

Can Technology Transfer Help Public-Sector Researchers Do More with Less? The Case of the USDA's Agricultural Research Service

Kelly Day Rubenstein and Paul W. Heisey

United States Department of Agriculture Economic Research Service

Private funding for agricultural research now exceeds that of the public sector. Other changes have included policies to make greater use of technology transfer mechanisms, such as patents and licensing and Cooperative Research and Development Agreements (CRADAs). A review of the United States Department of Agriculture's Agricultural Research Service (ARS) suggests these mechanisms did not displace more traditional instruments, such as scientific publications, nor is there any evidence that their use shifted the ARS's research priorities. Although technologies transferred through these mechanisms tended to be of greater interest to private-sector partners than the ARS's research generally, in many cases transferred technologies had public goods attributes.

Key words: agricultural research, Agricultural Research Service, ARS, Cooperative Research and Development Agreements, CRADAs, licensing, patents, technology transfer, United States Department of Agriculture, USDA.

Research and technology development have been the foundation of impressive productivity gains in the agricultural sector (Ball & Norton, 2002; Shane, Roe, & Gopinath, 1998). Historically, the public sector was the primary supporter and conductor of agricultural research and the primary supplier of new technologies. Over the past thirty or more years, however, private-sector spending for food and agricultural research in the United States has grown very rapidly. It has exceeded agricultural research expenditures by the public sector since the early 1980s (Fuglie et al., 1996). Despite minimal funding increases, demands on the public system have grown increasingly complex as food consumption increases and the desire for environmental amenities and food safety grows. Because industry may retain few financial returns from innovations that improve environmental benefits and food safety, the public sector remains the primary source for new technologies with these characteristics.

The transfer of technology from the public agricultural research system to the private sector is, in theory, one way to do more with less. Public-sector technology transfer has several major goals: bringing the benefits of public research and development (R&D) to potential users, finding innovative ways to fulfill agency missions in an era of relatively scarce resources, influencing the direction of technology development, and enhancing research funds through licensing revenues. Instruments used to achieve these goals may include direct communication between scientists and technology users, scientific publications, networking among scientists, using

intellectual property instruments such as patenting and then licensing the protected technologies, or undertaking cooperative research. Critics have questioned whether such mechanisms will emphasize research with social benefits or will focus instead on private research interests (see National Research Council, 1995, for discussion). In this paper, we will review empirically recent experience in public-sector technology transfer by the United States Department of Agriculture (USDA), focusing on patents and licensing and cooperative research and development agreements, or CRADAs. We will consider whether newer mechanisms of technology transfer such as patents and licensing can be used to promote technologies with social benefits. We will also ask whether USDA research priorities have changed significantly as a result of expanded technology transfer mechanisms.

Conceptual Approaches to the Study of Technology Transfer

Analyzing technology transfer is difficult, in part because of numerous conceptual and measurement problems in defining *technology*, understanding the many concurrent processes in its transfer, and conceptualizing and measuring the impacts of technology transfer (Bozeman, 2000). The definition of *technology transfer* differs notably from one discipline—economics, sociology, or management science—to the next (Zhao & Reisman, 1992). Bozeman (2000) distills the various approaches to studying technology transfer into three competing models for technology policy. The *mar-*

ket failure paradigm is the model most frequently adopted by economists. In this paradigm, the market is perceived as an efficient determinant of scientific research and technical change in general. However, there may be a role for the government in science and technology policy when there are clear externalities, when transaction costs are high, or when information is asymmetrical. The *mission technology* paradigm is based on theories of governance with a broad definition of the government's role. It "assumes that the government should perform R&D in service of well-specified missions in which there is a national interest not easily served by private R&D" (Bozeman, 2000, p. 632). The *cooperative technology* paradigm is based on theories of industrial policy or regional economic development. It covers a variety of policies that emphasize cooperation among sectors. In this perspective, government can serve both as a research performer and broker.

Each of these three paradigms has a somewhat different implication for technology transfer. Under the market failure paradigm, the government's chief policy role is to remove market barriers (for example, through the establishment of intellectual property policies) or to fund or conduct research if market failures cannot be corrected otherwise. In the mission technology paradigm, the government's unique ability to marshal research resources is emphasized. The cooperative technology paradigm focuses not only on technology transfer from government labs to private firms, but also on the government's role in brokering research cooperation and technology transfer among any combination of institutional types, including universities and private firms.

The history of agricultural R&D illustrates that all three paradigms could be used to explain various features of technology transfer. Within the agricultural sector, the federal government's role in providing research funds, coordinating the establishment of the State Agricultural Experiment Stations (SAES), and performing some research itself seems best understood as an example of the mission technology paradigm (Huffman & Evenson, 1993). However, the numerous studies of generally positive social returns to agricultural R&D (Alston, Chan-Kang, Marra, Pardey, & Wyatt, 2000; Evenson, 2001; Fuglie et al., 1996) have often been interpreted as implying considerable underinvestment in agricultural research, which in turn would imply market failures in the provision of such research. Finally, the current multiple policy changes affecting technology transfer have grown in large part out of the cooperative technology paradigm. These include changes in rules

regarding the patenting of research partially funded by the federal government, through the Bayh-Dole Act of 1980; increased emphasis on technology transfer from federal laboratories to the private sector through the Stevenson-Wydler Act of 1980; and establishment of rules for CRADAs through the Federal Technology Transfer Act of 1986.¹ These changes have led directly to the instruments of federal patenting and licensing, and the establishment of CRADAs, that we review in depth in this paper.

Some Trends in USDA ARS Technology Transfer Indicators

Figure 1 compares trends in USDA Agricultural Research Service (ARS) publications, patents, and CRADAs from 1990 through 2003. The number of CRADAs rose faster than either patenting or publications until 1999, after which it fell to around mid-1990s levels. Around 1998, ARS patent counts rose somewhat. Publication counts remained fairly level, dipping slightly for several years before rising slightly again. Even though it is not possible to weight these disparate measures of technology transfer, it is important to note the differences in absolute levels. From 2000 to 2003, there were between 220 and 260 active CRADAs each year and roughly 60–75 patents awarded each year. Over the same period, scientists with ARS affiliations were partially or fully responsible for approximately 4,000 or more publications annually.

It is also possible to compare ARS patenting with patenting by land-grant universities over the same period, although it is important to note that many patents issued to land-grant universities fall outside the area of agriculture. Nonetheless, over the past two decades or so the number of patents issued to land-grant universities increased at a rate about two and a half times the rate of increase in ARS patents. Given this extremely high increase, it is highly likely that patenting by land grant universities across a broad range of agricultural areas has also risen at a rapid rate. Pray, Oehmke, and Naseem (this issue) demonstrate this for agricultural biotechnology patents. To compare absolute levels, land-grant universities were issued roughly 1,200–1,300

1. *The Bayh-Dole Act illustrates the difficulty of shoehorning any particular policy to a particular technology transfer paradigm. The Act used an instrument Bozeman (2000) defines as part of the market failure paradigm—patent policy—in an attempt to achieve ends more easily understood as part of the cooperative technology paradigm.*

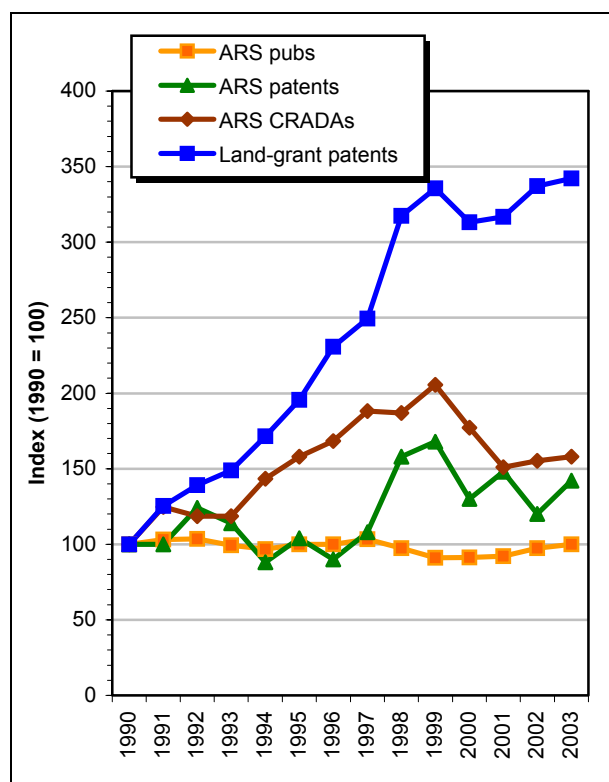


Figure 1. Indices of ARS technology transfer, 1990-2003.

Note. Data from ERS analysis of data from ARS; CSREES; USPTO; Institute for Scientific Information Current Contents.

patents annually between 2000 and 2003, while USDA patents ranged between 60 and 75.²

ARS Patents and Licensing

To examine both the possible benefits and common concerns about public-sector patenting and licensing, Day Rubenstein (2003) addressed two questions in the context of the ARS technology transfer program: (a) What types of technologies has ARS patented and licensed?

2. The ERS Agricultural Biotechnology Intellectual Property Database suggests that a higher proportion of USDA patents are for broadly defined agricultural/biological technologies than are university patents. However, patenting in this technological area has grown faster for universities than for the USDA. Furthermore, because the absolute number of patents by universities is so much higher, the absolute number of biological patents by universities is higher. For example, from 1998 through 2000 all universities (land grant and non-land grant) were issued seven times as many broadly defined agricultural biotechnology patents as the USDA. Universities were issued 21 times as many patents when a narrow definition of agricultural biotechnology was used.

and (b) Are social benefits associated with these technologies?

Data

The data used in this study were provided by the ARS Office of Technology Transfer. They are comprised of 224 active licenses granted by ARS through June 2000. The ARS database provides information about the licensing process but limited detail about the technologies themselves. Consequently, US Patent and Trademark Office (USPTO) data were another critical source of information for this study. The need for consistent and detailed information forced a majority of the analysis to be limited to licenses of patents for which patent text was available from the USPTO (i.e., patents already issued). Of the 224 licenses, only 187 were of technologies that had been awarded patents. The classification taxonomy used was the Research Problem Area topics from the USDA Current Research Information System (CRIS) classifications. A number of patents fell under more than one category. In these cases, the patent was not “split,” but was classified into both categories.

Aggregate data indicate that of the 270 active licenses in fiscal year 2003, 56 generated royalty income. The median earned royalty income was \$3,102 (Blalock, 2004). Such market impact and economic development measures are often misleading as measurements of a technology’s impact, however. There is consistent evidence that the primary benefit provided by technology transfer is the scientific and human capital found in federal laboratories; less often is it physical technologies (Bozeman, 2000). Blalock (personal communication, 2001) stated that interaction with ARS scientists and access to their expertise is seen by licensees as the primary benefit of the technology transfer program. Therefore, every license was assessed without regard to whether it resulted in a marketed technology. In any event, ARS structures its total licensing fees such that they help cover the technology transfer program costs. As a matter of ARS policy, licensing fees are not used to fund research.

Types of Technologies Licensed by the ARS

CRIS has designated nine major Research Problem Area topics. Figure 2 shows that, in terms of licenses issued, the leading areas, not surprisingly, were plant and animal research. The largest single category of patent licenses was plant protection technologies (about 44 licenses). Animal protection is the second largest category with 35 licenses. There were nearly as many

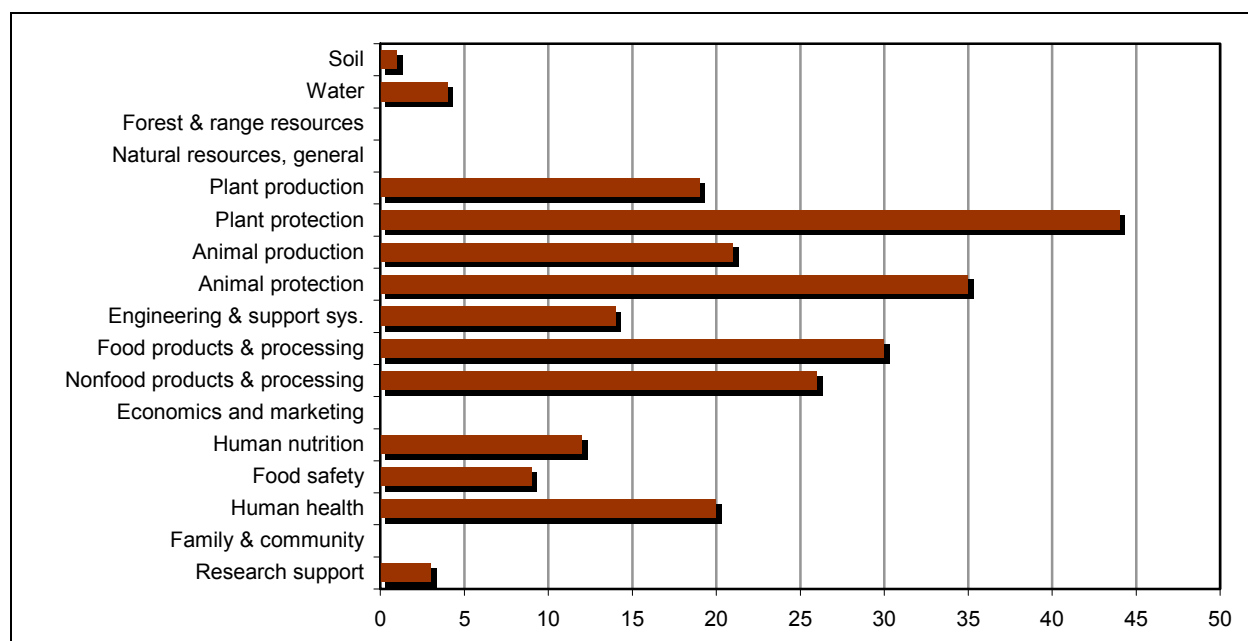


Figure 2. Licenses of patents by ARS.

Note. Patents may be licensed more than once. Patents may be captured in more than one category. Data from Day Rubenstein (2003).

licenses for products and processing technologies as for plant technologies (30 for food products and processing, 26 for nonfood technologies). The plant and animal protection categories had about 20 licenses apiece, as did human health. Engineering and support systems had 14 licenses. The human nutrition and food safety areas had 12 and nine licenses, respectively. The natural resources area had few patents, and thus only five licenses.

One explanation for the relatively low numbers of licenses in the natural resource area stems from the fact that innovations directly affecting natural resources, such as soil and water, are less likely to be commercialized. Therefore, private incentives for technology adoption are less pronounced than with plants, animals, food, or nonfood products.

Multiple licenses can be granted on a single patent (either nonexclusive, exclusive for a particular use, or coexclusive, meaning that licenses will be limited to an agreed number of cooperators). Therefore, the data can also be analyzed in terms of patents as well as in terms of licenses. The dominance of plant protection technologies is even more pronounced in terms of patents (Day Rubenstein, 2003). Several topics are notable for their number of multiple licenses. Plant production patents averaged 1.7 licenses per patent, as did human nutrition. The greater number of licenses per patent suggests that the demand for particular technologies may be stronger.

Another possibility is that topics with lower license-to-patent ratios may contain innovations that require more exclusivity before outside cooperators would seek to commercialize the technology.

Public Goods

Addressing the question about the public goods that may or may not be embodied in these technologies is complex. Pure public goods are both nonrival and non-exclusive. Any technology that is licensed exclusively would be disqualified by definition. However, technologies can have public good characteristics. That is, they can contribute to reducing a negative externality or otherwise benefit society as a whole.

When patents are classified in broad categories, determining the economic benefits, such as reduced production costs or enhanced marketing potential, is difficult. Separating social benefits, which themselves are generally not marketed, from economic benefits adds a layer of complexity. Assessing the social benefits offered by innovations must be done on a detailed level and is, by its nature, subjective. Throughout the process, every attempt was made to be consistent and to assign social benefits only when the technology clearly offered the potential for them. We assessed each patent as to whether it offered one of four social benefits: food safety, human nutrition, human health, and environmen-

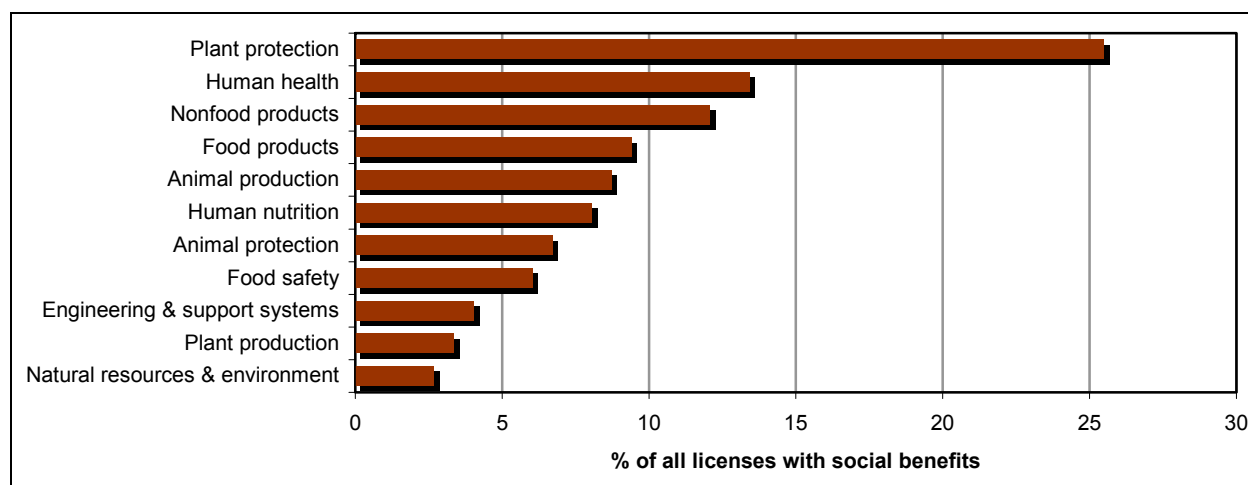


Figure 3. Contribution of Research Problem Area topics to licenses with social benefits.

Note. Data from Day Rubenstein (2003).

tal or natural resource protection. For example, several technologies dealt with textile processing. Enhanced efficiency in textile processing may offer economic benefits, but none of the four social benefits could be discerned. We decided that a textile processing method that eliminated the need for formaldehyde did offer human health benefits, however, because the objective of the technology was to reduce textile-based human exposure to chemicals by developing an economically acceptable alternative. Other public goods than the four used here exist, most notably the public good associated with an enhanced base knowledge in agriculture (Fuglie et al., 1996); however, this was not addressed in the current study because such social benefits are too diffuse to be associated with any particular technology.

Figure 3 shows that over a third of the technologies providing one or more of the four social benefits defined above fell in the plant protection area or in human health and well-being. Plant protection provided the greatest number of ARS licenses characterized as providing social benefits. Biological pest control (21 licenses) dominated the set of technologies. The biopesticides program is particularly strong at ARS. In addition, the genetically engineered varieties licensed by the ARS offer improved resistance to specific pests, and therefore are assumed to offer at least a potential reduction in agrochemical use. The same logic is applied to traditionally bred resistant varieties.

The numbers of licenses providing social benefits are determined both by the total number of patents in that category and by the nature of the technology itself. Human nutrition, food safety, human health, natural resources, and plant protection each ranked high in its

propensity to provide social benefits. Animal protection, plant production, and research support ranked low (Figure 4). The dominant technologies in animal protection are related to vaccines. As social benefits are defined above, the social benefits associated with vaccines are ambiguous, therefore many animal protection technologies were excluded from the social benefit category.

Comparisons with the ARS Research Program

Finally, when the composition of the licensing program is compared with that of the ARS's research program as a whole, topics of interest to the private sector play a stronger role in the licensing program. For example, product development includes about 24% of patent licenses. However, it accounts for less than 15% of ARS research efforts. This may reflect the fact that the ARS must offer technologies of interest to developers in order for the program to succeed. A topic area of social benefit in which research effort and proportion of licenses are roughly equivalent is the consumer health, nutrition, and food safety area. Thus, this may be a promising area for transferring research results via patent licenses, perhaps not only at the ARS, but also at other public research institutions. Licenses for patents focused on natural resources are limited, and this area has the lowest ratio of licenses relative to research effort. This result may be difficult to avoid due to the nonmarket characteristics of environment and resource protection.

USDA ARS CRADAs

The Cooperative Research and Development Agreement (CRADA) has been a principal mechanism for joint

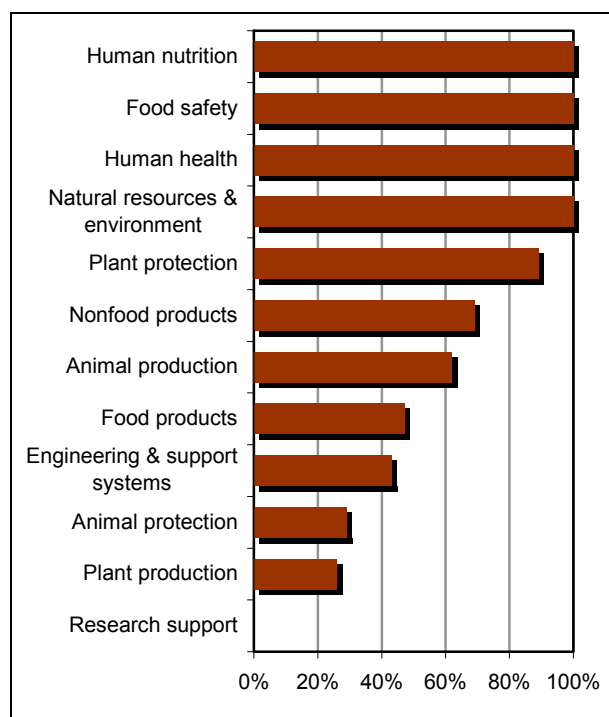


Figure 4. Percent of each category's licenses with social benefits.

Note. Data from Day Rubenstein (2003).

public-private R&D. In a CRADA, a federal laboratory and an outside cooperator agree jointly to develop and commercialize a technology. CRADAs may also grant intellectual property rights to the cooperator. CRADAs are generally initiated by ARS scientists, and the research plan must be consistent with the agency's mission. Both sides contribute in-house resources to R&D. Since CRADAs were first authorized by Congress in 1986, they have resulted in several economically important technologies, including the anticancer drug Taxol, animal vaccines and various biopesticides (Day & Frisvold, 1993; General Accounting Office, 1994).

Day Rubenstein and Fuglie (1999) assumed that the share of research expenditures allocated among different technology areas reflects the respective priorities of the public and private sectors. Public research was assumed to emphasize areas where potential social benefits are significant but where private research incentives are weak. The study hypothesized that (a) the allocation of research resources in joint public-private research will reflect a middle ground between the priorities of each partner and (b) that the private sector will take on a larger share of the research and development costs of technologies with a relatively large private good component.

Testing these hypotheses required judgments about the divergence of social and private returns to research among various kinds of technologies. For this purpose, the USDA's classification system for its research programs was employed. Agricultural research was grouped into five main technology areas: (a) postharvest use of agricultural commodities, (b) plant production and protection, (c) animal production and health, (d) natural resources, and (e) human health and nutrition. The share of total research resources devoted to each of these five technology areas was estimated for the ARS and in the ARS CRADA program. The former was assumed to reflect the USDA's priorities for its perceived mission to provide public goods, while the latter reflected the implicit priorities in the ARS's joint public-private research activity. For comparison, the USDA Small Business Innovation Research (SBIR) program was also analyzed. The SBIR program receives proposals from small private companies and provides funds for intramural research. To the extent that the grant allocations reflect research interests by the private sector, they provided an indicator of private intramural research priorities. Because SBIR grants are restricted to small firms, the private research interests of sectors where large firms predominate, such as agricultural chemicals and food processing, may be underrepresented.

The estimates of resources devoted to joint public-private research (CRADAs) were from a database maintained by the ARS Technology Transfer Office. Between 1987 and 1995, the ARS established 528 CRADAs with nonfederal partners, most of which were for-profit companies. Detailed financial data were available for only 366 of the 528 CRADA projects. These show total research expenditures by each partner for the project and private contributions to ARS research activities. Therefore, research allocations were presented by technology area for all 528 CRADA projects. Estimates for the shares of financial resources only included data from 366 projects.

Results: Resource Allocation and Cofinancing of Joint Public-Private Research

The relative shares of research resources allocated to the five technology areas for the public intramural research (ARS expenditures), public-private joint research (CRADA resources), and private intramural research (SBIR grants) are shown in Table 1. Note that for private intramural research, the shares allocated to natural resources and human nutrition are much lower than the shares to postharvest utilization, plant research, and ani-

Table 1. Resource allocation by public, joint public-private, and private research.

Technology area	Public-private (CRADAs)			Private (SBIR)
	Public (ARS)	By # of projects	By \$ resources	
share of column total (%)				
Postharvest utilization of agricultural commodities	20.8	37.6	34.6	27.0
Plants	36.9	32.2	36.5	25.7
Animals	17.6	23.1	17.2	23.0
Natural resources	13.8	4.4	6.3	9.5
Human nutrition and well-being	9.3	1.1	2.7	0.8
All research	100.0	100.0	100.0	100.0
Total expenditures in 1996 (million \$)	677.0	n.a.	98.9	9.1

Note. Percentages sum to less than 100% because a "general" research category and a "rural issues" category used only by SBIR grants are not shown. Data calculated from ARS databases and USDA Current Research Information System (CRIS).

mal research. Public agricultural research priorities (represented by ARS research), on the other hand, are more evenly distributed among the categories. Although the shares allocated to postharvest uses, plants, and animals are the largest, there is clearly greater interest by the public sector than the private sector in natural resources (nearly 14% of ARS research compared with 9.5% for SBIRs) and human nutrition research (9.3% of ARS research compared with less than 1% for SBIRs). This reflects a larger divergence between the perceived social and private returns to research in natural resources and human nutrition compared with the other areas.

Another way to view the allocation of resources in public-private joint research is to examine the share of research that each party finances. Table 2 shows the average public and private shares of research costs in CRADA agreements. For joint research on postharvest utilization, plants, and animals, the private sector financed 63–66% of total R&D costs. The private-sector share of the costs of natural resources research was somewhat less at 60%, and for human nutrition research only 48%. The relative contributions by the USDA and outside collaborators indicate that the private sector plays a substantial role in the CRADA research process.

The allocation of public-private joint research generally conformed to expectations that this research represents a middle ground between public and private interests, but with some important exceptions. The shares of both the number of CRADA projects and total dollars allocated to plant, animal, and human nutrition research lie between those of public research and private research. However, postharvest utilization research appears to be overrepresented and natural resource research is underrepresented in CRADA activity. These conclusions may be influenced, however, by the fact that the indicator for private research priorities (SBIR

Table 2. Public and private contributions to costs of joint research.

Technology area	Public contribution	Private contribution ^a
	Share of row total (%)	
Postharvest utilization of agricultural commodities	36.6	63.4
Plants	33.4	66.6
Animals	36.5	63.5
Natural resources	40.2	59.8
Human nutrition and well-being	52.0	48.0
All research	36.1	63.9

^a Private contribution includes grants given to ARS and in-house research conducted by private-sector partner in support of the CRADA project. Contribution based on the value of resources contributed to 366 CRADA agreements between USDA and outside cooperators between 1987 and 1995 (out of a total of 528 CRADA projects during this period.)
Note. Data calculated from ARS databases.

grants) may not fully reflect private-sector demand for public science and technology, because this indicator only includes research projects involving small companies.

Changes in USDA Research Resource Allocations over Time

One key question was whether increased public-private collaboration in the USDA's research programs may have been associated with a shift in public research priorities. During the late 1980s and 1990s, attention to private-sector research collaboration increased, not just through CRADAs, but also through exclusive patent licensing, contract research, and other technology transfer mechanisms noted above. According to the cooperative technology framework outlined above, greater

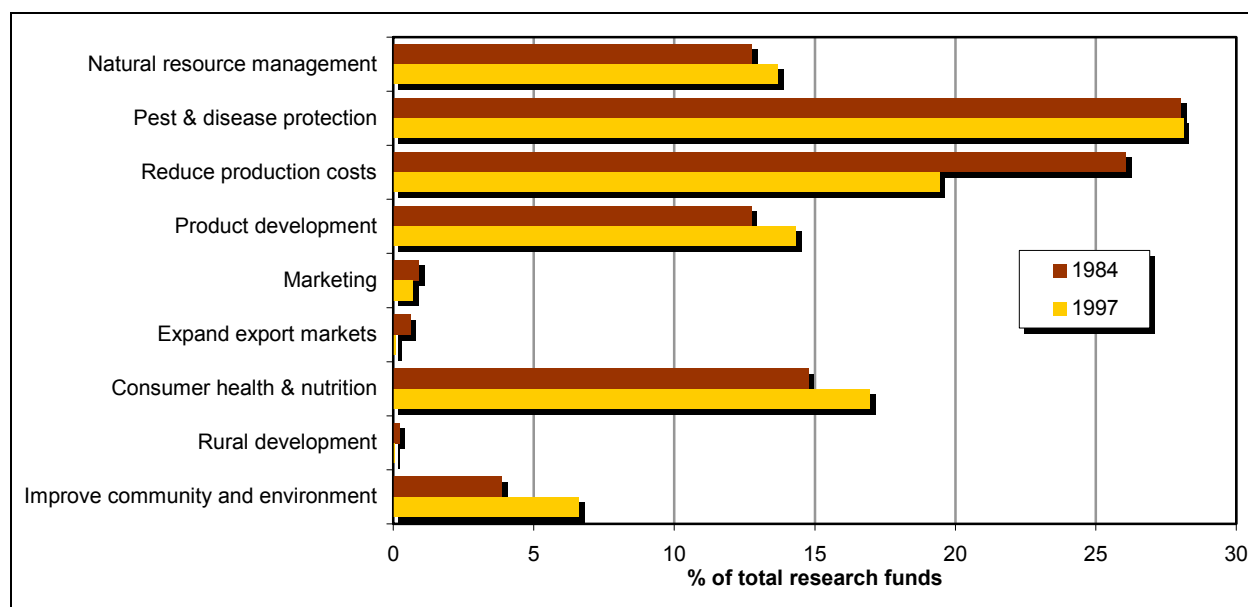


Figure 5. ARS research priorities, 1984 and 1997.

Note. Data from ERS analysis of data from USDA CRIS.

reliance on public-private cooperation in R&D should enable more public resources to be shifted to areas where private incentives are weakest. Another possibility, however, is that to build political and financial support for public research programs, more public resources may be diverted to areas where private companies show the greatest interest.

Figure 5 compares the allocation of ARS research expenditures in 1984 and 1997 for the nine research problem areas designated by CRIS. Overall, ARS research allocation was fairly stable over time. Consistent with the comparative advantage view, some public resources were shifted to research on natural resources and human nutrition—areas where market failures severely constrain private research incentives. In addition, shares allocated to reducing production costs for plants and animals—areas where private research expanded rapidly over this period—fell. However, at the same time, the share of public resources devoted to product development increased slightly. This is an area where private incentives are thought to be relatively strong. One component of product development, post-harvest research, also seemed to receive a disproportionately large share of joint public-private research activity (Table 1). Increased public-sector attention to product development may reflect the interests of food and agro-processing companies, farm groups, and heightened interest in food safety.

Conclusions: Technology Transfer at the USDA

Changes in US technology transfer policy starting about 1980 have elicited large changes in behavior both by universities and by the federal government, with greater emphasis placed on the development of technology transfer offices and greater use of such instruments as patenting, licensing, and cooperative research agreements. However, the USDA experience illustrates substantial differences in the federal and university responses. In particular, the expansion of patenting and licensing by the ARS was not nearly as large as the increase by the land-grant universities.

Several reasons may underlie this difference in response. First, royalty income is not seen as a significant source of research funds for federal agencies, even at the margins. As a result, federal patenting and licensing in and of itself is unlikely to influence the federal research agenda to shift from public to private good research (Just & Huffman, 2004). Second, federal research priorities continue to be determined much more by the congressional allocation of funds than by changes in technology transfer policy. Third, written regulations for technology transfer are more restrictive for federal R&D labs. One example is the requirement that the ARS must publish intent to issue an exclusive license in the Federal Register.

A look at changing resource allocations by research problem areas indicates that to date neither the patent

licensing program nor the CRADA program appear to have altered the ARS's research agenda. Furthermore, for the most part, the new technology transfer mechanisms used by USDA appear to complement older mechanisms, not substitute for them. Technology transfer activities, particularly through the CRADA program but also through patents and licensing, seem to bridge public and private interests. One reason for this is that access to human capital and the USDA's reputation are seen as key benefits for private-sector partners.

References

- Alston, J.M., Chan-Kang, C., Marra, M.C., Pardey, P.G., & Wyatt, T.J. (2000). *A meta-analysis of rates of return to agricultural R&D: Ex pede herculum?* (research report no. 113). Washington, DC: International Food Policy Research Institute.
- Ball, V.E., & Norton, G.W. (Eds.). (2002). *Agricultural productivity: Measurement and sources of growth*. Boston/Dordrecht/London: Kluwer Academic Publishers.
- Blalock, D.J. (2004, March). *Commercializing USDA innovations via public-private partnerships*. Presentation to the Agricultural Biotechnology Research Advisory Committee, Washington, DC.
- Bozeman, B. (2000). Technology transfer and public policy: A review of research and theory. *Research Policy*, 29(4-5), 627-655.
- Day, K.A., & Frisvold, G.B. (1993). Medical research and genetics resources management: The case of taxol. *Contemporary Policy Issues*, 11(3), 1-11.
- Day Rubenstein, K. (2003). Transferring public research: The patent licensing mechanism in agriculture. *Journal of Technology Transfer*, 28(2), 111-130.
- Day Rubenstein, K., & Fuglie, K. (1999). Resource allocation in joint public-private agricultural research. *Journal of Agribusiness*, 17(2), 123-134.
- Evenson, R.E. (2001). Economic impacts of agricultural research and extension. In B. Gardner & G. Rausser (Eds.), *Handbook of agricultural economics* (vol. 1). Amsterdam: Elsevier Science.
- Fuglie, K., Ballenger, N., Day, K., Klotz, C., Ollinger, M., Reilly, J., et al. (1996). *Agricultural research and development: Public and private investments under alternative markets and institutions* (agricultural economic report number 735). Washington, DC: USDA Economic Research Service.
- Huffman, W.E., & Evenson, R.E. (1993). *Science for agriculture: A long-term perspective*. Ames, Iowa: Iowa State University Press.
- Just, R.E., & Huffman, W.E. (2004). *The role of patents, royalties, and public-private partnering in university funding* (mimeo). College Park, Maryland, and Ames, Iowa: University of Maryland and Iowa State University.
- National Research Council. (1995). *Allocating federal funds for science and technology*. Washington, DC: National Academy Press.
- Pray, C., Oehmke, J.F., & Naseem, A. (in press). Innovation and dynamic efficiency in plant biotechnology: An introduction to the researchable issues. *AgBioForum*. Available on the World Wide Web: <http://www.agbioforum.org>.
- Shane, M., Roe, T. & Gopinath, M. (1998). *U.S. agricultural growth and productivity: An economy-wide perspective* (agricultural economics report no. 758). Washington, DC: USDA Economic Research Service.
- United States Government Accounting Office. (1994). *Technology transfers: Benefits of cooperative R&D agreements* (GAO/RCED-95-52). Report to the Vice Chairman, Joint Economic Committee, U.S. Congress.
- Zhao, L.M., & Reisman, A. (1992). Toward meta research on technology transfer. *IEEE Transactions on Engineering Management*, 39(1), 13-21.

Authors' Note

The views expressed in this article are the authors' and do not necessarily represent the views of the United States Department of Agriculture or the Economic Research Service.