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FEATURE

Have Seed Industry Changes Affected Research Effort?

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Early in the 20th century, agricultural productivity growth came primarily from innovations in mechanical inputs that replaced farm labor. Starting in the 1930s, increases in land productivity were driven largely by high-yielding crop varieties in concert with fertilizers and chemical pesticides. Average U.S. corn yields rose sevenfold from 20 bushels per acre in 1930 to 140 bushels by the mid-1990s, while wheat, soybean, and cotton yields increased 2-4 times. This unprecedented growth in U.S. agricultural productivity owes much to a series of biological innovations embodied in major crop seeds—in particular corn, cotton, soybeans, and wheat. Such innovations resulted from investments in crop variety research and development (R&D), including plant breeding, genetic engineering, and other biotechnology. However, the seed sector has changed substantially in recent years, raising questions about whether the intensity of research effort on improved seeds and the contribution to productivity growth are being sustained.

Crop variety R&D over the past 30 years has moved from being predominantly public to predominantly private. Private sector firms have evolved from small operations to large integrated enterprises capable of variety development and seed production, conditioning, and marketing (see box "Seed Production, Marketing, and Distribution"). Greater protection of intellectual property rights for crop-seed innovations through patents and certificates has spurred private investment in general and may increasingly stimulate private R&D, even on such crops as soybeans where farmers have often saved part of the current crop for use as seed the following year. Still, ERS analysis shows that consolidation in the private seed industry over the past decade may have dampened the intensity of private research undertaken on crop biotechnology relative to what would have occurred without consolidation, at least for corn, cotton, and soybeans.

Seed Production, Marketing, and Distribution

While different types of seed have distinct production processes and markets, the following description of how seeds are developed, produced, and distributed is generally applicable.

Plant breeding, including genetic engineering and other biotechnology, constitutes the foundation of the modern seed industry. By using science to create a unique and marketable product, plant breeders develop varieties embodying such improvements as higher crop yields, better crop quality, greater resistance to disease and pests, or traits aligned with regional agroclimatic conditions. Because of high costs, large-scale research and development (R&D) is limited to a few large companies, Federal agencies, and land-grant colleges and universities. High R&D costs require that varieties developed by the private sector be commercially viable, highly competitive, and well protected by intellectual property rights. Given the size of their R&D investments, plant breeders seek a central role in managing seed production, distribution, and marketing. The result has been extensive vertical integration of the industry.

Seed production. Seed firms with a marketable product typically contract out the production and multiplication processes to farmers, farmers' associations, and private firms. Breeders provide contract growers the *foundation seed* to produce either more foundation seed for continued R&D purposes, or *registered seed* for larger scale production purposes. Registered seed, in turn, is used to produce *certified seed* sold commercially to farmers. Certified seed conforms to standards of genetic purity and quality established by State agencies. The production of both registered and certified seed through contract growers is closely managed by seed firms to ensure that the desirable plant characteristics are carried through to subsequent generations, and to prevent open pollination, disease or pest infestation, or other problems that could affect product quality.

Seed conditioning and inspection. Once harvested, certified seed is *conditioned* for sale to farmers, a process that typically includes drying, cleaning, sorting, treating with insecticides and fungicides, and packaging for distribution and sale. Seed is also subject to inspection under various State programs to ensure that the final product meets quality standards. This may include tests for purity, germination, presence of noxious weed seeds, and moisture content.

Seed marketing and distribution. Large seed firms actively distribute their end product to regional, national, and international markets. Many firms also license or outsource marketing and distribution to private firms or individuals to improve access to local markets. Farmer-dealers, farmers' associations, company salespeople, and private wholesalers and retailers typically oversee local distribution. Different distribution channels are used in different regions and markets. In the Midwest, most corn seed is sold to farmers by farmer-dealers trained by the seed company. In the South, corn seed sales are channeled through agricultural supply stores. Also, seed companies often sell directly to large operations.

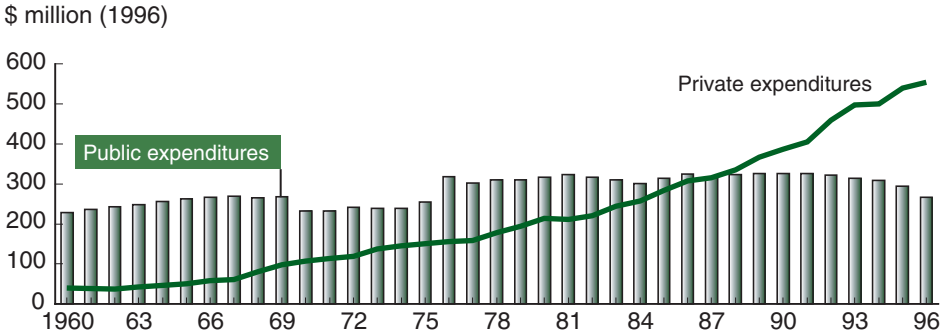
In addition to large integrated seed firms, the seed industry includes hundreds of companies operating under licenses and marketing agreements with the seed developers. Many firms are also involved in the production and distribution of public seed varieties. The absence of patents or plant variety protection (PVP) certificates on some seed varieties developed in the public domain allows individuals or firms to freely reproduce the seed.

Private Spending on R&D Has Jumped

Both public and private research contributed to new agricultural technologies and productivity growth after World War II. However, the relative importance of the public and private sectors has been changing. Private sector spending on overall agricultural R&D in the U.S. jumped from $2 billion in 1970 (expressed in 1996 dollars) to $4.2 billion in 1996, while Federal and State spending has flattened out at around $2.5 billion since 1978.

Expenditures on crop variety R&D alone show similar trends. Extensive private funding has been directed to research on marketable input and output traits of corn, soybeans, and cotton. In contrast, the focus of public research (as shown by USDA's Current Research Information System) is shifting to minor crops and to public goods such as environmental protection and food safety, areas less attrac-

Private expenditures on crop variety R&D have exceeded those of the public sector since the late 1980s



Source: Public expenditures are from the Current Research Information System, Cooperative State Research, Education, and Extension Service, USDA. Private expenditures are ERS estimates developed from various sources.

tive to the private sector because of lower profit potential.

Private spending on crop variety R&D increased 14-fold between 1960 and 1996 (adjusted for inflation), while public expenditures changed little. With the introduction in the 1930s of commercially viable hybrid seeds (higher yielding but degenerative, so farmers have to purchase new seed every year), R&D expenditures on corn began to shift from mainly public to mainly private. Private R&D expenditures on soybeans grew from almost zero to 25 percent of the total R&D on that crop between 1960 and 1984. In contrast, private R&D on wheat and many minor field crops, such as oats and barley, has been limited due to well-accepted public varieties and less profit potential.

Protection of Innovations Has Spurred R&D

Behind the growth in private R&D on crop varieties has been the legal protection of intellectual property rights in seed innovations. Two principal forms of legal protection are plant variety protection (PVP) certificates issued by the Plant Variety Protection Office of USDA and patents issued by the U.S. Patent and Trademark Office of the U.S. Department of Commerce. Both grant private crop breeders exclusive rights to multiply and market their newly developed varieties. However, patents provide more control since PVP certificates have a research exemption allowing others to borrow the new variety for research purposes.

Ag biotech patents, mostly dealing with some aspect of plant breeding, have outpaced the general upward trend in patenting throughout the U.S. economy. During the 1996-2000 period, 75 percent of over 4,200 new ag biotech patents went to private industry (see "Ag Biotech Patents: Who's Doing What?" in *Amber Waves*, November 2003).

USDA technician checks on tiny experimental trees grown from lab-cultured cells to which researchers have given new genes.

Photo by Scott Bauer, USDA/ARS

ERS analysis indicates that patent protection in particular increased private research during the 1990s on soybeans. However, patent protection seems to have been used less for hybrid corn and cotton, likely because firms perceive less need to protect their investments in these crops. Hybrid corn produces high yields with the first crop, but yields on homegrown seed decline quickly, discouraging use of crop output for seed. In the case of cotton, seeds are removed from the cotton lint at a mill and are not generally returned to farmers.

Purpose of the 1970 Plant Variety Protection Act

"To encourage the development of novel varieties of sexually produced plants and to make them available to the public, providing protection to those individuals who breed, develop, or discover them, and thereby promoting progress in agriculture in the public interest."

The number of PVP certificates issued has grown rapidly since the 1970 Plant Variety Protection Act (see box "Purpose of the 1970 Plant Variety Protection Act"), suggesting that certification has a positive effect on private sector crop variety R&D. The increases were most marked for soybeans and corn, which together accounted for more than half of all certificates issued for field crops. Many of the certificates have been for genetically engineered (GE) varieties (see box "GE Varieties Are the Latest Innovation in Seed Development").

By the end of 2002, USDA had issued 2,584 PVP certificates (excluding certificates of foreign origin) for the four major field crops: 1,078 for soybeans, 648 for corn, 568 for wheat, and 290 for cotton. The private sector holds nearly all of the certificates for corn, 84-87 percent of those for cotton and soybeans, and two-thirds of those for wheat. In addition to new varieties protected by certificates, USDA and some land-grant universities have developed and released varieties that are freely available.

GE Varieties Are the Latest Innovation in Seed Development

In the past two decades, U.S. companies embraced agricultural biotechnology research, as evidenced by the jump in USDA-approved applications for field testing of genetically engineered (GE) varieties. The number of applications received by USDA's Animal and Plant Health Inspection Service for GE varieties increased from 9 in 1987 to a high of 1,206 in 1998. By mid-2001, over 7,600 applications had been received and 6,700 (88 percent) had been approved.

Most applications were for field testing new GE varieties of major crops: corn (over 3,300 applications), potatoes (761), soybeans (601), tomatoes (532), cotton (481), and wheat (209). Applications for field testing between 1987 and 2000 included GE varieties with herbicide tolerance (27 percent); insect resistance (25 percent); improved product quality, such as flavor, appearance, or nutrition (17 percent); virus resistance (9 percent); and agronomic properties, such as drought resistance (6 percent).

After extensively field testing a GE variety, an applicant may petition USDA to deregulate (grant permission to produce and sell) the product. If, after extensive review, USDA determines that the new variety poses no significant risk to agriculture or the environment, permission is granted. As of mid-2001, USDA had received 79 petitions for permission to produce and sell GE varieties and granted 53 (18 for corn, 12 for tomato, 5 for soybean, 5 for cotton, and 13 for other crops). Thirty-six percent of the released varieties have herbicide-tolerance traits, 20 percent have insect-resistance traits, and 19 percent have product-quality traits.

Adoption of GE varieties in the U.S. has occurred rapidly despite consumer resistance in some other countries. Farmers planted herbicide tolerant (HT) soybeans on 75 percent of U.S. soybean acres in 2002, up from 17 percent in 1997. HT cotton, at 58 percent of planted acres in 2002, was up from 10 percent in 1997. Use of insect resistant Bt cotton expanded from 15 percent of cotton acreage in 1996 to 35 percent in 2002. In contrast, adoption of GE corn varieties has been much slower: farmers planted HT corn on only about 10 percent of corn acreage in 2002 and Bt corn on 24 percent.

Seed Industry Consolidation

The U.S. commercial seed market totaled $5.7 billion in 1997, making it the world's largest, followed by China's ($3 billion) and Japan's ($2.5 billion). Moreover, the U.S. seed market is growing, mainly from farmers increasing purchases of seed from seed firms and reducing the planting of homegrown seed. Growth in the seed market has been particularly rapid for major field crops—corn, soybeans, cotton, and wheat—that together constituted two-thirds of the seed market value in 1997.

Until the 1930s, most commercial seed suppliers were small, family-owned businesses lacking the financial resources to pursue their own research. Plant breeding research was conducted primarily by the public sector (USDA, State agricultural experiment stations, and other cooperating institutions). The primary role of the private seed business was to multiply and sell seeds of varieties developed in the public domain.

With the development and rapid producer acceptance of hybrid corn in the first half of the 20th century and with greater protection of intellectual property rights, the amount of private capital devoted to the seed industry and the number of private firms engaged in plant breeding grew rapidly until peaking in the early 1990s. Subsequently, seed industry consolidation prevailed, with fewer firms capable of investments in research sufficient to develop new seed varieties. The share of U.S. seed sales controlled by the four largest firms providing seed of each crop reached 92 percent for cotton, 69 percent for corn, and 47 percent for soybeans in 1997 (see box, "Four largest firms..."). One contrast to this general trend was wheat, with more than 70 percent of the planted wheat in 1997 coming from varieties developed in the public sector. However, herbicide-tolerant varieties of wheat developed by the private sector are on the horizon, so the private proportion could increase.

Four largest firms dominated sales of seed for cotton and corn in 1997, and to a lesser extent for soybeans

Crop and largest seed providers	Share of seed sales
	Percent
Corn seed:	
Pioneer Hi-Bred	42
Monsanto	14
Novartis	9
Dow/Mycogen	4
Four largest total	69
Cotton seed:	
Delta & Pine Land	73
Monsanto	11
CPSD[1]	6
All-Tex	2
Four largest total	92
Soybean seed:	
Pioneer Hi-Bred	19
Monsanto	19
Novartis	5
Dow/Mycogen	4
Four largest total	47

[1]California Planting Seed Distributors.
Source: Corn and soybean shares are from Hayenga, M., *AgBioForum*, 1(2)(1998):43-55. Cotton shares are ERS estimates based on volume of seeds planted as reported by USDA's Agricultural Marketing Service.

Is Consolidation Dampening Research Intensity?

An indicator of research output (as opposed to expenditures, which is an input measure) is the number of applications to USDA for field testing of GE crop varieties. All newly developed GE crop varieties have to go through USDA-authorized field trials and receive USDA permission before being produced and sold (see box "GE Varieties Are the Latest Innovation in Seed Development"). The annual number of field-trial applications for GE crops

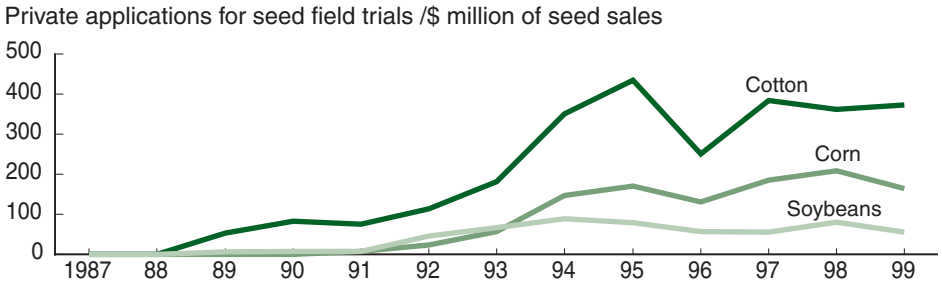
increased from 9 in 1987 to 1,206 in 1998. Dividing the annual number of field-trial applications from private firms by private industry sales of seed for each major crop provides a measure of research intensity (applications per million dollars of sales) comparable across crops.

Calculations for corn, soybeans, and cotton indicate that as the seed industry became more concentrated during the late 1990s, private research intensity dropped or slowed. Was there a connection between the concentrating industry and the slowing intensity? Further ERS analysis, using econometric methods, found a simultaneous self-reinforcing relationship. Those companies that survived seed industry consolidation appear to be sponsoring less research relative to the size of their individual markets than when more companies were involved. This finding runs counter to the hypothesis that dominant firms in consolidated industries conduct more new product research than they otherwise would in order to expand the size of their markets (because of less risk of being outcompeted during the long time periods required to bring new products to market). Also, fewer companies developing crops and marketing seeds may translate into fewer varieties offered. On the other hand, some multinational firms have recently spun off their agricultural divisions, in effect creating smaller new firms doing agricultural research. This reduction in concentration, after a time lag, could offset some of the prior dampening of research intensity.

Public Research Could Stimulate Private Research

Total spending on crop variety R&D will continue to increase and to contribute to agricultural productivity growth, but possibly dampened relative to what might otherwise exist in the absence of seed industry consolidation. One factor that could offset the dampening is additional public investment in crop variety R&D. ERS analysis indicates that public research on corn, soybeans, and cotton has a stimulative effect on private biotech research. Thus, increasing public research on these crops would not only sustain the oft-documented high rates of return to public research, but could also promote additional private research. W

Private research intensity on GE varieties of corn, cotton, and soybeans dropped or slowed in the late 1990s



Consumer acceptance of GE crops in the European Union did not become a major issue until 2000.

Source: Applications from private firms to USDA's Animal and Plant Health Inspection Service for field trials of biotech seed. Seed sales are ERS estimates based on seed use and prices paid by farmers.

Peggy Greb, USDA/ARS

This article is drawn from . . .

The Seed Industry in U.S. Agriculture, by Jorge Fernandez-Cornejo, with contributions from Jonathan Keller, David Spielman, Mohinder Gill, John King, and Paul Heisey, AIB-786, USDA/ERS, January 2004, available at: www.ers.usda.gov/publications/aib786/

"The Impact of Seed Industry Concentration on Innovation: A Study of U.S. Biotech Market Leaders," by David E. Schimmelpfennig, Carl E. Pray, and Margaret F. Brennan, in *Agricultural Economics* [in press]. Paper can be downloaded free from the Social Science Research Network website at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=365600#Paper%20Download/