Public-Private Collaboration in Agricultural Research

Historically, the Federal-State agricultural research and extension system played a direct role in developing new technologies and encouraging their commercialization and adoption by farmers. Agriculture has been unique in this respect, compared with other sectors of the U.S. economy. The emergence of a strong private sector capacity in agricultural R&D has created new challenges and opportunities for the agricultural research system. There is now less need for the public research and extension system to provide finished technologies to farmers. This allows more public resources to be devoted to more fundamental, or pre-technology, research on scientific problems. However, an effective research system should be organized in a way that closely links basic and applied research. Otherwise the productivity of each may be adversely affected (Ruttan, 1982, 1983). Without institutional linkages between public and private research, R&D efficiency may decline and economic competitiveness suffer (Mowery and Rosenberg, 1989; Congressional Research Service, 1991).

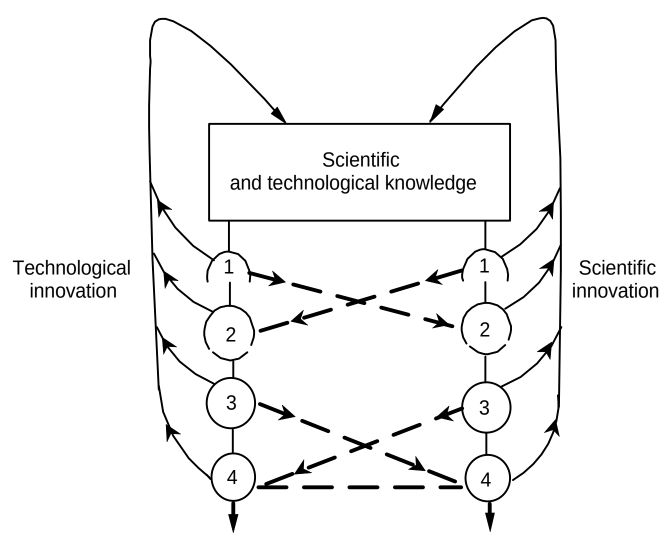
In the 1980's, concerns that the U.S. economy was losing its technological edge in key industries led to new Federal policies. These policies encouraged public-private research collaboration and promoted rapid commercialization of new inventions. These policies included the Bayh-Dole Patent Policy Act of 1980 (P.L. 96-817), the Stevenson-Wydler Technology Innovation Act of 1980 (P.L. 96-48), and the Federal Technology Transfer Act of 1986 (P.L. 99-502). The 1980 Patent Policy Act allowed researchers to patent and issue exclusive licenses for technologies developed from federally supported research. The 1980 Technology Innovation Act and its subsequent amendment, the 1986 Technology Transfer Act, created an institutional mechanism for direct collaboration between government and private research laboratories—a Cooperative Research and Development Agreement (CRADA). USDA has been particularly active in using CRADA's to foster research collaboration between its research laboratories and private firms.

A Model of Science and Technology Innovation[15]

The traditional view of science and technology was that there is a direct linear relationship between advances in the two: progress in basic science led to the development of new technology (Bush, 1945). However, the interactions between science and technology are often more complex than this view suggests. Modern perspectives of the innovation process consider scientific and technological research to be two parallel but interacting paths (fig. 11). The two innovation paths are connected through the pools of existing scientific and technological knowledge from which both borrow and to which both contribute. Innovation along each path is imagined as a four-step process involving: (1) perception of a problem or incomplete pattern; (2) collecting research resources that can address the problem; (3) act of insight, when a solution to the problem is found; and (4) critical revision, in which newly perceived notions become more fully understood (Usher, 1954). In this process, science policy has most influence on step (2), where the scientific and technical resources are brought together to develop a solution to the problem. Step (3), the act of insight, entails a large element of uncertainty. This uncertainty makes it difficult to predict the timing and type of innovations.

The linkages and interactions between science and technology occur at all of the stages of the innovation process. For example, the development of a new alfalfa variety with enhanced nitrogen fixation involved contributions from science-oriented research in biochemistry,

Figure 11
Stylized model of scientific and technological innovation



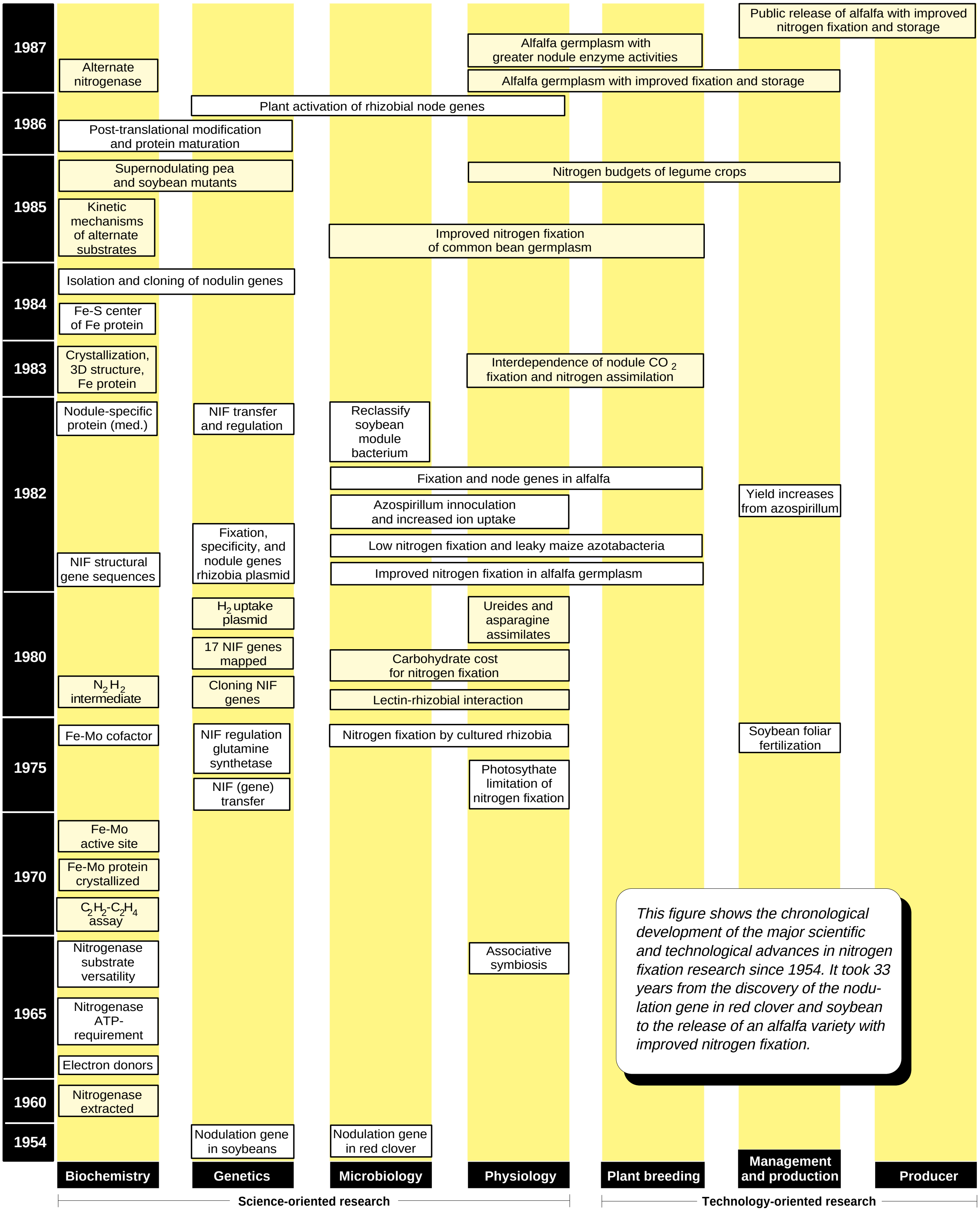
Stage 1: Perception of the problem
Stage 2: Bringing together elements of a solution
Stage 3: Act of insight, which permits solution of the problem
Stage 4: Revision, refinement, and improvement

Source: Economic Research Service from Ruttan (1982).

[15]This section draws heavily upon Ruttan (1982).

Figure 12

Science and technology breakthroughs in nitrogen fixation of a new alfalfa variety



Source: Economic Research Service adapted from Heichel, 1987.

genetics, microbiology, and plant physiology together with technology-oriented research in plant breeding and farm management (fig. 12). It took more than 30 years from the time science-oriented research identified the nodulation genes until technology-oriented research led to the release of the first alfalfa variety with enhanced nitrogen fixation. The effort relied on both disciplinary and cross-disciplinary research and interaction among scientists at several research institutions (Heichel, 1987).

Sometimes, a single individual or research team may occupy a leading position in advancing knowledge along both scientific and technical paths. In 1870, Louis Pasteur invented the modern science of bacteriology while he was trying to solve some practical problems involving wine fermentation and putrefaction. Commonly, however, leadership along each path proceeds at separate institutions and institutional partnerships are critical for success. In the 1920's, George Schull of the Carnegie Institute and Donald Jones of the Connecticut agricultural experiment station combined efforts. This led to the theory of hybrid vigor and the invention of the double-cross method of hybrid seed production. Presently, the close relationship between scientific (molecular genetics) and technological (genetic engineering) advances in biotechnology is also evident (Ruttan, 1982).

Effective institutional linkages between public and private research laboratories can increase the flow of both science-oriented and technology-oriented knowledge across the system. Private agricultural research is often more technology-oriented compared with public research. More than 40 percent of private agricultural R&D is for development research, compared with only 7 percent of public agricultural research. On the other hand, basic research is largely the responsibility of the public sector. Firms classify only about 15 percent of their agricultural research expenditures as basic research, compared with 47 percent of public agricultural research (table 18). The synergies between basic research and applied R&D suggest that effective linkages between public and private research laboratories can increase the productivity of both parts of the system.

Table 18—Shares of agricultural research expenditures devoted to basic, applied, and developmental research

	Type of research		
Source	Basic[1]	Applied[2]	Developmental[3]
Public	47.3	45.4	7.3
Private	15.0	43.5	41.5

[1]Basic research is conducted to determine the basic cause or mechanism of why certain results are obtained. [2]Applied research develops knowledge or information directly relevant to technology, to product development, or to market possibilities. [3]Developmental research generates a new or improved technology or product; supports market testing and introduction; maintains product performance and quality; or meets regulatory requirements.

Sources: Compiled by Economic Research Service. Public research data are for 1992 and from *Inventory of Agricultural Research,* USDA, 1993; private research data are for 1984 and from Crosby, Eddleman, Kalton, Ruttan, and Wilcke, 1985.

Public-Private Cooperation in Plant Breeding

Plant variety development is an area where there has been considerable discussion about the appropriate roles of public and private research (Ruttan, 1982; Knudson, 1990). Historically, the public sector was the dominant supplier of new varieties for field crops, while the private sector was the main source of new varieties for home garden and horticultural crops (Ruttan, 1982). For field crops, public sector plant breeders supplied foundation seed to private seed companies for multiplication and distribution to farmers. States enacted seed-certification programs to ensure that distributed seed was of appropriate quality. This pattern began to change in the 1930's when economical methods of producing hybrid corn became available. Hybrid seed technology offered a natural way to protect private investments in varietal improvement since farmers need to repurchase hybrid seed each season. The passage of the 1970 PVPA strengthened economic incentives for private research on nonhybrid crops as did *Ex parte Hibberd* in 1985.

The private sector is now making significant investments in plant breeding for most agricultural commodities. Between 1982 and 1989, there were significant increases in private plant breeding for corn, vegetables, soybeans, alfalfa, sugar beets, and canola (table 19). Both the number of companies and scientists engaged in breeding programs increased for these crops. Investments in wheat, sorghum, rice, and peanut breeding were stagnant over this period. While estimated nominal expenditures for these crops rose, the number of companies conducting wheat and sorghum breeding fell significantly and the number of breeders remained about the same. For cotton, sunflowers, safflower, and other small grains (oats, barley, rye, and triticale), private-sector investments in breeding declined. These adjustments reflect changing perceptions in the seed industry concerning the profit potential of its research investments. These perceptions are based on expectations about future growth in seed sales, the ability to protect intellectual property, and technological opportunities in biotechnology and plant breeding.

Table 19—Private plant breeding in the United States, 1982 and 1989

	Companies		Ph.D. breeders		Expenditures[1]	
Crop	1982	1989	1982	1989	1982	1989
	Number				*Million dollars*	
Corn	66	75	155	257	43.8	112.9
Vegetables	44	37	96	108	24.7	53.6
Soybeans	26	34	36	60	9.1	24.9
Wheat	21	11	23	25	6.7	13.5
Alfalfa/forage legumes	14	16	23	28	5.9	13.3
Sorghum	21	15	22	23	6.3	12.6
Sugar beets	5	10	14	22	1.7	9.8
Turf grass	8	16	9	8	1.7	5.9
Flowers/ornamentals	9	9	5	8	1.9	5.9
Sunflowers	16	9	15	7	4.1	4.8
Cotton	13	11	17	11	4.6	4.6
Rice	5	4	7	9	1.4	3.7
Canola	0	6	0	4	0.0	2.4
Oats, barley, rye, and triticale	11	6	7	5	1.5	2.3
Forage grasses	5	8	2	2	0.8	0.8
Peanuts	0	1	0	1	0.0	0.5
Safflower	3	2	2	1	0.4	0.4
Fruits	2	2	0	0	0.5	0.1
Total[2]	n.a.	n.a.	434	580	115.0	272.0

n.a. = Not available.

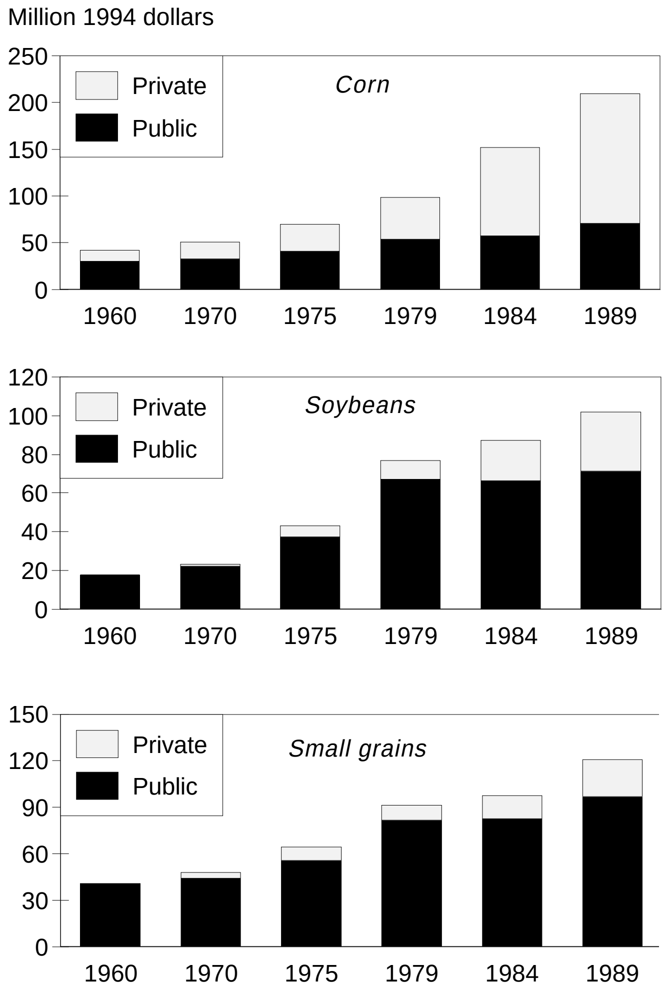
[1]Kalton, Richardson, and Frey (1989) only report an estimate of total expenditures for plant breeding. To compute expenditures for individual commodities, total breeding expenditure was multiplied by the proportion of all scientific full-time equivalents working on each crop. A weight of 1.0, 0.7, and 0.5 was given to each Ph.D., M.S., and B.A. scientist-year, respectively, to compute the proportions (see Kalton, Richardson, and Frey (1989) for complete data on scientist-years). [2]May not add due to rounding. The total number of companies participating in plant breeding cannot be inferred from this table since one company may breed many crops.

Source: Economic Research Service derived from Kalton, Richardson, and Frey, 1989. Private breeding for fruits and flowers is likely to be underestimated because breeding by individuals is not included.

The emergence of strong private breeding programs for some crops has affected the role and emphasis of public agricultural research. For hybrid corn, where the private sector can appropriate a large share of the gains from plant breeding, seed companies have invested heavily. By 1989, private seed companies accounted for more than 70 percent of total expenditures on varietal improvement for corn (fig. 13). Public sector programs moved to more pre-technology research, such as corn genetics and enhancing the germplasm pool used by private breeders (Ruttan, 1982). The Genetic Enhancement for Maize (GEM) initiative has established institutional linkages between public and private research in corn breeding. GEM is a consortium of Federal, State, and private seed companies designed to identify and introduce important new traits into the corn germplasm pool used to develop new varieties. The principal goal of the consortium is to screen and adapt exotic germplasm for use in corn breeding. Under the terms of GEM, the participants agree to share information and varietal crosses from exotic germplasm with other members. More than 20 private seed companies are participating in the consortium (Shands, 1995).

Since the late 1960's, private breeding in nonhybrid seed has increased significantly. In 1960, nearly all new varieties of soybeans came from public sector breeding programs (Huffman and Evenson, 1993). Private soybean breeding grew rapidly following the passage of the Plant Variety Protection Act in 1970. By 1990, the private sector had become the dominant source of soybean varieties, although it still provided only about 30 percent of total soybean-breeding expenditures. For small grains (wheat, rice, barley, oats, rye, and triticale), the public sector continues to be the most important source of new varieties. Much of the growth that occurred in private breeding for small grains in the late 1960's and 1970's was for hybrid wheat research. Hybrid wheat proved to have only limited commercial viability. As a result, many companies ended or reduced their

Figure 13
Public and private spending on plant breeding



Sources: Economic Research Service. Data for 1960-84 derived from Huffman and Evenson (1993); data for 1989 private research spending derived from Kalton, Richardson, and Frey (1989); and public research data derived from USDA, *Inventory of Agricultural Research*.

wheat improvement programs. Therefore, public wheat breeding continues to be an important source of finished varieties for farmers (Knudson and Ruttan, 1988; Knudson, 1990; Pray, Knudson, and Masse, 1993). Between 1975 and 1984, the share of private plant breeding for small grains fell from 20 percent to 15 percent of the total (fig. 13). While the overall capacity of the private sector to supply improved crop varieties has increased, it still may not be sufficient to maintain yield growth for several important field crops. The private sector continues to rely heavily on the public sector for pre-technology research.

Public support of research is justified when research is socially valuable but not profitable for private firms (the benefits are not appropriable). Fundamental research on improved breeding methods and the development of elite germplasm are areas that meet this criterion for investment by the public sector. For some crops, such as small grains, there appears to be no adequate incentive for the private sector to invest sufficiently in plant breeding. This is because private companies are unable to capture enough of the economic benefits from improved varieties. The 1994 amendments to the Plant Variety Protection Act may increase private sector research incentives for these crops. New advances in biotechnology breeding methods or hybrid seed technology would also encourage more private research by expanding market opportunities. Another reason for the public sector to maintain some capacity in applied plant breeding is to support its graduate education programs (Ruttan, 1982). Even with the growth in private sector plant breeding, universities will continue to be the main suppliers of scientific and technical staff to these companies. A continued presence by the public sector in applied research can also enhance market competition (Ruttan, 1982; Kloppenburg, 1988). If too few firms dominate the seed industry, lack of competition could result in reduced innovation. However, competition from the public sector can undermine the economic incentives provided by intellectual property rights. Currently there is little evidence to suggest a lack of competition among private seed companies (Butler and Marion, 1985). The role of the public sector in applied plant breeding needs to be periodically re-evaluated in light of developments in the private sector.

CRADA's: Public-Private Collaboration in Research

Federal technology-transfer policy was given new impetus with the passage of the 1980 Stevenson-Wydler Technology Innovation Act and its 1986 amendment, the Federal Technology Transfer Act. These acts mandated that Federal research agencies should pursue technology-transfer activities with private firms. The 1986 Act established a mechanism, CRADA's, through which Federal and non-Federal researchers could collaborate. Before these acts, each Federal agency had its own method for disseminating technological innovations. The acts both mandated the "full use of the Nation's Federal investment in research and development" as well as provided an institutional structure to ease this transfer.

The 1986 Technology Transfer Act permitted Federal laboratories to enter into CRADA's with universities, private companies, non-Federal government entities, and others. A principal objective of a CRADA is to link the fundamental, or pre-technology, research capacity of Federal laboratories with the commercial research and marketing expertise of the private sector. Under a

CRADA, a Federal laboratory may provide personnel, equipment, and laboratory privileges. While the Federal agency cannot provide Federal funds to a cooperating institution, the collaborator may contribute funds directly to a Federal laboratory. The act also established rules regarding the ownership of inventions developed through CRADA's. The cooperating institution receives the right of first refusal to any joint discoveries and may be given exclusive access to data obtained in the research.

CRADA activity at USDA has increased rapidly since the program was first instituted in 1987. Between 1987 and 1995, USDA entered into over 500 CRADA's with private firms. In 1995, USDA had 227 active CRADA's with private companies, involving $61 million of public and private research resources in 1994 (table 20). CRADA's have been particularly important in seeking to develop new industrial uses for agricultural commodities (Glaser and Beach, 1993). USDA also received $1.6 million from patent licenses in 1995.

Table 20—USDA technology transfer activities

Year	Patents awarded	Patent license royalties	Active CRADA's[1]	Value of CRADA's[2]
	Number	*Million dollars*	*Number*	*Million dollars*
1987	34	.09	9	1.6
1988	28	.10	48	8.7
1989	47	.42	86	15.6
1990	42	.57	104	18.9
1991	57	.83	139	25.6
1992	56	1.04	160	30.0
1993	57	1.48	185	34.0
1994	40	1.43	212	61.3
1995	38	1.60	227	n.a.

n.a. = Not available.

[1]Cooperative Research and Development Agreements.

[2]Includes the value of USDA and private sector resources committed to CRADA's.

Source: Economic Research Service compiled from Office of Technology Transfer data, U.S. Department of Agriculture.

The role of CRADA's in furthering technological development can be illustrated with a brief case study of the development of the anticancer drug taxol.[16] Taxol is derived from the bark of the Pacific yew, which is a slow-growing relatively rare tree. Pacific yew bark was first collected in 1961. USDA collected samples as part of an interagency agreement with the National Cancer Institute (NCI) to search for anticancer agents. The active ingredient in taxol was isolated in 1971 but never patented. After revisiting taxol in the 1980's, the NCI decided that the substance was a promising drug and should be commercialized. Through a competitive bidding process, NCI signed a CRADA with the Bristol-Myers Squibb (Bristol) pharmaceutical company. The CRADA specified that NCI would give Bristol exclusive access to its clinical data.[17] Meanwhile, Bristol would give NCI taxol samples for trials and seek regulatory approval from the FDA for commercialization. Shortly after that, Bristol entered an agreement with the USDA and the U.S. Department of the Interior for exclusive rights to harvest Pacific yew trees on Federal lands. In exchange, Bristol would conduct research on alternative sources of the derivative for taxol and the environmental effects of harvesting the Pacific yew. In 1992, the FDA approved taxol for the treatment of ovarian cancer.

The NCI-Bristol CRADA provided a framework to link and coordinate an extensive array of cooperative research contracts. Bristol entered a complex set of research agreements with other public and private entities. These parallel research projects generated substantial basic scientific and technical information about taxol and enabled Bristol to access imperfectly tradeable assets, such as human capital. Bristol could use the expertise of universities and other firms without making long-term employment agreements. This was particularly important for university scientists who were willing to receive financial support from Bristol but wished to remain in academia.

A particular concern of the Federal government was the management of the Pacific yew tree, a relatively scarce natural resource. The NCI pursued several alternative technologies for synthesizing taxol by other means. USDA, for example, patented and licensed a means of producing taxol from tissue culture. This technology along with other new technologies have been successful at reducing the pressure on Pacific yew trees as the source for taxol. Bristol no longer harvests Pacific yews from public lands.

Access to exclusive information and data gave Bristol a substantial head start in the development of taxol and taxol-like drugs. This significantly reduced financial risks for Bristol and led to the rapid commercialization of the taxol drug. However, it also created potentially significant barriers to entry by rival firms. To enhance market competition and public access to taxol, NCI

[16]This section is based on Day and Frisvold (1993).

[17]Amendments to the Technology Transfer Act were made in 1989 which exempted CRADA's from the requirements of the Freedom of Information Act for up to 5 years for Federally generated data and information.

continued research on alternative sources for taxol and on other taxol-like drugs. By pursuing alternative technologies, NCI helped assure its eventual commercial availability. Technology development programs sometimes fail because they consider a range of technological options that are too narrow (Cohen and Noll, 1991).

The taxol case study provides several policy lessons for technology-transfer activities. First, CRADA's can provide an effective institutional structure for coordinating research and development activities. The NCI-Bristol CRADA served as a unifying framework to connect an impressive array of sub-agreements between businesses, government agencies, and universities. Second, through fundamental and pre-technology research, Federal laboratories can contribute significantly to the rapid commercialization of new technology. Public research institutes helped reduce commercial risks faced by Bristol by generating new knowledge about taxol. Third, pursuing multiple paths to technology development can increase the likelihood of success and encourage market competition. NCI encouraged the exploration of many alternative paths for producing large-scale supplies of taxol.

Policy Implications

Formal institutional linkages between the public and private sectors in agricultural research are a relatively new undertaking. Such arrangements serve to more closely link together science-oriented public research with technology-oriented private research. Nevertheless, public-private cooperation in research raises new issues that have important social and economic consequences, such as the ownership of intellectual property and the content of the public research agenda. The nature and scope of public-private institution linkages in agricultural research are still evolving and warrant further analysis and discussion.