requires unrealistic assumptions.
Political	Did the technology agent or recipient benefit politically from participation in technology transfer?	Political exchange theory, bureaucratic politics models	Advantage: Realistic. Disadvantage: Does not yield to systematic evaluation.
Opportunity cost	What was the impact of technology transfer on alternative uses of the resources?	Political economy, cost-benefit analysis, public choice	Advantage: Takes into account foregone opportunities, especially alternative uses for scientific and technical resources. Disadvantage: Difficult to measure, entails dealing with the "counterfactual"
Scientific and Technical Human Capital	Did technology transfer activity lead to an increment in capacity to perform and use research?	Social capital theory (sociology, political science), human capital theory (economics)	Advantage: Treats technology transfer and technical activity as an overhead investment. Disadvantage: Not easy to equate inputs and outputs.
Public value	Did technology transfer enhance collective good and broad, societally shared values?	Public interest theory, public value theory	Advantage: Excellent and easily sanctioned criteria for public policy. Disadvantage: Extremely difficult to measure systematically [31]

Source: Bozeman, 2013

Of course, these criteria and the pros and cons of each are not confined to any particular types of institutions, and so apply for transfer from any source of publicly supported research to any type of potential user.

U.S. government reports of CRADA activity and outcomes, not surprisingly, focus on the number of CRADAs created, the number of active CRADAs at any given time, the number of invention disclosures filled out, patents filed for and granted, licenses granted, and licensing income; all of these are matters of record collected by the federal labs and required to be reported annually to the Department of Commerce. The most recent data, some of which were presented above, appear in U.S. Department of Commerce (2014). In addition to these regularly reported data, and in response to the 2011 Presidential Memorandum described earlier in this report, several agencies have conducted studies of the impact of their transfer activities, notably

[31] The DoD report can be accessed at http://static.techlinkcenter.org/techlinkcenter.org/files/economic-impacts/DoD-Economic-Impact-Final2.13.pdf

on economic benefits and employment. For example, the Department of Defense conducted a study that assessed how DoD licensing agreements contributed to new economic activity and job creation in the U.S., and how these licenses resulted in the transition of new technologies to military use. More than 500 companies with more than 600 license agreements were surveyed to determine the total sales of new products related to their DoD license agreements. Economic impact software was used to forecast how these agreements would affect economic output, value added, employment, labor income, and tax revenues (U.S. Department of Commerce, 2014). Similarly, a Navy study simulated the economic impact of 103 CRADA and licensing agreements between the Navy and primarily private firms and universities.[32]

Measuring the success of laboratory technology transfer and commercialisation activities was among the topics discussed in the STPI "landscape" study described above. Some agencies collected more data on effectiveness than others, more than the relatively few reported in the annual Commerce Department documents. ORTAs are responsible for collecting metrics from the labs for reporting purposes, but the interviews revealed that these metrics are not used to manage technology transfer processes. Indeed, the STPI report states that "Most of the ORTA representatives interviewed for this study could not provide an articulate definition of what success means for their laboratory and how specific components of technology transfer fit into achieving that mission." (Institute for Defense Analysis, 2011, p. 93).

[32] http://www.ibrc.indiana.edu/studies/t2.pdf

5 The Small Business Technology Transfer Program

5.1 Origins

In the late 1970s and early 1980s, as concerns in the U.S grew over the nation's ability to compete internationally, evidence began to accumulate that small businesses were playing an increasingly large role in national economic growth, job creation, and innovation. Within the federal government, the idea that research-intensive agencies should increase the share of funds going to innovative, technology-based small firms was first expressed from within the National Science Foundation. NSF initiated a program to achieve this objective, which was enthusiastically received by the small business community. The powerful small business lobby urged other agencies to follow the NSF's lead, but received little response. The lobby then targeted Congress and the Executive Office of the President, resulting in a White House-sponsored conference on small business in January of 1980. The conference recommended a program for small business innovation research, which had widespread appeal because there was evidence that the share of federal R&D going to small businesses was declining, that innovative small businesses were having difficulty raising capital owing to unusually high interest rates prevailing at the time, and new evidence that small businesses were important sources of job creation. Early in the Reagan administration, Congress responded quickly by passing the Small Business Innovation Research and Development Act of 1982, which established the SBIR program. The new program required agencies with R&D budgets greater than $100 million to set aside 0.2% of their funds for SBIR, with overall responsibility for the program assigned to the Commerce Department's Small Business Administration (SBA). In 1983, the first year of the program's operation, $45 million was set aside; the required set-aside was increased over the next six years, growing to 1.25%. According to the 1981 Senate Committee on Small Business report on the Act, the authorising legislation had two broad goals:[33]

- "to more effectively meet R&D needs brought on by the utilisation of small innovative firms (which have been consistently shown to be the most prolific sources of new technologies); and
- "to attract private capital to commercialize the results of federal research." (Wessner, 2008).

As part of the 1992 legislation reauthorising the SBIR program, Congress established the Small Business Technology Transfer (STTR) Program with the following four goals:

- stimulate technological innovation,
- use small businesses to meet federal research and development needs,

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[33] The current "official" statement of SBIR goals, which closely matches the original four goals of the STTR program, appears on the web site of the Small Business Association (SBA), www.sbir.gov:

- Stimulate technological Innovation.
- Meet Federal research and development needs.
- Foster and encourage participation in innovation and entrepreneurship by socialy and economically disadvantaged persons.
- Increase private-sector commercialization of innovations derived from Federal research and development funding.

- foster and encourage socially and economically disadvantaged persons' participation in technological innovation, and
- increase the private sector's commercialisation of innovations derived from federal R&D.[34]

Five agencies were to participate in the new program: the Departments of Defense, Energy, and Health and Human Services' National Institutes of Health; the National Aeronautics and Space Administration; and the National Science Foundation. The legislation authorized each agency having an external R&D budget great than $1 billion to set aside no less that 0.05% in FY 1994, not less than 0.1% in FY 1995, and not less than 0.15% in FY 1996. In the program's first year, these agencies spent about $20 million and estimated that funding would amount to $60 million in the third and last year of the program's original authorisation. The STTR program was closely modeled on the SBIR program, which had proved highly popular with Congress and the small business community during its first decade of operation. The two programs share the same basic goals, participation by many of the same agencies, use of a percentage of the external budget for funding, and a three-phased award structure. The one important difference between the two programs, to be elaborated in the next section of this chapter, is the requirement that to be eligible for an STTR award, a small business must collaborate with a nonprofit research institution: a university, a federally funded R&D centre (i.e., a Federal Laboratory), or similar organisation. Although such collaborations are permitted under the SBIR program, they are not mandatory. According to a 1992 House of Representatives report, this requirement was to "provide a more effective mechanism for transferring new knowledge from research institutions to industry" (General Accounting Office, 1996).

During its consideration of the proposed STTR authorising legislation, Congress was well aware of questions that might arise given the similarities between the STTR and the existing SBIR programs. The House report on the bill expressed the rationale for the STTR program by making two arguments. First, the nation's research institutions contain enormous scientific and technical resources—these public and nonprofit institutions employ one in four scientists and engineers in the nation and conduct one quarter of all U.S. R&D. If part of the U.S. competitiveness problem is the inability to translate these resources into technology and commercial applications that benefit the economy, then what is needed is an effective technology transfer mechanism to move new knowledge from research institutions to industry. Second, the report noted that SBIR had already been shown to be an effective mechanism for commercialising ideas originating in the small business community. But (the report said) SBIR is less effective at fostering ideas that originate in universities, federal labs, and nonprofit research institutions. STTR was thus envisioned largely as a technology transfer program that would facilitate movement of promising concepts originating in nonprofit research organisations (largely federally funded) on to commercialisation by small firms (General Accounting Office, 1996).

The 1996 GAO report called for in the 1992 legislation reauthorising SBIR and establishing STTR, concluded with three key questions relating to continuation of the STTR program, given its close similarity in structure and purpose to SBIR:

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[34] The SBA website's current description of STTA goals is:

- Stimulate technological innovation.
- Foster technology transfer through cooperative R&D between small business and research institutions.
- Increase private sector commercialization of innovations derived from federal R&D.

- Is the technology originating primarily in the research institution, as envisioned in the rationale for the program, or is it originating in the small business?
- Is the mandatory collaboration between the small business and the research institution effective in transferring the technology to the marketplace?
- Can the SBIR program accomplish the same objective without the collaboration required by the STTR program?

The numerous reviews of the SBIR program and the relatively few assessments of the STTR program over the past fifteen years unfortunately provide only limited information that could address these questions. The results of these reviews will be presented later in this chapter.

5.2 Structure and provisions of the STTR program

Under the initial provisions of the STTR program, each agency is responsible for organising and managing its own project solicitations, targeting research areas and setting priorities, administering proposal reviews, and making funding arrangements with awardees. Agreements can include contracts, grants, or cooperative agreements between a federal agency and a small business for the performance of experimental, developmental, or research work funded in whole or in part by the federal government. The SBA was required to issue a policy directive for the general conduct of STTR programs within the agencies. It was to include requirements such as simplified, standardized, and timely solicitations; a simplified, standardized funding process; and minimisation of the regulatory burden for participating small businesses. Agencies are required to report annually to SBA key data such as the percentage of STTR funding as a proportion of total extramural budget; number of solicitations released; number of proposals received and awarded, by phase and dollar amount of awards; and profile of institutions collaborating by number and dollars awarded (FFRDCs, universities, other non-profits).[35]

Eligibility requirements for an STTR award are that the small business must be:

- independently owned and operated,
- other than the dominant firms in the field in which they are proposing to carry out STTR projects,
- organized for profit,
- the employer of 500 or fewer employees (including its affiliates), and
- at least 51% owned by U.S. citizens or lawfully admitted permanent resident aliens.

Under the original law, the three-phase funding structure for the program was:

- Phase I: designed to determine the scientific, technical, and commercial merit and feasibility of a proposed idea; limits of one year and $100,000.
- Phase II: designed to further develop the idea; limits of two years and $500,000.
- Phase III: more flexible; expected to result in commercialisation or further continuation of R&D. No STTR funding is provided for this phase, and there are no time limits. This phase can include non-STTR federal funds and private sector funds.

[35] See https://www.sbir.gov/awards/annual-reports.

Funding for Phase II was to be based on the results of Phase I and the scientific and technical merit and commercial potential of the Phase II proposal.

Both the SBIR and STTR programs have been reauthorized several times. The SBIR program was scheduled to terminate in September 2008, and the STTR program the following year. A series of temporary extensions by Congress kept both programs in operation until the SBIR/STTR Reauthorisation Act of 2011 was enacted. The new legislation, which reauthorized both programs through September 2017, increased the set-aside for SBIR by 0.1% per year to 3.2% by FY 2017 and beyond, and incrementally expanded the set-aside for STTR awards from 0.3% to 0.45% in FY 2016 and beyond. Until 2010, Phase I awards remained at $100,000, but an SBA Policy Directive of March 2010 raised the limits of both SBIR and STTR Phase I awards to $150,000 and the limits of Phase II awards, which had been previously raised to $750,000, to $1 million. The 2011 reauthorisation act confirmed these changes, and added a number of additional provisions, as follows:

A recipient of a Phase I grant from one federal agency is permitted to apply for a Phase II award from another agency to pursue the original work. A small business is allowed to switch between the SBIR and STTR programs. Duplicative awards are not permitted.

A new pilot program is created in DOD, the Department of Education, and the National Institutes of Health (NIH) to permit the award of a Phase II grant without the small business receiving a prior Phase I grant.

Also at NIH, a new “Phase 0 proof of concept partnership program” is established to “accelerate the creation of small businesses and the commercialisation of research innovations” from universities or other research institutions that participate in the NIH STTR program.

Phase III awards are to go to companies that developed the technologies in Phase I and Phase II and all grants are to be made on a competitive and merit-based basis.

Perhaps the most contentious issue was that of permitting majority venture capital owned small companies to receive grants under the SBIR and STTR programs. In what might be considered a compromise position, the new law permits NIH, DOE, and NSF to award not more than 25% of SBIR funds to “small business concerns that are owned in majority part by multiple venture capital operating companies, hedge funds, or private equity firms through competitive, merit-based procedures that are open to all eligible small business concerns.” Other federal agencies may not award more than 15% of SBIR funds to “small business concerns that are owned in majority part by multiple venture capital operating companies, hedge funds, or private equity firms through competitive, merit-based procedures that are open to all eligible small business concerns."

In order to promote the use of federally funded research and development, the legislation provides for commercialisation pilot programs for Phase II SBIR and STTR technologies in DOD and the civilian agencies. It also encourages the award of SBIR and STTR grants to small businesses that work with federal laboratories or are involved in cooperative research and development agreements (CRADAs). Agencies are required to establish minimum performance standards (benchmarks) to measure the commercialisation success of awardees.

A pilot program is created to permit no more than 3% of SBIR program funds to be used for administrative activities, oversight, and contract processing. As part of this pilot program, a portion of these funds is to be used to increase participation of states which have traditionally received low levels of SBIR awards (Schacht, 2012).

5.3 Assessments of the STTR program

The 1996 GAO report referred to in the opening section of this chapter offered a number of observations and comments concerning how the new STTR program was being implemented. These observations are interesting in that they raised issues that required responses from SBA and the various agencies operating STTR programs, but at the time of the report it was premature to draw any conclusions about the effectiveness of the program in achieving its goals or about possible overlaps with the SBIR program. Nonetheless, if the Australian government decides to initiate a new program similar to STTR, identifying some of these early implementation issues may be of considerable value. For this reason, the GAO's major conclusions are summarised below. Further details can be found in the GAO report itself.

To assess the quality and commercial potential of STTR research, GAO reviewed all of the agencies' technical evaluations for just over 200 proposals that received Phase I awards. If an agency used an external peer review process, these evaluations were made by experts in other federal agencies or the private sector. GAO staff also obtained further information about the evaluation process from discussions with program officials. To determine whether the legislation's requirement for avoiding conflict of interest was being met, GAO obtained relevant program documents and interviewed program officials.[36] To address the question of whether

[36] The major concerns here were that researchers at federal labs (e.g., under the aegis of DOD, DOE, or NIH) might use privileged internal information gained from work performed for an STTR agency in the preparation of a proposal, or that an evaluator internal to the STTR may realise benefits due to an affiliation with the proposing

there was a need for two programs with such similar provisions, staff interviewed STTR program officials at SBA and at the five agencies with STTR programs.

Regarding the quality of proposals and the proposal evaluation process, GAO found that reviewers awarded perfect scores to many proposals, in some agencies rated proposals among the top 10% of research in those agencies, described some proposals as “cutting edge,” and generally found the quality to be excellent. For commercial potential, evaluators came to similarly positive conclusions, but were somewhat cautious because of the newness of the program or the risk associated with the proposals. The evaluation process itself varied widely across the five agencies. Some evaluation sheets provided no analysis in support of the ratings given. Almost half of DOD’s winning proposals received only one review, and in many of these cases the reviews were (in the GAO investigators’ view) too brief to support the findings. GAO expressed considerable concern in these cases about the reliability of the results.

GAO confirmed that participating agencies had taken steps to avoid potential problems resulting from organisational conflicts of interest, notably situations in which a federal lab might form a partnership with a company submitting a proposal, and then helped a federal agency evaluate the merits of its own and other proposals. Anticipating this problem, DOD carefully restricts participation by its own labs in STTR collaborations, thus preventing labs from using inside knowledge in preparing proposals. DOE policy prohibits staff members from requesting or receiving assistance from personnel in research institutions that are eligible to participate in the STTR program in preparing technical topics for the STTR solicitation.

Congress reauthorized the STTR program in FY 1997, with little apparent concern about the possible overlap between SBIR and STTR (and little data on the STTR pilot program’s performance). This was probably a result of the great disparity in size and visibility of the two programs, so few if any negative effects of one program on the other were expected. In preparation for the review and potential reauthorisation of the STTR program in 2001, however, both the Senate Committee on Small Business and the House Committee on Science requested that the GAO determine the views of companies participating in the STTR program on the contributions the companies and the research institutions made to the R&D, the results of the R&D, and options for the future relationships between the STTR and SBIR programs. GAO surveyed all 166 companies that had received a total of 201 Phase II STTR awards in FY 1995 though FY 1997. The survey instrument identified companies that had received both STTR and SBIR awards, which enabled responding companies to choose among various options for the future of the STTR program in relation to the SBIR program. The results, based on company

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company or collaborating lab.

responses for 102 projects, were summarised in a letter report to the requesting committees (GAO, 2001). The following is excerpted from the letter report.

- ***For the 102 partnerships that we reviewed, the companies reported that both the companies and the research institutions contributed significantly to the R&D.*** For example, the companies believed that both parties contributed significantly to the knowledge and/or expertise essential to the project. Furthermore, they generally believed that both parties contributed significantly in constructing or testing prototypes and in providing special equipment or facilities. However, the companies reported that, in aggregate, the companies played a substantially greater role in originating the key ideas for the R&D; in their view, they originated or were primarily responsible for originating the key ideas in 72% of the projects.

- ***The companies reported a variety of results, including sales of a product, process, or service, the receipt of additional developmental funding, patents granted, and discontinuation of projects*.** As of April 2001, the companies reported about $132 million in total sales and about $53 million in additional developmental funding. About two-thirds of the projects with reported sales achieved their first sale in 1999 or 2000 and projected about $900 million in additional sales by December 31, 2005. The companies also reported receiving 41 patents for the core technologies associated with their projects and the creation of 12 spin-off companies. Twenty-seven projects were discontinued. When asked to identify those factors that had a great role in the decision to discontinue the project, companies most frequently cited insufficient additional funding for further technical development.

- ***The companies reported a preference for maintaining the current separation of the STTR and SBIR programs.*** For 96% of the projects in our survey, the companies had also won an award under the SBIR program. In this context we asked them to choose between four options for the future of the STTR program in relation to the SBIR program: (1) preserve its current separation from the SBIR program, (2) subsume it under the SBIR program with a portion of funds reserved for STTR-type partnerships, (3) subsume it under the SBIR program with no funds reserved for STTR-type partnerships, and (4) eliminate it entirely. For approximately 50% of their projects, the companies preferred the current separation of the STTR program from the SBIR program. Thirty-three percent favoured the second option, 19% the third option, and only 1% supported the program's elimination.

Although interesting, these results are too limited to shed much light on the key questions posed in the 1996 GAO report. One reason is that the findings are from the viewpoint of the participating companies, with no equivalent results from a survey of partner research organisations. A second reason is that the report contains no interpretation of these results, again greatly limiting their use for evaluative purposes. For instance, there is no information on the basis for the responding companies' preferences on maintaining the current separation of the STTR and SBIR programs. Later reviews and assessments provided additional but by no means conclusive information on these questions.

Debates in Congress accompanying the 2011 reauthorisation of the SBIR and STTR programs centred on several contentious issues. Much debate revolved around the existing provision requiring at least 51% ownership of the participating small business by an individual or individuals. Some experts argued that small firms majority-owned by venture capital companies should be eligible for awards because, especially in biotechnology fields, the most innovative firms do not meet the ownership criterion. Opponents maintained that both programs were designed to provide early stage financing where venture capital is virtually unavailable. As such, they argued, the program is working as planned to bring new concepts to the point where venture financing is feasible. As described in the previous section, a new provision under the reauthorisation act does permit limited participation by majority venture capital owned companies, but it remained unclear how this would affect the goals of the two programs. Again, questions arose about whether the two programs are meeting their different mandated objectives or, instead, are serving basically identical purposes. And, as usual, some conservative critics of these programs argued that government has no role in directly supporting industrial R&D (Schacht, 2012).

To this author's knowledge, there are no comprehensive reviews of the STTR program itself. Because of the much larger size of the SBIR program and the similarity in structure and funding provisions of STTR and SBIR, much greater attention by policymakers and researchers has been paid to SBIR.[37] However, an article published in 2008 in the *Journal of Research Administration* (Ford, et al., 2008) discusses the advantages, from the perspectives of universities and small businesses, of participating in the SBIR/STTR programs. The authors underscore the necessity of forming commercialisation partnerships to maximize the potential for success of funded SBIRs/STTRs in Phase III. "From an academic standpoint, the SBIR and STTR programs provide an avenue to transition some university technologies/research to the private sector by extending the technology work from pure research into the development regime, and therefore create a pipeline of more attractive technologies for SBC [small business concerns] collaborative development and ultimate commercialisation through an SBIR or STTR project." For purposes of this report, the most relevant parts of the article are brief descriptions, based on the authors' extensive experience with the SBIR and STTR programs, of how major challenges to collaborations between universities and small businesses can be overcome.

Negotiations over ownership of intellectual property. Often viewed as the most serious barrier to effective commercialisation of ideas originating in university-industry collaborative research, the authors observe that "experience shows, and university technology licensing and industrial collaborative research data support, the premise that universities and the private sector have learned to overcome this obstacle. . . . Boilerplate industry-sponsored research agreements in universities usually include a first option to a royalty-bearing license to technology produced in the research project on a good-faith negotiations basis."

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[37] See, for example, the excellent, extensive review of the SBIR program by the National Research Council of the National Academies (Wessner, 2008). This review is unusual for the NRC in that, in addition to being overseen by a prestigious committee of experts from industry, government, and universities, the Committee staff and a research team of 19 experienced researchers and consultants engaged in primary data collection (surveys, interviews, and case studies) as well as analysis of existing data as the basis for findings and recommendations. Many of the issues considered and addressed in the Committee's final report apply to the STTR as well. Key findings that relate most directly to the features of STTR intended to distinguish it from SBIR are summarized later in this section.

Limited resources in the private sector for external research support. University faculty can no longer count on multi-year industrial contracts with sometimes vague objectives. Both entrepreneurs and small businesses must understand that technologies “developed in SBIR or STTR programs are more often than not advanced along the R&D curve from the university standard basic research. . . . they are now dealing with . . . follow-on research with an organisation (the university) and professionals (the faculty and graduate students) who are influenced by different cultural drivers and timeframes . . . .”

Research guidance/focus to meet company-specific needs. The results that industry seeks must dovetail with the educational mission of the university. “…a university researcher’s up-front understanding of and an SBC’s continued communication of the nature, timing, and criticality of a company sponsor’s needs can go a long way toward establishing an SBIR or STTR research project that is truly focused on meeting the sponsor’s needs and timelines.”

***Confidentiality*. ** Publication requirements for students and faculty can clash with small business desires to withhold company-sensitive information and proprietary research results from competitors and to protect intellectual property. “. . . this potential problem can usually be mitigated with clear, on-going communications throughout the SBIR or STTR project so that confidential or proprietary information can be properly managed in publications without affecting a student’s educational progress or unduly delaying a faculty member’s publications or endangering patent positions.” (Ford, et al., 2008: pp. 75-76).

The National Research Council’s 2008 *Assessment of the SBIR Program* was undertaken as the major part of a series of studies by the NRC, at the request of Congress, as part of the 2000 reauthorisation of the program. These studies, published between 2004 and 2009, included separate evaluations of the SBIR programs of the five agencies with the largest programs: NSF, Energy, NIH, Defense, and NASA. The 400-page report published in 2008 synthesized the results of these studies and added new results obtained by work of the study’s research team. The study’s core finding was that “the SBIR program is sound in concept and effective in practice.” Specifically, the report states that the program is effectively:

- Generating multiple knowledge outputs.
- Linking universities to the public and private markets.
- Increasing private sector commercialisation of innovation.
- Using small businesses to meet federal research and development needs.
- Providing widely distributed support for innovation activity.
- Fostering participation by minority and disadvantaged persons in technological innovation.

The Congressional request to the NRC also asked for a similar assessment of the STTR program, but given the size and attention focused on SBIR, NRC divided the study into two phases. The SBIR assessment took five years to complete, and the Phase II assessment of STTR is still in progress. As a consequence, the SBIR report contains few separate references to the STTR program, and nearly all of the data collected and reported either combines data on the two programs or reports only SBIR data. For example, the NRC survey of 1239 firms did not ask firms to distinguish between SBIR and STTR awards, and the survey of 1916 Phase II participant companies asked companies about SBIR awards only. STTR is rarely referred to in the case studies, and only one of the committee’s findings and recommendations mentions it:

"Despite the generally flexible approach, there is evidence from the agencies that in some cases, SBA has believed itself obliged to limit flexibility in the application of its guidelines to the program. For example, projects initially funded as a Phase I STTR cannot be shifted to a Phase II SBIR, even if circumstances make this the most effective way to proceed." (Wessner, 2008, p. 69)

So far, then, the key question of whether or not the two programs are meeting basically the same goals remains unresolved, at least as far as published evidence is available. However, some clues to the likely findings of the Phase II study of STTR are available as a set of videos covering presentations and discussions at a National Academies workshop held on May 1, 2015.[38] The workshop's purpose was to "offer an opportunity to explore STTR program operations and outcomes in view of the program's legislative objectives, including, among other things, the program's effectiveness in transferring technologies; the application process; impact of and experiences in creating collaborations between small business and research institutions, including labs; experiences in establishing IP agreements; and economic outcomes." Workshop participants and presenters included representatives from STTR programs from several federal agencies, small businesses with STTR experience, universities, and a key Congressional staffer from the Senate Small Business Committee. This author's impression is that the NRC committee is likely to conclude, as it did in the SBIR report, that the STTR program was meeting its goals effectively but could be improved. There appeared to be consensus among participants that the STTR program was filling an important gap in bridging the "valley of death" in commercialising promising university-based research results, a gap that SBIR was addressing but nevertheless remained significant. Workshop participants considered the remaining gap sufficiently large to justify the separate existence of STTR, and perhaps justifying a major increase in the scale of the program. So one can expect in the NRC final report findings and recommendations related to distinctions between the two programs.

Until the STTR report is published, one has little to rely on to address the fundamental issue of whether there is a need for different programs. Years of data on both programs in SBA's databases document program activity and outputs but contain no measures of performance and impact. Nonetheless, some of the data shed a bit of light on this issue. The proportion of STTR collaborations that involve universities, non-profits, and federal labs, if compared to a similar statistic for the SBIR program, could indicate whether STTR projects actually involve such partners to a greater extent than do SBIR projects. Although STTR annual reports include such data, SBIR annual reports do not. The following table shows that, over the period 2001-2012, about 37% of the total STTR dollars awarded annually to universities and small businesses went to universities.

Table 5.1: Average number of annual STTR Awards and dollars to various types of awardee institutions, 2001–2012

Total dollars of awards	261,955,250
Dollars to small business	110,770,226
Dollars to research institution	69,694,731
Number of awards to universities	692
Dollars to universities	67,370,241

[38] Workshop on the Small Business Technology Transfer Program, https://vimeo.com/album/3393463/sort:preset/format:detail

Number of awards to FFRDCS	35
Dollars to FFRDCS	2,995,569
Number of awards to other non-profits	65
Dollars to other non-profits	7,053,059

Source: STTR Annual Reports, 2001-2012, www.sbir.gov

Although comparable data are not available for the SBIR program, the NRC survey of companies awarded SBIR Phase II projects provided some data on university involvement in these projects. The survey results, based on data from nearly 2000 companies, showed the following:

Table 5.2: University involvement in SBIR projects

2%	The Principal Investigator (PI) for this Phase II project was a faculty member.
3%	The Principal Investigator (PI) for this Phase II project was an adjunct faculty member.
22%	Faculty or adjunct faculty member(s) work on this Phase II project in a role other than PI, e.g., consultant.
15%	Graduate students worked on this Phase II project.
13%	University/College facilities and/or equipment were used on this Phase II project.
3%	The technology for this project was licensed from a University or College.
5%	The technology for this project was originally developed at a University or College by one of the percipients in this phase II project.
17%	A University or College was a subcontractor on this Phase II project.

Source: Wessner, 2008, Table 4-13, p. 167.

Although a weak reed on which to rely for evidence of important distinctions between the outcomes of STTR and SBIR programs, the above information suggests that STTR does attract a relatively larger proportion of collaborative research projects involving universities than does SBIR. On that basis one might further argue that knowledge transfer to industry, and perhaps commercialisation of university-based research results, is occurring to a relatively greater degree under STTR than SBIR. As the next section will show, the kinds of comparative data on the two programs, now beginning to be collected, will provide a far more solid basis for reaching conclusions on the issue of program duplication.

5.4 Measuring the effectiveness and impact of the STTR and SBIR programs

As mentioned above, to date the annual reports for the SBIR and STTR provide data on program activity and output rather than outcomes and impact.[39] Specifically, SBIR annual reports spanning 2001-2012 include data on agency obligations, award profiles (dollar awards to minority-owned/disadvantaged by phase; HUBZone dollar awards by phase, manufacturing dollar awards by phase, women-owned dollar awards by phase), and an agency solicitation profile (number of solicitations released, number of topics in solicitations, and number of proposals by phase). For reasons that are unclear to the author, STTR data are richer, though still lacking outcome or impact measures. STTR annual reports include all the categories of data

[39] Two exceptions are "impact" data on (1) percentage of award dollars to women-owned small businesses (data first collected in 2012), (2) percentage of award dollars to HUBZone certified companies, and (3) percentage of award dollars to socially and economically disadvantaged small business concerns. HUBZone awards are awards to Historically Underutilized Business Zones.

reported by SBIR, but adds (as illustrated in the STTR annual awards table in the previous section):

- agency research institution profile (number of awards to FFRDCS, universities, and other non-profits;
- agency cooperative research profile (total dollars and number of awards, and
- dollars and number of awards by phase to small business, research institution, universities, FFRDCs, and other non-profits).

Although not referred to in the SBIR or STTR annual reports available on the SBIR website, agencies with one or both programs have independently gathered commercialisation data. In response to a recent request from the House Committee on Science, Space, and Technology asking for information on "the extent of SBIR program data available to evaluate progress in increasing commercialisation of SBIR technologies," GAO reviewed program data available in the SBIR database as well as documents from the five largest agencies participating in SBIR, and conducted interviews with agency officials (GAO, 2011). GAO concluded that "although agencies participating in the program have gathered commercialisation data for their own purposes, comparable data on commercialisation are not available across agencies. . . . most of the participating agencies we reviewed did not verify the accuracy of commercialisation data from their prior award recipients, and SBA has not identified best practices for participating agencies to use in doing so."

The current situation—a dearth of annual, systematically-obtained, and consistent program data that would prove useful in evaluating the performance and impact of SBIR—is about to change. As part of the SBIR/STTR reauthorisation act of 2011, the Interagency Policy Committee (IPC)[40] is charged with "Developing and incorporating a standard evaluation framework to enable systematic assessment of SBIR and STTR, including through improved tracking of awards and outcomes and development of performance measures for the SBIR program and STTR program of each Federal agency." (SBIR/STTR Interagency Policy Committee, 2014) In September 2014 the IPC issued a report proposing a standard evaluation framework for the SBIR/STTR programs. This was probably also a response to the directive in President Obama's 2011 Memorandum, Accelerating Technology Transfer and Commercialisation of High-Growth Businesses, requiring that research agencies develop criteria to assess the effectiveness and impact of planned or future technology efforts.

The IPC report proposes a six-step evaluation framework and recommends that further investigation be conducted to assess the feasibility of specific, detailed performance and impact measures identified in an appendix to the report. The recommended measures were based on information gathered and reported in the 2008 assessment of the SBIR program by the National Research Council. The IPC further recommends that, after assessing feasibility of the proposed measures, the SBA "revise its commercialisation database as necessary to collect the necessary data, automatically generate these metrics, and make the metrics available on its website." The proposed evaluation metrics fall into the following categories:

[40] The Interagency Policy Committee was established by the 2011 reauthorization act. It is co-chaired by the White House Office of Science and Technology Policy and the SBA and includes representatives from federal agencies that participate in the SBIR or STTR programs. The Committee is required to review certain issues and make policy recommendations to Congress on ways to improve program effectiveness and efficiency.

- Outreach to new applicants (e.g., number and percent of Phase I applications by new applicants),
- Outreach to women-owned small businesses (e.g., number and percent of applications by women-owned firms compared to historic numbers and rates of participation by such firms),
- Outreach to socially and economically disadvantaged small businesses (e.g., number and percent of applications by disadvantaged firms compared to historic numbers and rates of participation by such firms),
- Targeted geographic outreach (e.g., number of applications by firms in targeted geographic areas as compared to the number of applications from firms in those geographic areas over the previous five fiscal years),
- Outreach activity assessment (e.g., new applicants should identify how they learn about the program),
- Funding level (e.g., percentage above or below statutory level),
- Processing times (e.g., average and/or median days to notify each phase),
- Data collection (e.g., percentage of reports received on time),
- Fraud, waste, and abuse (e.g., number of incidents reported),
- Progress to commercialisation (e.g., percent of Phase II award recipients that achieve at least $100,000 in sales or investment or received a patent on the technology, and/or achieve sales or investment at least equal to SBIR/STTR awards),
- Return on investment (e.g., sales and investments since the Phase II award minus SBIR award amounts, divided by SBIR award amounts),
- Jobs created or sustained (e.g., number of jobs associated with the technology).

The report includes the following graphic summarising the recommended key evaluation criteria:

SBIR / STTR Evaluation Criteria

Outreach
- New Applicants
- Women and Disadvantaged
- Geographic
- Outreach Activity Assessment

Compliancy & Efficiency
- Award levels
- Data requirements
- Processing Times
- Fraud, Waste & Abuse

Commercialization & Other Economic
- Commercialization
  - Phase I to Phase II Conversion
  - Initial
  - Full
- Return on Investment
- Jobs Created/Sustained

6 Technology-based economic development in the States

6.1 Background[41]

Promotion of regional economic development by U.S. state governments has a long history. Subsidies for “strategic” industries such as ironworks began in the late 1700s; subsidies to canal and railroad companies were common throughout the 19th century; tax concessions and grants to construct industrial parks became widespread in the 1950s. At about this time, states began to offer a range of subsidies to manufacturers to encourage them to relocate to the offering state or construct a branch plant there. This strategy became known as “smokestack chasing,” and for decades was among the most important (and costly) strategies in states’ economic development toolkit, The objective was to attract new jobs to the state, with number of jobs rather than their quality or longevity the primary measure of success.

In the 1980s a number of factors led to a rethinking of state economic development strategies. The economic downturn demonstrated the fundamental weakness of smaller states’ narrow industrial bases; for example, agriculture, oil, and even federal installations alone could not sustain employment growth. Studies and experience showed that smokestack chasing may initially attract new jobs, but all too often such jobs were short-lived and low-paying, ultimately adding little to the state’s growth. Moreover, it became clear that often the cost of the subsidies exceeded the value of their measureable economic benefits. Meanwhile, the U.S. was experiencing declining international competitiveness, and a number of highly visible public commissions identified insufficient technological innovation as a major cause. With national politics working to resist federal actions that smacked of “industrial policy” or “picking winners,” states began to fill the vacuum by investing in new regional strategies that focused in various ways on science and technology. Their models were California’s Silicon Valley, Massachusetts’s Route 128, and North Carolina’s Research Triangle Park. A new set of economic development tools emerged that emphasized the creation of new firms and jobs in rapidly expanding, “high tech” industries. Venture capital funds, incubators, research parks, and centres of advanced technology became staples of state economic development portfolios. Technological change was seen as the key to regional economic development.

At about this time, states changed their targeting of phases of the knowledge-generation-to-commercialisation process. Initially most, but not all, major state initiatives concentrated on “upstream” activities that sought to foster the transfer of results from academic R&D (most of which was federally funded) by strengthening the academic research infrastructure. These efforts produced programs such as eminent scholars, university-based centres of excellence, and university-industry-(state) government R&D centres.

About 1990, however, a shift in many states to more conservative governors led, at times quite abruptly, to emphasis on “downstream” applied R&D and product development programs that promised shorter-term and more visible payoffs—i.e. new jobs. This shift meant increased use of direct grants to private firms and less support for university-based R&D or knowledge infrastructure activities. More recently, though, states have again turned attention to more “upstream” activities built around university R&D. The new priority emphasizes the importance of universities as a critical part of a state’s knowledge infrastructure—a reflection of the

[41] This section draws extensively on Roessner, 2000, Chapter 2.

recognition that it is not only innovative technology that generates regional economic growth, but also the formation of high-tech clusters of both small and large private firms, sources of human capital, diverse research-oriented institutions, and networks that link them. Venture capital funds, incubators, research parks, and centres of advanced technology now have become staples of state economic development strategies (Wessner, 2013).

By 1988, 43 states had at least one program designed to encourage technological innovation. More than half of these programs included a technology transfer mission, and by 1996 all 50 states had established a formal program to foster technology-based economic development (TBED). All states had developed some kind of cooperative venture that drew upon private sector and university-based assistance (Melkers and Cozzens, 2007; Plosila, 2004). Also at this time, the significance of these TBED programs, both economically and politically, was signalled by the formation in 1996 of the not-for-profit State Science and Technology Institute (SSTI), based in Ohio. Since its inception, SSTI has developed a national network of economic development practitioners and policymakers; conducts an annual conference for its members; and develops and disseminates information about best practices in state-level TBED programs. One of the first of its many important reports presented data on state funding for "cooperative technology programs" (SSTI, 1996), defined as "public-private initiatives involving government and industry, and often universities, that sponsor the development and use of technology and improved practices to benefit specific companies or groups of companies." Exclusively in the report were programs administered or directly sponsored by the executive branch of state governments. Total state funding for these programs was $369 million in FY1994 and $405 million in FY1995. SSTI's 1996 report was followed quickly by a 1997 report to the Commerce Department's Economic Development Administration that:

- identified best practices in science and technology strategic planning,
- described how states were addressing the needs of distressed areas in their strategic planning initiatives, and
- recommended ways states and the federal government could leverage science and technology investments to benefit distressed areas. (SSTI, 1997).

Of particular value to state TBED organisations was an appendix to this report that contained an overview of state S&T and economic development plans completed during the previous five years, a review of the contents of these plans and the processes by which they were prepared, and examples of state science and technology-based development strategies. A more recent report of this type, published in 2006 and funded again by the Commerce Department's Economic Development Administration (SSTI, 2006), was a practical resource guide for state TBED officials on strategies to position universities to drive knowledge-based economic growth, foster regional entrepreneurship, and increase the region's access to venture capital. The results of this study and similar analyses and examples of effective TBED policies and programs are presented later in this chapter.

The U.S. recession of 2008-9 dealt state economies a serious blow, with 44 states reporting a budget deficit. Nonetheless, a significant minority of states had previously committed to long-term efforts to promote innovation, and as a result enjoyed sustained funding through the end of the recession and on to 2013. For example, Ohio's Third Frontier initiative, launched in 2002 with ten-year funding of $1.6 billion devoted to expanding research and technology based economic development, sustained its programs throughout the period, even adding $700 million for an innovation institute in 2010. New York sustained funding for its nanotechnology initiative since 2008, including a $400 million contribution for a College of Nanoscale Science and

Engineering at the State University of New York at Albany. Arkansas' knowledge-based economy initiatives focused on research received $61 million in state funding from 2008 through 2011 and leveraged $192 million in non-state support (Wessner, 2013). SSTI's most recent "Trends" report (SSRI, 2013) confirms these observations about the existence of longer term commitments, and adds considerable details on a state-by-state basis. The report notes that the outlook for state budgets has improved: after five quarters of decline in tax revenues in 2008-2009, an extended period of modest growth is projected. 2013 saw efforts to expand research capacity and commercialize research, invest in knowledge-based industries, support specialized workforce training, and strengthen industry clusters.

6.2 Landscape of current state TBED organisations

Not only do state TBED organisations vary individually over time in their size, structure, and program priorities in response to shifting state politics and economic conditions (as suggested above), but at any given time they vary widely on all these parameters across the states. To this author's knowledge, there is no currently available, up-to-date, comprehensive survey of all state TBED organisations. In any event, it would be a major task to classify them and present their key characteristics in a systematic way. However, numerous studies and reports offer snapshots of selected TBED organisations, and these provide a useful overview of the varieties of approaches states have taken to promote technology based growth. A sampling of the more visible (i.e., longstanding and generally recognized as among the more effective of such programs)[42] illustrates the varied landscape of U.S. TBED organisations.[43]

Arkansas Science and Technology Authority Technology Development Program*.* The Technology Development Program provides assistance in development and commercialisation of new technology-based products and processes through innovative technology development projects. The program provides royalty financing for qualified projects possessing well developed, comprehensive project plans, and that utilize the benefits of science and technology to provide economic and employment growth potential in Arkansas. Qualified applicants are: (1) researchers at Arkansas colleges and universities, (2) researchers at federal laboratories in Arkansas, (3) Arkansas-based small businesses, and (4) inventors in Arkansas.

Connecticut Innovations*.* Connecticut Innovations provides strategic capital and operational insight to push the frontiers of high-tech industries such as energy, biotechnology, information technology, and photonics. Since 1995, Connecticut Innovations has operated on returns from its investments, rather than state funding.

Georgia Research Alliance. The Georgia Research Alliance (GRA) is an independent non-profit organisation funded by state appropriations since 1993. Its operating budget is also

[42] Although survival over the years is one indicator of program effectiveness, it is by no means the most accurate, as survival rests not only on careful evaluations of program impact or goal attainment, but also on the program's ability to satisfy key political stakeholders (who are not necessarily attuned to standard measures of impact such as job growth over other factors, but rather favor other accomplishments such as the ability to spread program resources geographically and evenly among various targeted groups). And, shifts in political ideology at the gubernatorial level can and do cut short the lives of apparently effective programs. See further discussion on this issue in the section on metrics later in this chapter.

[43] This list and associated descriptions are taken from SRI International, 2008 and 2012.

supported by industry and foundation contributions. GRA's main activity has been to recruit researchers to Georgia universities by attracting academic "stars" through the Eminent Scholars program (see case study of GRA that follows this section), but more recently the GRA Ventures program promotes commercialisation of university-based technologies through grants and low-interest loans to start-ups.

IllinoisVENTURES, LLC. Established in 2000, IllinoisVENTURES is a seed and early-stage technology investment firm focused on research-derived companies in information technologies, physical sciences, and life sciences, with a particular emphasis on those deriving from research conducted at the University of Illinois and other regional research institutions and federal laboratories. IllinoisVENTURES is the general partner for the Illinois Emerging Technology Fund (IETF), a $20 million venture capital fund formed in 2004. The State and the University of Illinois provide about $4 million for IllinoisVENTURES, but the IETF is entirely privately funded.

Ohio Third Frontier. The Ohio legislature created the Ohio Third Frontier (OTF) program in 2002 to expand Ohio's technology-based research capabilities and to promote innovation and new company formation to create and retain high-wage jobs. It is Ohio's largest-ever investment in a technology-based economic development program and consists of the following programs:

- Wright Centers of Innovation and Wright MegaCenter funds university-based Centers of Excellence in target technologies.
- Research Commercialisation Program provides awards for applied research in science and technology with excellent commercialisation potential.
- Ohio Research Scholars Program endows chairs at Ohio universities in targeted technology platforms.
- Wright Projects provides awards for capital equipment purchases to build university and firm collaboration.
- Entrepreneurial Signature Program provides mentoring to entrepreneurs.
- Pre-seed Fund Capitalisation provides grants to accelerate the growth of early-stage Ohio technology companies.
- Fuel Cell Program supports applied R&D that addresses technical and cost barrier to fuel cell commercialisation.
- Advanced Energy Program supports applied R&D that addresses technical and cost barrier to commercialisation and adaptation of advanced energy system components.
- Ohio Research Commercialisation Grant Program provides support to improve the commercial viability of technologies development through SBIR, STTR, and Advanced Technology Program R&D projects.
- Targeted Industry Attraction Grant Program provides incentives for out-of-state companies in target industry sectors to locate new technology facilities in Ohio;
- Innovation Ohio Loan Fund provides subsidized debt financing to established companies.
- OTF Internship Program supports internship of science, engineering, technology, and mathematics students with Ohio companies.

Of the total funds awarded from 2003-2008, 76.2% went to improving university-industry-non-profit research collaboration and creating a world-class R&D capacity in target technology platforms relevant to Ohio industry. Approximately 13.3% of awarded funds went to supporting technology entrepreneurs through investments in formal support programs, as well as investments in pre-seed funds. Close to 10% of awarded funds went to product development assistance – providing support to new or existing companies trying to commercialize products based on new technologies. Less than 1% of award funds during this period went toward incentives to attract out-of-state companies in target industry sectors and toward supporting the placement of science, engineering, technology and mathematics students with Ohio technology-based companies.

Pennsylvania Ben Franklin Technology Partners. The Pennsylvania General Assembly created the Ben Franklin Technology Partners (BFTP) in 1982. The organisation has four regional offices located across the state. Each regional office is run independently; however, they speak as one voice to the legislature through their Managing Director of Statewide Initiatives. BFTP is funded mainly through the Department of Community and Economic Development via a general appropriation divided evenly between the offices. Although some BFTP funding goes to education and economic development organisations, BFTP mainly supports entrepreneurs and early-stage and established companies. In previous years it has supported some basic and translational research, but these programs have not been funded since 2007. Each BFTP office decides how to implement its program in the context of its region's strengths and needs. All offices provide both financial investments in companies as well as business mentoring in the form of networking, experts-in-residence, incubators, and SBIR/STTR[44] editorial assistance and award matching.

Utah Science Technology and Research Initiative. In 2006, the Utah legislature created Utah Science Technology and Research Initiative (USTAR) with the following goals:

- Recruit top-level researchers;
- Build state-of-the-art interdisciplinary research and development facilities;
- Form science, innovation, and commercialisation teams across the state.

The majority of USTAR's funds support innovation teams at the University of Utah and Utah State University. The money goes to attract researchers from other states using USTAR funds for research support and to build research space. The buildings are funded through bonds and private donations, whereas the funds to attract and support researchers are appropriated by the Utah Legislature every year. USTAR also runs the Technology Outreach Program, which supports commercialisation activities across the state and includes SBIR application assistance and two business incubators. This program has six satellite offices throughout the state associated with non-research universities. The program is a resource for universities to commercialize innovations and to assist Utah entrepreneurs, businesses, and innovators by providing support in business development and SBIR/STTR editorial support.

Virginia's Center for Innovative Technology. Virginia's Center for Innovative Technology was established in 1985 and is funded by the Commonwealth of Virginia. It seeks to create new technology companies and jobs. It provides R&D funding and first seed stage investment. The CIT GAP Funds is a family of venture funds designed to bridge the gap between "family and friends" funding and early stage equity investments for Virginia-based technology and live science companies.

[44] See https://www.sbir.gov and Chapter V of this report.

6.3 The Georgia Research Alliance: example of a highly successful TBED organisation[45]

The Georgia Research Alliance (GRA) represents the most recent of three significant statewide efforts by Georgia to develop and implement policies to promote science and technology-based economic development. The first was the Industrial Extension Service, a state-wide network of Georgia Tech field offices established in 1960; the second was the Advanced Technology Development Center, a university-based high technology business incubator created in 1980; and the third was the Georgia Research Alliance, founded in 1990 to foster economic development by improving and leveraging the capabilities of the state's research universities. Although statewide rather than metropolitan or regional in its focus, GRA offers an interesting and successful model for fostering cooperation among both public and private universities, while simultaneously strengthening their capabilities to leverage increased research support from federal and industrial sources.

GRA's genesis rested in part on failure: the failure of Georgia to compete successfully in the 1984-85 competition to site the Microelectronics and Computer Consortium (MCC), eventually built in Austin, Texas. As was the case in several states that competed unsuccessfully for this and similar high-tech prizes during the 1980s, Georgia's political and industrial leaders understood more fully than before both the potential that research-based activities offered for economic development, as well as the significance of the research infrastructure that such development required. Strongly encouraged by Lawrence Gellerstedt and Thomas Cousins, two wealthy and politically well-connected real estate developers, Governor Joe Frank Harris created a committee of businessmen who in turn asked McKinsey & Co. to analyse the reasons for Georgia's failure to win MCC. The resulting report recommended that the state enhance its university-based research capabilities by investing in laboratories and equipment, stronger research faculty, and a new organisation to link universities and industry. In 1985, Governor Harris established the Governor's Research Consortium, an R&D investment program to establish centres of excellence at Georgia's research universities. The Consortium funded an Advanced Computational Methods Center and a Life Science Center at the University of Georgia (1985-86), the Manufacturing Research Center and Institute of Paper Science and Technology at Georgia Tech (1988), and the Rollins Research Center at Emory University (1988). Typically, the state provided substantial support for facilities and equipment, with commitments from the universities to attract additional research funding from external sources.

The Consortium provided facilities and equipment and leveraged sponsored research, but did not provide funds for investment in research personnel, nor did it foster linkages between universities and industry. Gellerstedt and Cousins recognized this gap and conceived the GRA in 1990, an election year. The key concept of GRA was drawn from North Carolina's Research Triangle experience, which focused on cooperation and collaboration among the state's research universities. Realising the importance of having the top research universities in the state buy into the idea at an early stage, the business group obtained the support of the

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[45] This historical analysis of the Georgia Research Alliance draws extensively on R.S. Combes and W.J. Todd, *From Henry Grady to the Georgia Research Alliance: A* Case *Study of Science-Based Development in Georgia*. Atlanta, GA: Georgia Research Alliance, nd., available at http://www.gra.org/background.html; and W. Henry Lambright, Catalyzing Research Competitiveness: The Georgia Research Alliance, *Prometheus*, 18, 4 (2000): 357-372.

presidents of Georgia Tech, the University of Georgia, and Emory University (two public and one private institutions), with the other research universities expected to join the Alliance later. (The cooperation of the university presidents was facilitated by the fact that Gellerstedt and Cousins served on the Boards of Trustees of two of the three initial university members of the Alliance.)

The business leaders who conceived of the GRA lobbied both gubernatorial candidates before the election and secured their support. As a result, the GRA became part of both candidates' economic development plans. It did not hurt that Gellerstedt and Cousins were potential contributors to both candidates' campaigns; they made it clear that their contributions were contingent upon each candidate's support of GRA. Zell Miller was elected Governor and fulfilled his promise by supporting GRA enthusiastically and guiding the funding initiative through the legislature. GRA was created as a 501c3 (not-for-profit) corporation, with the Governor serving as an ex officio member of the Board of Trustees. The Trustees initially consisted of twelve CEOs of Georgia-based businesses and the presidents of six Georgia research universities, each of whom has one vote.[46] Gellerstedt served as chair of the first GRA Board of Trustees. (The Medical College of Georgia, Georgia State University, and Clark Atlanta University joined GRA shortly after its creation.) The first appropriation (FY 1993) was for $15 million, to be used to fund three Eminent Scholar positions and to modernize research laboratories at the state's research universities.

Cooperation among Georgia's research universities was critical to the success of GRA. First, support of the initial three presidents was essential if the GRA proposal was to be deemed credible by the gubernatorial candidates and the legislature. Second, after its formation, the Alliance was promoted as "an initiative that heralded a new era of cooperation among the state's research universities." Finally, proposals from Georgia universities and colleges, to be considered eligible for funding by GRA, must involve more than one institution. It is important to note that, prior to 1986, Georgia's university presidents had been "disinclined to pursue such cooperative efforts." The Board of Regents of the University System took advantage of turnover in the presidents at Georgia Tech and the University of Georgia after 1986 by charging the new presidents explicitly with interuniversity cooperation. Since the Regents are responsible for allocating state appropriations among its public institutions of higher education, this charge had more than a little clout.

GRA's research support programs are concentrated largely in three strategic areas: advanced communications, biotechnology and environmental technologies. The choice of these three areas was strongly influenced by a second McKinsey & Co. analysis that recommended targeting these areas as well as funding "eminent scholars" as the key GRA strategy for research-based economic development. Through fiscal year 1999, the state of Georgia had invested $242 million through the Alliance in research and development programs at its six member universities, matched by $65 million in private funds. This investment, in turn, helped to attract over $600 million in additional sponsored research. This investment program includes the establishment of endowments for 32 eminent scholar chairs, priced at about $3.5 million each.[47]

[46] Membership on the Board was later expanded to include representatives from other sectors. Contributions from business and university assessments support the Board's operations.

[47] http://www.gra.org/background.html

Concrete evidence that GRA's strategy was paying off began to accumulate beginning in 1994, when Georgia Tech won an NSF Engineering Research Center award. This was followed by another ERC award to a Georgia Tech-Emory team in 1998, and an NSF Science and Technology Center award to a coalition led by Emory and Georgia State in 1999. Usually, GRA-supported eminent scholars provided the intellectual leadership behind the proposals for these centres.

In the mid-1990s, GRA faced a political challenge based on the inevitable pressure from the legislature to spread public largesse geographically. GRA investments were largely confined to the metropolitan Atlanta area, and its supporters argued that the "trickle down" effect meant that, eventually, the entire state benefited from targeted investments in the research infrastructure. GRA argued that a critical mass was essential if the strategy were to work, that any effort to distribute funds more broadly among Georgia's institutions of higher education would sacrifice quality and thereby diminish GRA's economic impact on the state. These arguments prevailed, but the distributional issue has to be addressed continually.

Thus GRA has been, in Lambright's words, an effective "catalyst" for enhancing Georgia's research competitiveness. Lambright identified five factors that account for GRA's effectiveness:

- "Patrician" leadership, consisting of CEOs and university presidents with the authority to commit their organisations' resources, augmented by GRA's astute first Executive Director, Bill Todd, and by consistent and strong support from then-Governor Miller;
- Autonomy arising from GRA's nongovernmental structure in a politically conservative atmosphere, where a governmental agency might not have received the same support;
- A strategy that targeted specific areas of comparative advantage in research and attracted research "stars" in these areas;
- The Georgia context, which was permissive for an enterprise such as GRA to be conceived and managed by an elite group that emphasized economic rather than social (distributional) goals;
- A competitive spirit, driven by Georgia's strong desire to move out from behind the shadow of North Carolina and directly challenge even the leading states in the nation for leadership in research-based economic development.

GRA has acquired a total of $595 million in public support over its entire history. This support has been invested almost completely in the Alliance's programs; currently, 100% of its operations and management comes from private sources. In addition to its flagship Eminent Scholars program, its newer commercialisation program, GRA Ventures, focuses on commercialising technologies and discoveries emerging from the state's research universities. Since 2002, GRA Ventures has evaluated more than 900 university technologies and inventions, facilitated the commercialisation of more than 250 university-based technologies through commercialisation grants totalling $17 million, and provided $8 million in low-interest loans to 35 promising companies. GRA's FY2013 budget was $20.7 million, increasing to just over $23 million for FY2014. In its first 20 years, GRA helped to increase the state's six universities' sponsored research by 250%, and generate $2.6 billion in federal and private investment over the same period. The Eminent Scholars program has recruited 62 new faculty "stars," instrumental in generating the increases in university research funding. According to the 20th Anniversary report, the Alliance "fuelled the launch" of more than 175 companies, and its overall activities led to the creation of 5500 high-wage jobs (Georgia Research Alliance, 2010, and www.gra.org).

6.4 TBED best practices

Most state TBED organisations have been evaluated by an external evaluator at some point in their history, and many of them several times. These reports sometimes include discussions of the features of what the organisation's management considers to be effective policies and practices. In addition, organisations such as the SSTI, the National Governors Association, and the National Academies have generated reports that augment the material found in individual evaluations with additional data acquired from interviews and workshops. Most of these reports, such as the 2006 SSTI Resource Guide, are far too long and complex to summarise here. However, the SSTI report remains a valuable reference for state planners interested in initiating or improving the following types of development strategies:

- University-industry research centres
- Eminent scholars programs
- Industry-university matching grants
- University Technology Commercialisation Programs
- Assisting start-ups
- Increasing deal flow
- Promoting a culture of entrepreneurship
- Encouraging private investment
- Providing direct funding to firms

Of particular relevance for the present report is SSTI's summary description of key success factors in university commercialisation programs:

- Managers of commercialisation programs say that having sources of flexible funding is a key factor in being able to move technology into the marketplace. There are few, if any, sources of very early-stage funding to assess the commercial potential of a new discovery. A small amount of funding, that does not require a repayment, is needed to conduct testing, to validate the technology and to determine whether it meets a market need at a competitive price.
- A second critical factor in the success of commercialisation of programs is their ability to connect university inventors with investors and commercial partners. Managers of commercialisation programs report that their primary role, and the factor that will determine how successful they will be, is their ability to make connections: connecting researchers with promising technology with the entrepreneurs who have the ability to commercialize it; then connecting those entrepreneurs with sources of capital.
- A final factor that centres like the Deshpande Center at MIT[48] have identified as critical to successful commercialisation is the ability to tie research to market needs. Encouraging interactions between university researchers and industry can help to ensure that researchers are aware of both developments in the marketplace and the technological challenges facing specific industries. If this knowledge drives their research, it is much more likely to lead to discoveries with commercial potential.

[48] deshpande.mit.edu.

Another valuable synthesis of lessons learned about state and regional innovation initiatives can be found in the 2013 report edited by Wessner of the National Academies. Again, there is far too much material to cover in the space available here, but following are the report's short summaries of lessons learned in key categories of development initiatives.

State and Regional Development and Clustering

- State, regional, and local governments are in a strong position to lead local innovation-based economic development, reflecting their control over local factors of production and influence over the education and research infrastructure, and knowledge of local innovation culture.
- State and regional governments are pursuing the establishment of innovation clusters as their major development policy tool.
- Most of the state and regional developmental efforts that the Committee has considered seek to build on existing local advantages arising out of their geography, industrial legacy, and culture, rather than seek to establish entirely new competencies.
- Regional culture and attitudes toward innovation, collaboration, and entrepreneurialism are a key determinant of success as failure in innovation-based development.

Universities as Innovation Drivers

- A distinguishing feature of the American innovation ecosystem is that it is driven by a network of superb research universities.
- This innovation ecosystem is dominated by triadic collaborations involving universities, industry, and government, with institutional arrangements that promote ilo-breaking and multidisciplinary research.
- The decentralisation of the U.S. university system lends itself to differentiated state and regional innovation strategies that leverage local geographic, industrial legacies and cultural advantages.
- U.S. community colleges are an important resource base for creating the high-skills work force needed to sustain an innovation-based economy.
- The decline in state funding for public research universities and community colleges represents a fundamental threat to the nation's capacity to create and capture the fruits of innovation.

State Strategies for Innovation

- State government economic development efforts, traditionally centred on incentives-based industrial recruitment, are now also emphasising knowledge-based initiatives and the creation of innovation clusters.
- Recruitment-based development efforts centred on research universities have proven effective) Research Triangle Park in North Carolina, Tech Valley in New York State).
- As the experience of Michigan's Battery Initiative demonstrates, even very well-endowed state innovation initiatives face daunting challenges, including demand uncertainties intrinsic to investments in industries of the future, formidable foreign competition, and gaps in U.S. industry chains.

6.5 Measuring the effectiveness and impact of TBED programs

In an early study of performance measurement in state technology transfer and commercialisation organisations and programs, Melkers and Cozzens (1997) surveyed science and technology-based programs in all 50 states and conducted eight case studies to determine the extent to which such programs used performance measures and conducted evaluations of program effectiveness. They also collected information on the specific kinds of measures used and the reasons for using some measures over others. They found that the reasons for evaluating program performance, not surprisingly, varied widely across programs. Many states require publicly-funded state agencies to produce performance measures and data as part of their legislative mandates. As alternatives to, or in addition to, legislatively-based requirements, ten states (at the time of the study) were required to produce performance-based measures either by Executive Order or from the central budget authority. Often more important than such mandates were internally-generated assessments conducted for management purposes (outcome-based management). Usually both rationales were at work, with organisations varying widely on the resources devoted to each performance measurement, the methods used to collect data, the measures of performance used, and ways results were communicated to stakeholders.

Forty-four states responded to the survey. Almost half of the respondents reported collecting performance information on a regular basis, and a third indicated they had also supported at least one large external evaluation. The most common measures used were a mix of process, demand, and outcome metrics, with outcome measures receiving the greatest attention. Typical outcome measures included jobs created and jobs retained, new business starts, patents awarded, and cost savings. Typical output measures included number of clients served, funds leveraged, and business plans completed. Activity measures included grants awarded, application received, seminars given, workshops held, etc. The following table shows the proportion of respondents reporting use of specific measures.

Table 6.1: Performance measures reported in State science and technology programs, 2006

Measures	Reported Collection (n=44)
Number of projects the organization has funded	68.20%
Matching/leveraged funds	68.20%
Jobs created/new jobs	65.90%
Number of organizations assisted	61.40%
Number of requests for assistance	56.80%
Spinoffs/new firms	56.80%
Patent/license application/receipt	54.50%
Jobs retained	54.50%
Customer satisfaction measures	50.00%
New products	50.00%
Average salary of jobs created	43.20%
Increased sales	45.50%
Cost savings/cost avoidance	43.20%
Average salary of jobs retained	36.40%
Number of collaborations	36.40%
Profits	34.10%
Number of publications	34.10%

Source: Melkers and Cozzens, 1997

The case studies conducted by Melkers and Cozzens reflected these patterns, e.g., the most common were measures of job creation and leverage of funds awarded under various programs. Table 6.2 shows these results on a state-by-state basis. In the interviews, however, anecdotal evidence received high marks as a means of communicating performance to key stakeholders such as state legislatures.

Table 6.2: Output and outcome measures in the case study States

Measures	AR	IN	KS	MN	OK	PA	TX	UT
Jobs created/new jobs	X	X	X	X	X	X	X	X
Average salary of jobs created				X		X	X	X
Jobs retained		X	X	X	X	X		
Average salary of jobs retained						X		
Spinoffs/new firms						X	X	X
Patents/licensing	X		X		X		X	X
Matching/leveraged funds	X		X		X	X	X	X
Increased sales		X	X	X	X			
Cost savings/cost avoidance		X	X	X				
New product development	X		X	X				
New products commercialized			X			X		
Number of publications					X		X	
Number of collaborations					X		X	
Increased capital spending		X	X					
Customer satisfaction measures			X	X				

More recently, SRI International (SRI, 2012) conducted an assessment for the Oklahoma Center for Advanced Science and Technology (OCAST) of their internal performance measures and how the results were communicated to relevant stakeholders. As part of the study, SRI staff interviewed representatives of benchmark states to obtain information on what metrics each found most useful and/or effective, and what means of communicating results to stakeholders proved to be most effective in communicating the value of their organisation's programs to stakeholders. In advance of these interviews, SRI obtained advice via telephone from Dan Berglund, SSTI President, on his views of the most effective and valid measures of impact (which are not necessarily the same), the most effective means of communicating the results, and which states practices should be benchmarked against Oklahoma. Regarding performance measures, Berglund recommended two sets, the first for programs that seek to stimulate early stage innovative activity, and the second set for later stage programs:
"Upstream" performance metrics, such as:

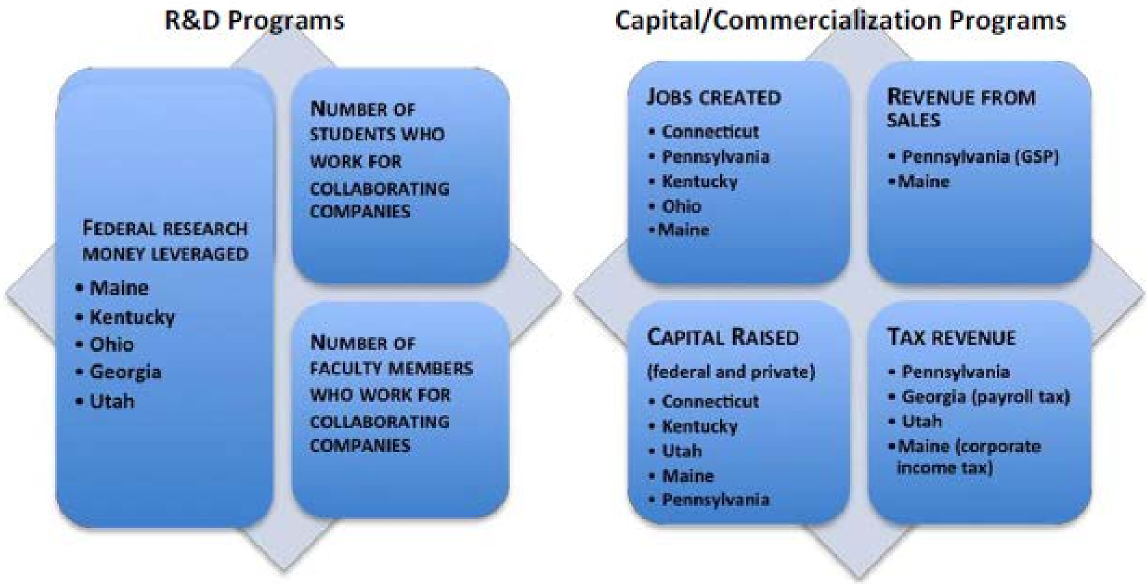
- Federal research funds leveraged by the state's investment,
- Number of graduate students hired by collaborating companies, and
- Number of faculty hired by collaborating companies.

"Downstream" performance metrics, such as:

- Jobs created,
- Sales revenues, and
- Capital raised, especially from outside the state.

Following interviews with representatives from seven benchmark states (Connecticut, Utah, Pennsylvania, Maine, Kentucky, Ohio, Georgia), SRI combined the results and produced the following graphic showing SSTI-recommended metrics in two groups, those targeting upstream programs (R&D related) and those targeting commercialisation focused programs, and usage of these metrics across the seven benchmark states (SRI, 2012).

Figure 6.1: Recommended metrics grouped by benchmark States



Interviews with representatives from the benchmark states showed that although some use return-on-investment measures occasionally, most do so only in aggregate form rather than for specific programs within the scope of their funding. This is considered effective in getting the attention of stakeholders, especially legislators, since typically it serves as a necessary element in the arsenal of arguments used by other agencies competing for public funds. Several states use input-output models of the state economy to generate estimates of the impact of the TBED agency's investments on employment, tax revenues, gross state product, change in personal income, and various other measures of economic development. Some argue that measures such as increased tax revenues can be compelling to stakeholders, but others argue that the multipliers used in such models have little credibility in some quarters.

Finally, in thinking about the merits of various measures of impact or performance, it is important to distinguish between the rigor of metrics typically chosen by professional evaluators concerned about their validity and reliability, and the credibility or effectiveness of the same metric set in the eyes of the policymakers it is intended to influence. Experience has shown that a measure may be valid and persuasive in the eyes of the professional evaluator, but not necessarily credible in the eyes of the policymaker, and vice versa.[49] This explains why virtually all TBED agencies use a mix of "rigorous" metrics and methods for gauging performance and anecdotal cases that illustrate specific examples of causal links between program investments and desired economic outcomes.

[49] See, for example, Shapira, P. and Youtie, J. 1998. Evaluating Industrial Modernization: Methods, Results, and Insights from the Georgia Manufacturing Extension Alliance, *Journal of Technology Transfer* 23(1): 17-27.

7 Concluding observations: applicability to the Australian context

Each of the five measures described in this report requires some form of collaboration between two types of disparate institutions: non-profit organisations whose primary or secondary mission is the conduct of research, and profit-making businesses whose profits depend significantly on their ability to develop and commercialize new technology. All five measures faced similar barriers or constraints to their effectiveness: the clash of institutional cultures, differences in primary goals and incentive systems, lack of familiarity and trust between the prospective collaborators, burdensome regulations imposed by governments to protect taxpayers' investments, and potential conflicts of interest. These constraints are common in one form or another to nearly all such measures, regardless of the larger political or economic contexts in which they are implemented.

The Australian experience illustrates that, broadly speaking, constraints faced by U.S. measures of this type are faced there as well. Chapter 3 of ACOLA's 2014 report*, The role of science, research and technology in lifting Australian productivity*, describes these barriers and provides examples of successful programs (such as the Collaborative Research Centres) showing they can be overcome. At the same time, the report states that, despite some successes, overall Australian experience with measures to foster researcher-business collaborations is not satisfactory. Since the majority of researchers in Australia work in the public sector rather than in industry (the reverse of the situation in the U.S. and Europe), and the research expenditures by private businesses vs. public institutions in Australia reflect this structural situation, it strikes this author that significant movement toward the desired levels of public-private research collaboration are unlikely to occur without accompanying changes in the structure of public vs. private expenditures on R&D. In any case, decades of U.S. experience shows that even within a more favourable context of institutional expenditures for R&D, overcoming barriers originating in mismatched institutional cultures, lack of trust based in unfamiliarity or inexperience across institutional boundaries, and burdensome rules and regulations requires powerful incentives and a lot of patience in both government and industry.

All five measures considered in this report had their origins nearly four decades ago. Although negotiations over intellectual property rights remains an issue, the sea change (almost literally a revolution) in U.S. political views and public perceptions regarding how best to realise the national economic value of publicly-funded research launched the legislative foundations that began, albeit slowly, to change the conflicting institutional cultures and cross-institutional mistrust and inexperience that impeded researcher-industry collaborations. The core of the revolution was a misleadingly simple realisation: "that which belongs to everyone creates value for no-one." Launched only five years after the Bayh-Dole Act was passed in 1980, the first generation of NSF's Engineering Research Centers demonstrated by the mid-1990s that both companies and universities could benefit from research collaboration, and they did so in the face of years of painful learning experiences between university technology transfer offices and prospective company licensees. In the first decade of the new century, many more students and faculty realised the benefits of working on industry-relevant problems—literally a slow revolution in university culture. In U.S. federal laboratories, CRADAs provided the legal mechanism for federal lab-industry research collaborations, but implementation required strong, top-down pressure on labs to support a secondary laboratory mission. Here, too, a long adjustment period for cultural changes by lab managers, lab researchers, and potential business partners was required before CRADAs began to pay off as desired. In the case of SBIR/STTR, despite general recognition of a serious lack of financing for early-stage technology ventures and the important role that small businesses played in national innovation and job growth, the influece of the powerful small business lobby was instrumental in getting the initial legislation passed and contually reauthorized with ever-increasing funding. Even after decades of favourable experience with SBIR and STTR, presenters at the STTR workshop held by the National Academies in May of this year referred to continuing issues of burdensome rules and regulations and lengthy intellectual property negotiations. Nonetheless, one key university participant in the workshop observed that the STTR program was an important influence in changing not only the culture of the university, but the culture of small businesses as well. Finally, state TBED organisations relied heavily on the legal and financial foundations provided by Bayh-Dole, CRADAs, SBIR, STTR, and most importantly the large amount of federal support for research conducted in state-based universities. States that failed to provide long-term, stable support for TBED organisations suffered economically relative to states that had the foresight and patience for the cultural changes and learning experiences in their local universities and businesses to bear fruit. In sum, powerful incentives can induce behavioral change, but in the U.S. experience, the effectiveness of policy and program measures rests substantially on changing institutional cultures—all too often a painful and slow process.

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