Incentives for Private Investment in Agricultural Research

Private expenditures for food and agricultural research tripled in real terms between 1960 and 1992. The growth in private research on biological technologies was particularly rapid. Both government policies and market forces have influenced private investment in agricultural research. An important market incentive has been the growing world demand for food and agricultural products. Global population and income growth have increased the demand for new agricultural innovations. Industry has also been attracted by new technological opportunities in biotechnology, made possible by earlier public investments in basic biological sciences.

Public policies affect private incentives to conduct research in several ways. Public investments in fundamental and pre-technology research create new commercial opportunities for private firms. Governments can increase incentives for private research by strengthening IPR's for new inventions. Stronger IPR's enable inventors to capture a greater share of the commercial value of their inventions, which encourages more investment in research. Other policies, such as environmental, public health, and food safety regulations, also affect private incentives to invest in research (though not as directly). Regulations change the cost structure of firms and influence consumer demand for final products. Consequently, they affect market incentives to develop new agricultural technologies and food products.

At least two sets of policies affect private investments in agricultural research: (1) intellectual property rights for biological inventions, and (2) environmental, health, and food safety regulations. Each type of policy involves a trade-off between competing objectives. While IPR's provide private companies with more incentives to conduct research, they also increase the market monopoly power of these firms. The extent to which IPR's have increased private agricultural research and the effects of IPR's on seed prices and scientific progress are reviewed. Regulations, while helping to correct certain market failures, also may raise production costs, reduce innovation, and adversely affect market structure.

Intellectual Property Rights for Biological Inventions

One major development in science policy over the past 25 years has been the strengthening of intellectual property rights for new biological inventions. Historically, appropriating the gains from biological inventions was difficult because the product of a biological invention, such as a new variety of seed or livestock breed, also provides the means to reproduce it. Furthermore, biological inventions were considered "products of nature," and, therefore, not subject to standard patent law. Inventors of new plant varieties and animal breeds may now obtain the same patent protection that had long been afforded to chemical and mechanical inventions.

The strengthening of IPR's for biological inventions has been controversial. While stronger intellectual property rights for biological inventions increase the incentive for private industry to invest in new agricultural technology, it also raises important policy questions: Will the incentive lead to more research and improved technology for agriculture? Who will capture the economic benefits from new technology? Will competition for and ownerships of patent rights reduce the exchange of scientific information needed for the long-term advancement of science? Answers to these questions are essential for designing effective science policy.

Establishment of IPR's for Biological Inventions

The U.S. Constitution grants Congress broad powers to "promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries." The Patent Act of 1790 and its subsequent amendments established a system of intellectual property rights to encourage inventors and manufacturers to develop new industrial inputs and consumer products. Until recently, the patent system's principal contribution to agriculture was the protection it offered for mechanical and chemical inventions. Biological inventions, such as new plant varieties and animal breeds, were not patentable because they were products of nature. As a result, plant breeders in the private sector concentrated most of their efforts on hybrid seed technology. Hybrid seeds offer a natural form of protection for intellectual property since the yield of second-generation progeny of a hybrid declines markedly. Thus, farmers do not save their own seed but buy new hybrid seed each season. However, hybrid seed technology has been commercially successful for only a few crops, such as corn, sorghum, and sunflowers. Most other crops grown in the United States are produced using open- or self-pollinated seed.[11]

To provide an incentive for private firms to increase their efforts in crop improvement, Congress enacted special plant breeders' rights for new plant varieties.

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[11]Hybrid seed technology is technically feasible but currently not economical for many other crops, such as wheat, alfalfa, and soybeans. The unsuccessful attempt to develop commercial varieties of hybrid wheat in the United States is examined in Knudson and Ruttan (1988).

The 1930 Plant Patent Act (an amendment to the 1790 Patent Act) established a special category of patents for asexually reproduced plants. Plants reproduced asexually are genetically identical, or clones, to the parent plant. These are plants that are not grown from seed but from cuttings, and include many types of tree crops (fruits and nuts), sugar cane, and ornamentals. Tuber crops, however, were specifically excluded from the act. Under the terms of the Plant Patent Act, breeders are given proprietorial ownership of new varieties for 17 years. Seed crops were not included in the act because of concerns that sexually reproduced crops would not be true clones of the parent plant.

Protection for new varieties of sexually reproduced seed crops other than hybrids became available in 1970, when the Plant Variety Protection Act was passed. Improvements in seed technology allowed breeders to develop new varieties that maintained the characteristics of the parent plant. Under this act, breeders are awarded Plant Variety Protection Certificates for new varieties shown to be distinct, uniform, and stable. Hybrid varieties were excluded from the act because they lack stability over generations. A Certificate gives a plant breeder proprietorial ownership of a new variety for 17 years. Unlike Plant Patents, which are awarded by the Patent and Trademark Office of the Department of Commerce, Plant Variety Protection Certificates are administered by the Department of Agriculture.

In their original form, these acts offered relatively weak intellectual property protection for plant breeders. Courts interpreted the acts as only protecting exact copies of the varieties. Phenotype variations, or variations in plant appearance due to environmental conditions, were unlikely to be protected (Schmid, 1985; Stallman, 1986). Other plant breeders were also allowed to use the protected variety in their breeding programs. One concern was that this would not prevent "cosmetic breeding," in which economically insignificant changes are bred into a protected variety to claim a new variety. In addition, under the Plant Variety Protection Act, farmers were allowed to save seed for replanting and to sell part of their seed to other farmers. While these limitations helped assure the wide availability of new varieties, they also reduced the returns to private plant breeding and lowered the incentive for private companies to invest in varietal improvement.

The Plant Variety Protection Act was amended in 1994 to increase incentives for private plant breeders. Also, the amendment made U.S. law conform with international standards for plant breeders rights established by the International Union for the Protection of New Varieties of Plants (UPOV). These amendments increase the scope of protection offered by Plant Variety Protection Certificates. Farmers are no longer permitted to sell seed without a license from the owner of the variety, although they may still save seed for their own replanting. While the 1994 amendments affect only varieties released after April 1995, a recent decision by the Supreme Court (*Asgrow* vs. *Winterboer*) eliminated the farmer exemption for varieties released in earlier years. Also, a provision was added to extend the scope of the Certificates to include "essentially derived varieties." This provision is designed to protect breeders from cosmetic infringement (for example, superficial changes in appearance that do not increase its yield or value). "Essentially derived varieties" refer to how much change must be introduced before a variety is considered truly different from its parent varieties. However, the legislation is vague on how this is to be determined. The 1994 amendments also extended plant breeders' rights to 20 years and included protection for tuber crops (U.S. Congress, 1993).

Judicial action in the 1980's also significantly expanded legal protection for biological inventions, particularly those involving biotechnologies such as genetic engineering. In 1980, the U.S. Supreme Court ruled in *Diamond* vs. *Chakrabarty* that living material was patentable. This case involved a genetically engineered microorganism that can digest and break down crude oil. Although patents for biological process inventions had been awarded since the 1800's, the Patent and Trademark Office did not permit patents on living products because they were a "product of nature" and not subject to the statutory subject matter defined by the Patent Act.[12] In *Diamond* vs. *Chakrabarty*, the Supreme Court determined that a human-made microorganism is patentable subject matter as a "manufacture" or "composition of matter" (Office of Technology Assessment, 1992).

While the *Chakrabarty* decision applied specifically to microorganisms, subsequent rulings by the Patent and Trademark Office's Board of Appeals and Interferences extended this protection to include all plants and nonhuman animals. In 1985, in *Ex parte Hibberd*, the Board concluded that patents could be issued for all plants, including open-pollinated seeds. This includes seeds, plants, plant parts, plant genes, and tissue cultures. In 1987, in *Ex parte Allen*, the Board awarded a patent for a genetically modified oyster and established a policy of allowing patents for new, nonhuman animal breeds, genes, and traits. The first patent for a mammalian

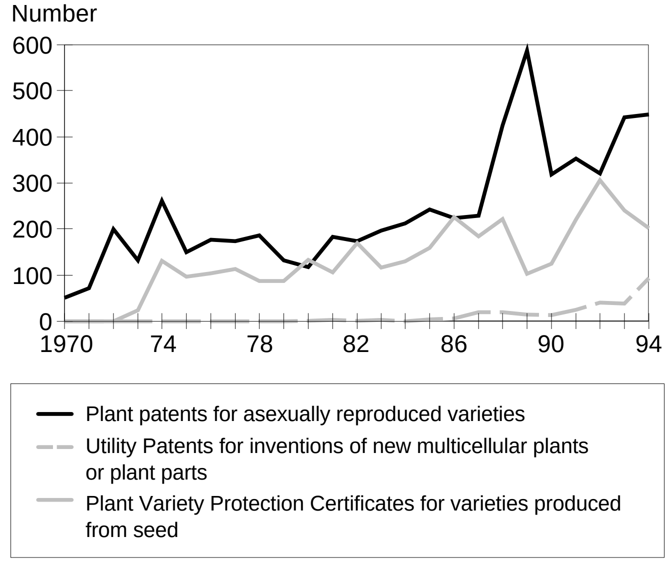
[12]The Patent and Trademark Office had previously awarded patents for compositions containing living organisms, such as microbial spores, yeast compositions, vaccines, and various dairy products (Office of Technology Assessment, 1992).

species, the genetically modified “Harvard Mouse,” was granted in 1988.

These decisions expanded the scope of intellectual property protection available for biological inventions. Patents awarded by the 1790 Patent Act (called Utility Patents) grant the owner broader powers of exclusion compared with plant breeders’ rights. For inventions covered by a Utility Patent, no one may make, use, or sell the invention without the permission of the owner. Biological processes and materials protected by a Utility Patent cannot be used by other researchers, except for purely academic or noncommercial research (Barton, 1993). For example, a new crop variety protected by a Utility Patent cannot be used in a breeding program without a license from the owner. The breadth of patent claims awarded for Utility Patents has generated considerable controversy in the research community.

There are now several options for protecting investments in biological inventions (table 9). Plant Patents grant proprietorial ownership for asexually reproduced plants and Plant Variety Protection Certificates are available for new varieties of seed crops. These ownership rights are restricted to specific varieties or close relatives and are generally called “plant breeders’ rights.” Awards of Plant Patents have experienced a general upward trend since 1980, with around 300-500 awarded per year by the early 1990’s (figure 7). Awards of Plant

Figure 7
Annual issues of intellectual property rights for new plants and plant varieties



Sources: Economic Research Service. Data derived from U.S. Department of Commerce, Patent and Trademark Office, CASSIS data base and USDA, *Plant Variety Protection Journals.*

Table 9—Intellectual property rights and private plant breeding

Coverage	Policy/action	Time	Application	Economic effects
Hybrid seed	Technological advances (protected by trade secret law)	1920	Corn	Large
		1952	Sorghum	Large
		1968	Wheat	Small
Plant varieties produced asexually	Plant Patent Act	1930	Fruits, nuts, ornamentals	Small
Plant varieties produced from seed	Plant Variety Protection Act	1970	Field crops	Moderate
	PVPA amendment	1980	Vegetables	n.a.
	PVPA amendment	1994	Reduced exemptions	n.a.
	Supreme Court A v W	1995	Reduced exemptions	n.a.
Biological inventions	Supreme Court D v C	1980	Microbes	n.a.
	Ex parte Hibberd	1985	Plants	n.a.
	Ex parte Allen	1987	Animals	n.a.

n.a. = Not available.

A v W: *Asgrow* v. *Winterboer.*
D v C: *Diamond* v. *Chakrabarty.*

Source: Economic Research Service compiled from Griliches (1958), Butler and Marion (1985), Stallman (1986), and Knudson and Ruttan (1988).

Variety Protection Certificates for seed crops have remained steady over the past decade at about 200 per year. A stronger form of ownership rights, Utility Patents, can be used to establish ownership for specific plant and animal parts, traits, genes, and for new breeding and biotechnology methods. Utility Patents offer a broader scope of protection, and on average are of greater economic value for the owner. However, Utility Patents are generally more difficult to obtain since they require that the scientist show an "inventive step" (the nonobvious criterion). Since 1987, there has been a modest upward trend in awards of Utility Patents involving new plants, with 94 issued in 1994. Some Utility Patents are for specific genes or traits and may cover more than one variety or crop that expresses that trait.

Private Sector Investment in Plant Breeding

Private investment in agricultural research tripled in real terms between 1960 and 1992 (table 10). Private plant breeding underwent particularly rapid growth since the late 1960's. By 1992, private companies spent an estimated $400 million annually for plant breeding research in the United States. Private firms have also invested heavily in modern biotechnology techniques. Agricultural biotechnology is applied not only to plant breeding, but also to food product development, livestock research, and biological pest control.

The private sector plays an important role in developing finished varieties for the major crop commodities. Between 1970 and 1994, 3,306 Plant Variety Protection Certificates were issued for new crop varieties, including 661 for soybeans, 322 for corn, 314 for wheat, and 211 for cotton (table 11 and fig. 8). Roughly 87 percent of the Certificates were awarded to commercial seed companies, with the rest going to public institutions.[13] By the mid-1980's, private research had also expanded for secondary crops, including canola (rape), sorghum, and safflower. By 1989, nearly 900 scientists at the M.S. or Ph.D. level were engaged in plant breeding for private seed companies in the United States, an increase from about 700 in 1982. More than a third of these specialized in corn breeding (Kalton, Richardson, and Frey, 1989). However, for some small grains (oat, barley, and rice), the number of new private varieties developed remains low.

Of particular interest for policy is the extent to which the provision of plant breeders' rights stimulated private investment in plant breeding. Economic studies have found mixed and uneven results (table 9). Assessments of the 1930 Plant Patent Act and the 1970 Plant Variety Protection Act suggest that the incentives for private plant breeding were uneven across commodities. Stallman (1986) found that the Plant Patent Act had little effect on private investment in fruit breeding.[14] High development costs of new fruit varieties and difficulties

[13]These numbers do not include all the new varieties released for these crops over this period. The USDA and some land-grant universities do not seek Plant Variety Protection Certificates for their varieties, but instead make them freely available to seed companies for multiplication and sale to farmers.

[14]Currently, about a fourth of Plant Patents issued every year are for new varieties of fruits and nuts, and three-fourths are issued for flowers and ornamentals (American Association of Nurserymen).

Table 10—Private agricultural research expenditures by product areas, 1960-92[1]

Year	Food and kindred products		Farm machinery		Agricultural chemicals		Animal health		Plant breeding		Total agriculture[2]	Agricultural biotechnology[3]
	Mil. do.	*Pct.*	*Mil. do.*	*Pct.*	*Mil. do.*	*Pct.*	*Mil. do.*	*Pct.*	*Mil. do.*	*Pct.*	*- - - Million*	*dollars - - -*
1960	92	45	75	36	27	13	6	3	6	3	206	n.a.
1965	131	41	96	30	64	20	23	7	9	3	323	n.a.
1970	206	44	89	19	98	21	45	10	26	6	464	n.a.
1975	273	39	138	19	169	24	79	11	50	7	709	n.a.
1980	488	34	363	25	395	27	111	8	97	7	1,453	n.a.
1985	842	39	311	15	683	32	159	7	179	8	2,167	347
1990	965	32	360	12	1,127	37	245	8	314	10	3,012	516
1992	1,038	30	394	12	1,279	37	306	9	400	12	3,416	595

n.a. = Not available.

[1]Expenditures expressed in nominal dollars. [2]May not add due to rounding. [3]Agricultural biotechnology refers to the use of genetic engineering, tissue culture, monoclonal antibodies, and biosensors for food and agricultural purposes. These techniques are applied in several product areas, including plant breeding, food product development, and livestock research. To avoid double counting, research expenditures for agricultural biotechnology were not added with the other product areas in calculating total private expenditures for food and agriculture research.

Source: Economic Research Service calculated from Klotz, Fuglie, and Pray (1995).

Table 11—Plant Variety Protection Certificates issued for new crop varieties

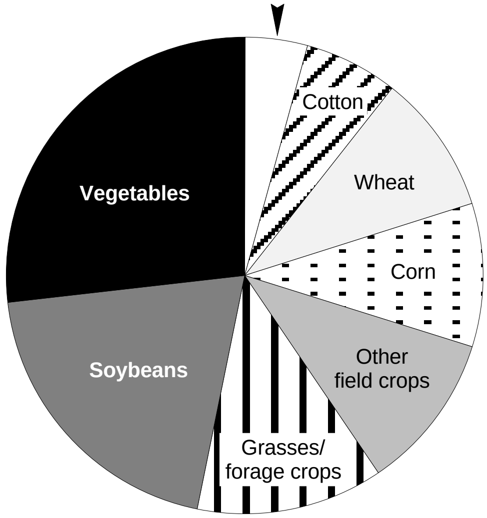
Crop	Certificates issued							Certificate ownership	
	1971-74	1975-78	1979-82	1983-86	1987-90	1991-94	Total	Private	Public
	Number							*Percent*	
Field crops:									
Soybeans	34	69	132	150	114	162	661	84	16
Corn	0	1	6	50	104	161	322	100	0
Wheat	12	52	59	30	74	87	314	68	32
Cotton	24	35	41	38	34	39	211	87	13
Barley	0	12	2	22	6	35	77	82	18
Beans, field	0	1	5	18	10	28	62	77	23
Oats	0	10	6	0	9	8	33	36	64
Rice	0	8	4	2	5	15	34	100	0
Sorghum	0	0	0	0	2	31	33	100	0
Canola	0	0	0	2	8	15	25	72	28
Safflower	0	3	2	1	5	6	17	88	12
Other field crops	0	16	15	13	18	13	75	85	15
Total field crops	70	207	272	326	389	600	1,864	84	16
Grasses and forage crops:									
Fescue	0	5	16	28	38	30	117	90	10
Ryegrass	0	10	13	35	26	14	98	95	5
Alfalfa	0	3	22	16	30	11	82	84	16
Bluegrass	0	8	11	11	13	20	63	89	11
Other grasses	0	8	18	5	14	13	58	57	43
Total grasses	0	34	80	95	121	88	418	85	15
Vegetables:									
Peas	20	54	43	66	16	51	250	100	0
Beans, garden	31	39	20	29	21	70	210	100	0
Lettuce	13	16	14	17	32	70	162	100	0
Other vegetables	2	29	46	72	43	71	263	80	20
Total vegetables	66	138	123	184	112	262	885	94	6
Ornamentals	17	31	18	18	13	42	139	94	6
Total	153	410	493	623	635	992	3,306	87	13

Source: Economic Research Service from U.S. Department of Agriculture, Agricultural Marketing Service, Plant Variety Protection Journals.

enforcing property rights constrained the profitability of private plant breeding for these crops. Perrin, Hunnings, and Ihnen (1983) found that, for some nonhybrid seed crops (particularly soybeans), private investments in plant breeding did increase significantly around the time of the 1970 Plant Variety Protection Act. For other crops, the incentives provided by the act seemed small. In a review of the economic effects of the Plant Variety Protection Act, Butler and Marion (1985) concluded that "the evidence . . . suggests the Act has resulted in modest private and public benefits at modest private and public costs" (p. 79).

One limitation of these studies is that they examined plant breeding efforts only until the late 1970's, less than a decade after the passage of the Plant Variety Protection Act. New investments in plant breeding often take several years to result in new crop varieties. Thus, these studies were not able to assess the effect of most new investments made once plant breeders' rights for seed became available. In a more recent study, Lesser (1994) found that Plant Variety Protection Certificates increased the value of New York soybean varieties about 2 percent. At this rate, according to Lesser, insufficient revenue would be generated to support much additional plant breeding by private firms. However, Lesser's results are limited to only one crop in one State.

Figure 8
Plant Variety Protection Certificates, 1970-94



Total = 3,306

Source: Economic Research Service. Data derived from USDA, *Plant Variety Protection Journals*.

Advances in basic biological science during the past 20 years have greatly expanded opportunities for applying biotechnology for agriculture. Biotechnology is being used to incorporate new traits in crops and livestock breeds. It is also being used to develop new livestock growth hormones and pharmaceuticals, biological pesticides, and food products (Caswell, Fuglie, and Klotz, 1994). The most important intellectual property right for biotechnology inventions is Utility Patents. As discussed previously, Utility Patents offer stronger protection than Plant Variety Protection Certificates or Plant Patents. Utility Patents may cover a trait that can be expressed in more than one commodity or species. As of December 31, 1994, 324 Utility Patents had been awarded for multicellular living organisms (table 12). Of these, 286 were for new plants or plant parts, and 38 were for animals. Most of the animal patents are for medical research purposes. About half the Utility Patents issued for plants involved recombinant, or genetically modified, varieties and cover a wide range of commodities. By far the most important use of Utility Patents has been for corn varieties, many of which are for inbred corn lines used in hybrid seed production.

The ownership of Utility Patents for plant inventions has been more diverse than that for plant breeders' rights for new varieties. Sixty-three percent of Utility Patents for multicellular organisms were issued to U.S.-based companies, compared with about 90 percent of the Plant Variety Protection Certificates (table 13). Twenty-two percent of the Utility Patents are owned by foreign companies or institutions, while 15 percent are owned by the U.S. Government or U.S. universities. While plant breeders' rights are issued for new varieties that are ready for sale, Utility Patents generally cover inventions that are still at a pre-commercial stage. Public institutions that own patents may grant licenses

Table 12—Utility Patents issued for multicellular organisms through 1994

Item	Patents issued
	Number
Technology[1]:	
Animal	38
Plant:	286
Plant, seedling, or plant part	154
Recombinant plant	103
Somatic cell fusion-derived plant	10
Mutant plant	25
Grafted plant	3
Total	324
Plant commodity[2]:	
Corn	83
Tomato	24
Tobacco	23
Soybean	17
Rice	15
Sunflower	10
Potato	9
Wheat	8
Canola	8
Cotton	8
Mushrooms	8

[1]A single patent may involve more than one technology or commodity. [2]Only commodities with eight or more patents are listed.

Source: Economic Research Service adapted from CASSIS database, Patent and Trademark Office, U.S. Department of Commerce.

Table 13—Ownership profile for Utility Patents

Owner	Private	Public	All
United States	204	48	252
Foreign	63	9	72
Total	267	57	324

[1]Includes patents awarded for multicellular organisms (patent class 800).

Source: Economic Research Service calculated using CASSIS database, Patent and Trademark Office, U.S. Department of Commerce.

to private companies to develop them into marketable products. Licenses raise revenues for public research institutions and can also protect a company's investment in commercialization. In fact, companies may be unwilling to make such investments in product development and marketing unless they have an exclusive license to the patented invention.

The principal rationale for granting stronger patent rights over new inventions is to stimulate more research by private entrepreneurs. Thus far, few agricultural biotechnology products have reached the marketplace, and, consequently, little information exists on the economic effect of Utility Patents for agriculture. However, one indication of how biotechnology is being applied to agriculture is the number of permits issued for field testing genetically modified organisms. Researchers wishing to conduct field tests with genetically modified plants and organisms must notify and/or receive a permit from the Animal and Plant Health Inspection Service (APHIS) before the test. Genetically modified plant varieties have been developed and tested for herbicide tolerance, resistance to insect pests or viruses, quality characteristics, or for pure research (table 14). Corn received the most permits for field tests (76 permits), followed by tomatoes (74 permits). Nearly a third of the permits were for plants modified for herbicide tolerance. Field test permits were issued to chemical and pesticide companies, seed companies, biotechnology firms, food companies, and public institutions.

Economic studies have shown that possessing a biotechnology patent significantly increases a firm's market value. In an analysis of the 20 largest publicly traded biotechnology firms, Austin (1993) estimated that each biotechnology patent added, on average, about 0.7 percent, or $1.7 million, to the firm's stock value. Patents that were closely identified with commercial products increased a firm's value by 1.9 percent, or $4.7 million. In a more comprehensive study of 535 venture-capital biotechnology companies, Lerner (1994) found a significant correlation between the number of patents owned by the company and its valuation in venture financing. Lerner also found that broader patents (defined by the number of international patent classes to which the patent was assigned) were of much greater value to a firm. Asset valuation of venture-capital firms is a critical factor in determining access to continued sources of financing. It also enables them to raise revenue by licensing the patented invention to other companies. Utility Patents appear to have enabled firms to maintain their investments in biotechnology research, though few final products have yet reached the marketplace.

Neither Austin (1993) nor Lerner (1994) distinguished agricultural biotechnology patents from other kinds of biotechnology applications. Most of the firms investigated in these studies were in the pharmaceutical and medical industries. However, Lerner tested whether the value of patents differed among firms specializing in human therapeutics, human diagnostics, biotechnology research equipment, and agricultural or industrial applications, and found no significant differences in patent values. Additional evidence comes from a 1991 survey of agricultural research firms by Pray, Knudson, and Masse (1993). They received responses to a question-

Table 14—Field test permits issued for genetically modified plants, through June 1993

Crop	Herbicide tolerance	Insect resistance	Virus resistance	Product quality	Research	Total
			Number			
Corn	31	22	12	5	6	76
Tomato	11	15	13	27	8	74
Potato	2	7	39	10	6	64
Soybean	48	0	1	4	4	57
Cotton	25	14	0	0	0	39
Tobacco	6	11	9	3	6	35
Rapeseed	4	1	0	11	0	16
Alfalfa	3	0	8	1	0	12
Melon	0	0	10	0	0	10
Cantaloupe	0	0	10	0	0	10
Rice	1	2	1	1	2	7
Other	1	6	12	5	8	32
Total	132	78	115	67	40	432
Percent	31	18	27	16	9	100

Source: Economic Research Service compiled from Ollinger and Pope (1995).

Table 15—Selected mergers and acquisitions in the seed industry

Parent firm (Type) [Nationality]
Subsidiaries (Year of acquisition)

Atlantic-Richfield (petroleum) [USA]
- Dessert Seed Co. (1980)
- Castle Seed Co.

Cargill (food) [USA]
- ACCO Seeds (1980)
- Dorman Seeds (1971)
- Kroecker Seeds (1979)
- P-A-G Seeds
- Paymaster Farms
- Tomco Genetic Giant

Celanese (chemical: merged with Hoechst in 1987)
- Celpril, Inc. (1975)
- Moran Seeds (1974)
- Joseph Harris Seed Co. (1978)
- Niagara Farm Seeds (1980)

Ciba-Geigy (chemical: merged with Sandoz, 1996) [Swiss]
- Columbiana Farm Seeds (1973)
- Funk Seeds International (1976)
- Germain's
- Hoffman
- Louisiana Seed Co. (1976)
- Peterson-Biddick
- Shissler
- Steward Seeds (1974)
- Swanson Farms

George J. Ball (seed) [USA]
- Denhold Seeds
- Pan-American Seeds
- Petoseed

Hoechst (chemical) [German]
- Canners
- Hild
- Nunhems

Imperial Chemical Industries (chemical) [British]
- Cotinseed (1985)
- Grast (1985)
- Miln Marsters (1985)
- SES (1985)
- Sinclair McGill (1985)

IT&T (telecommunication) [USA]
- Moran Seeds (1978)
- W. Atlee Burpee Co. (1978)

Limagrain (seed) [France]
- Ferry-Morse (1981)
- Shissler
- Tozier
- Vilmorin

Lubrizol (chemical)
- Agricultural Laboratories
- Arkansas Valley Seed
- Colorado Seeds
- Gro-Agri
- Jacques Seed (1985)
- Keystone Seed Co.
- Lynville (1985)
- McCurdy Seed
- R.C. Young
- Seed Research Associates
- Sigco (1985)
- Sun Seeds
- Taylor-Evans Seed Co.
- V.R. Seed

Monsanto (chemical) [USA]
- Hybritech Seed International
- Jacob Hartz Seed Co. (1983)
- DeKalb Hybrid Wheat (1982)

Occidental Petroleum (petroleum: merged with Sandoz, 1983)
- Excel Seeds (1972)
- East Texas Seed Co. (1973)
- Missouri Seeds
- Moss Seed Co. (1972)
- Payne Brothers Seed Co. (1973)
- Ring Around Products (1978)
- Stull Seeds (1975)
- West Texas Seed Co. (1975)

Royal Dutch/Shell (petroleum: merged with Dupont in 1986)
- Agripro Inc. (1980)
- Ferry-Morse, Farm Seed Division
- H.P. Hybrids (1979)
- Nickerson American
- North American Plant Breeders (1973)
- Rudy Patrick (1974)
- Sokota Hybrid Producers Assn.
- Tekseed Hybrids (1979)Celpril

Pfizer
- Clemens Seed Farms (1975)
- Jordan Wholesale Co. (1975)
- Ramsey Seed
- Trojan Seed Co. (1975)
- Warwick Seeds

Sandoz (chemical; merged with Ciba-Geigy, 1996) [Swiss]
- Gallatin Valley Seed Co.
- Hilleshog (1976)
- Ladner Beta
- McNair Seeds (1980)

Continued—

Table 15—Selected mergers and acquisitions in the seed industry—cont'd

Parent firm (Type) [Nationality] Subsidiaries (Year of acquisition)	**Parent firm** (Type) [Nationality] Subsidiaries (Year of acquisition)
Sandoz—cont'd	**Stauffer** (chemical: merged with ICI in 1985)
Northrup King (1975)	Blaney Farms (1979)
Pride Seeds	Prairie Valley Seed Co. (1978)
Rogers Brother Seed Co. (1974)	Rauenhorst, Bellows & Assoc. (1980)
Sluis & Groot (1976)	**Upjohn** (chemical) [USA]
Stauffer Seed (1976)	Asgrow (1972)
Vaughans (1976)	Associated Seeds (1972)
Woodside Seed Growers (1974)	Bruinsma (1968)
	Farmers Hybrid Seed Co. (1975)
	O's Gold (1968)

Sources: Economic Research Service compiled from Doyle (1982), Butler and Marion (1985), Kloppenburg (1988) and various trade journals.

naire from 90 companies with plant breeding and/or agricultural biotechnology research programs. Fifty-two percent of the respondents said that the availability of Utility Patents increased their ability to profit from research. Ten percent of respondents said it decreased their ability to profit, presumably because other companies that own patents can restrict access to scientific information and germplasm.

IPR's, Seed Monopolies, and Scientific Progress

The legal establishment of a system of intellectual property rights reduces market failures that result because some forms of knowledge cannot be appropriated. However, it creates a market failure resulting from a limited monopoly. During the life of a patent, the owner will encourage the use of the invention, at a cost, to reap some benefits of the invention. However, under a monopoly, the use of the invention will generally be less than if it were freely available. Thus a patent system reduces the social value of the invention, although it is preferable to having no invention at all. Legal protection of intellectual property provides a means of encouraging profit-oriented firms to allocate resources to research activities, although it achieves this at a social cost.

The tension between these two types of market failures underlies much of the public policy debate about intellectual property rights. How these rights are defined and enforced carries implications for both economic efficiency and equity. Inventors often favor stronger intellectual property rights so they may obtain the largest possible share of the social benefits of their invention. Users of the invention, on the other hand, seek to limit the monopoly power of the patent to increase the availability and reduce the cost of using the invention. The monopoly power afforded by a patent depends upon its duration and the breadth of exclusion given to the owner.

IPR's and the cost of seed. The extension of intellectual property rights for new crop varieties and biotechnology inventions raised concerns that it would enhance the market power of private seed companies and result in higher seed costs to farmers. These concerns were exacerbated by a series of mergers and acquisitions that took place in the seed industry beginning about the time the Plant Variety Protection Act was enacted (table 15). The first wave of acquisitions and mergers occurred in the late 1960's and 1970's, when many large chemical, oil, and food corporations acquired many medium- and small-sized seed companies. Another wave of mergers occurred during the 1980's, when many of these food, oil, and chemical companies sold their interests to agricultural chemical firms. While these changes to market structure reduced the number of independent seed companies, it also stimulated an infusion of new capital for plant breeding and biotechnology research. Large, multinational corporations had greater access to research resources and could sustain greater risks than small, independent companies (Chandler, 1990). Furthermore, agricultural chemical companies could achieve economies of scale in research and marketing by using synergies between biological and chemical technologies.

Table 16—Seed sales, private plant breeding, and trends in seed prices and yields, major field crops

Crop	Seed sales	Private plant breeding[1]	Seed cost	Share of seed purchased	Growth in seed price[2]	Annual growth in crop yield[2]
	- - - - Million 1989 dollars - - - -		*- - Dollars/acre - -*	*- - - - - - - - - - - - - - Percent - - - - - - - - - - - - - -*		
Hybrid seed:						
Corn	1,031	112.9	21.09	95	4.75	1.33
Sorghum	90	12.6	5.13	95	5.08	1.54
Non-hybrid seed:						
Wheat	256	13.5	8.92	40	.97	1.13
Soybeans	610	24.9	12.03	73	1.92	1.23
Cotton	108	4.6	14.93	74	4.46	2.23

[1]Private research investment derived from Kalton, Richardson, and Frey (1989). [2]Average annual rate of growth in seed price and crop yield between 1975 and 1992. Annual seed price is divided by crop price to account for inflation.

Sources: Crop yields, crop prices, and seed prices were compiled by Economic Research Service from U.S. Department of Agriculture, *Agricultural Statistics*, various issues.

So far, there is little evidence that the changes in the structure of the seed industry have been detrimental to market efficiency or performance. Yields increased at an average annual rate of 1.0-1.5 percent for major field crops between 1975 and 1992, except for cotton yield, which increased at more than 2 percent per year (table 16). Probably about half of this yield growth can be attributed to improved varieties of seed (see box, “Contribution of Plant Breeding to Agricultural Productivity Growth”). Over this period, the real price of seed (measured as the ratio of the nominal seed price to the crop price) generally grew at a faster rate than yields. Prices for hybrid seed (corn and sorghum) rose more rapidly than prices for self-pollinated seed. Since farmers must repurchase hybrid seed each year, commercial seed companies are best able to capture the gains from varietal improvement for these crops. For self-pollinated crops, like wheat, some farmers save part of their crop as seed for the following year. Eventually, farmers purchase new seed even for these crops because of a breakdown in disease resistance, deterioration in uniformity, or the development of new, improved varieties.

Provided there is sufficient competition in the seed industry, seed companies will be unable to capture the full economic value of improved seed. They need to price their seed so that farmers will adopt their varieties. Otherwise, farmers could continue using old varieties or purchase seed from another company. For crops grown with hybrid seed, like sorghum and corn, seed companies appeared to capture only 35 to 48 percent of the value of improved seed, with the remainder going to farmers (fig. 9). For nonhybrid crops (wheat, soybeans, and cotton), seed companies obtained even lower shares of yield gains, from 12 to 24 percent. For the hybrid seed crops, seed companies invested over 10 percent of seed sales in research. For the nonhybrid crops, only 4 to 5 percent of seed sales were reinvested in research. The inability to capture a larger share of the gains from breeding nonhybrid crops served as a disincentive for seed companies to invest more in research.

Private incentives for investing in biological technology, such as plant breeding, appear to be less than those for manufacturing or chemical technology. Mansfield and others (1977) estimated that manufacturing firms capture about 50 percent of the gains from their research investments. Seed companies, on the other hand, appear to capture less than 25 percent of the gains from plant breeding of nonhybrid crops and between 33 and 50 percent of the gains from improved hybrid seed. The inability to appropriate these gains is a major reason the private sector tends to underinvest in research. Continued public support of applied plant breeding may be necessary to assure adequate investment in biological research.

IPR’s and the progress of biological science. Some scientists and legal scholars have argued that the patenting of biological inventions could constrain varietal improvement and slow the rate of growth of the biotechnology industry. Varietal improvement and scientific advancement in biotechnology are largely an incremental process relying on past developments. For example, having ready access to the rice germplasm pool helped raise rice yields in the United States by 149 percent between 1950 and 1990 (Plowman, 1993). In the pedigree of the rice variety Lemont, the most widely grown variety in the United States, each of the parent varieties contributed one or more important traits (fig. 10). Restricted access to any one intermediate variety or contributing patent-

Contribution of Plant Breeding to Agricultural Productivity Growth

Before 1930, crop yields in the United States increased at a rate of less than 1 percent per year. With the development of new breeding methods, increased use of fertilizers and chemicals, and other improvements, yields began to increase more rapidly—especially after World War II. Between 1940 and 1992, corn yields increased at an average annual rate of 3 percent, cotton and wheat yields by nearly 2 percent, and soybean yields by 1.3 percent. While part of this growth was due to more fertilizers and pesticides, better agronomic practices, and investments in irrigation and drainage, a large part can be attributed to plant breeding. Plant breeders developed new varieties, which used fertilizers more efficiently, increased pest resistance, and were better suited for local growing conditions.

Several previous studies have attempted to determine the contribution of plant breeding to yield growth in the United States. A recent study evaluated changes in the yield potential of sorghum, corn, soybeans, cotton, and wheat (Fehr 1984). This study found that between 1930 and 1980, the maximum yield potential of hybrid corn increased by 4.6 tons per hectare, or more than double the 1930 level. This is equivalent to 89 percent of the gain in corn yields achieved by Iowa farmers over this period. Sorghum yield potential increased by 1.6 tons per hectare, or 63 percent of the total change in average farmers' yields. For other crops, the study estimated that genetic improvement equaled 90 percent of soybean yield gains between 1902 and 1977, 67 percent of cotton yield gains between 1936 and 1960, and 50 percent of wheat yield gains between 1958 and 1980. The study compared the yield of old and new varieties in carefully controlled experiments that characterized intensive management conditions. This approach may overestimate the contribution of genetic changes to changes in farmers' yields since it does not take into account changes in the use of other inputs, such as fertilizers and irrigation. Farmers' yields are often below the maximum potential yield of a variety due to economic, management, and biophysical factors.

Thirtle (1985) estimated the contribution of biological inputs to the growth in farmers' yields, after accounting for changes in fertilizer, labor, machinery, and land use and allowing for substitution among inputs. Biological inputs include the use of improved varieties and changes in agronomic practices. Thirtle (1985) estimated that between 1939 and 1978, biological inputs increased corn yields by an average of 1.7 percent per year, wheat yields by 1.5 percent, soybean yields by 1.1 percent, and cotton yields by 0.5 percent. Compared with total yields realized by farmers over this period, biological inputs accounted for 50 percent of the yield growth in corn, 85 percent for soybeans, 75 percent for wheat, and 24 percent for cotton. Other studies using a similar methodology have estimated that genetic improvement in wheat contributed to about 50 percent of yield gains over roughly the same period (see Dalrymple 1980, p. 111, for references).

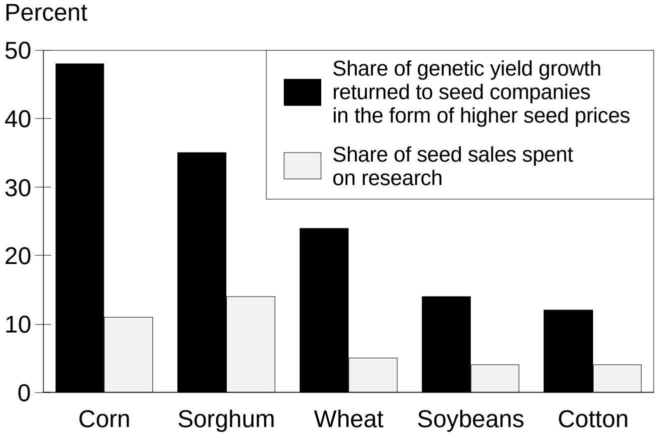
These estimates vary considerably for different crops and for the same crop during different periods. Technological advances often occur unevenly. Occasionally, a major technological breakthrough results in rapidly increasing yields for some years, but then yield growth slows until another major advance takes place. The discovery of economical methods of hybridization led to dramatic increases in corn yields after the 1930's that have continued up to the present time. Sorghum yields doubled in the 1960's when hybrids were first introduced, but yield growth has slowed since then. The introduction of semi-dwarf wheat and rice varieties helped to raise the yields of these crops in the 1960's and 1970's rapidly. Cotton yields increased dramatically in the 1950's, were stagnant between 1960 and 1980, and since 1980 have achieved steady increases. Plant breeding, like all research endeavors, is an uncertain and risky undertaking in which successes are difficult to predict.

able technologies might have slowed progress in the development of this rice cultivar.

Restricted access to new technology is of particular concern for Utility Patents with broad claims. In a patent application, an inventor lists claims to indicate the scope of the invention. Patent claims stake out the technologies that the inventor controls. Obviously, it is in the inventor's interest to have as broad a claim as possible, as this increases the value of the patent. The patent examiner decides which claims are allowed. As a rule, the patent examiner must prove that a particular claim exceeds the information revealed by the invention to refute the claim. However, it is often difficult to determine the unique contribution of a particular invention from prior scientific advances. Significant overlaps can also arise between the claims of different patents. Once a patent is issued, narrowing of uncertain patent claims is left to the courts in particular infringement suits (Merges and Nelson, 1990). One difficulty in interpreting the claims of biotechnology patents is that, in biology, the structure-function relationships are not understood as well as mechanical and chemical technologies. The biotechnological inventive process is characterized by randomness and unpredictability. Applications of an invention or slight modifications of it can often be found in areas not envisioned by the inventor (Ko, 1992).

Questions about the patenting of new biological inventions are not only an issue for research conducted by

Figure 9
Appropriability and private research investment in plant breeding



This figure shows the share of genetic yield growth for these crops captured by seed companies in the form of higher seed prices and the share kept by farmers. To determine these shares, we first made two assumptions: (1) half of the growth in farmer yields can be attributed to genetic improvements and (2) the other half of the growth can be attributed to other factors. Then, we adjusted the change in yields for changes in seeding rates to get the increase in bushels of crop yield required to purchase one bushel of seed. The ratio of yield growth to genetic seed price growth gives the share of genetic improvement going to seed companies; the remainder is the share going to farmers. For example, between 1975 and 1992, corn yields grew by 4.78 bushels per bushel of seed planted. Assuming half of this increase is due to improved varieties implies a real yield improvement of 2.39 bushels per bushel of improved seed. Over the same period, the price of corn seed (in terms of the number of bushels of corn production needed to by one bushel of seed) increased by 1.16 bushels. Therefore, 48 percent of real yield growth was returned to seed companies in the form of higher seed prices. The remaining 52 percent was kept by farmers.

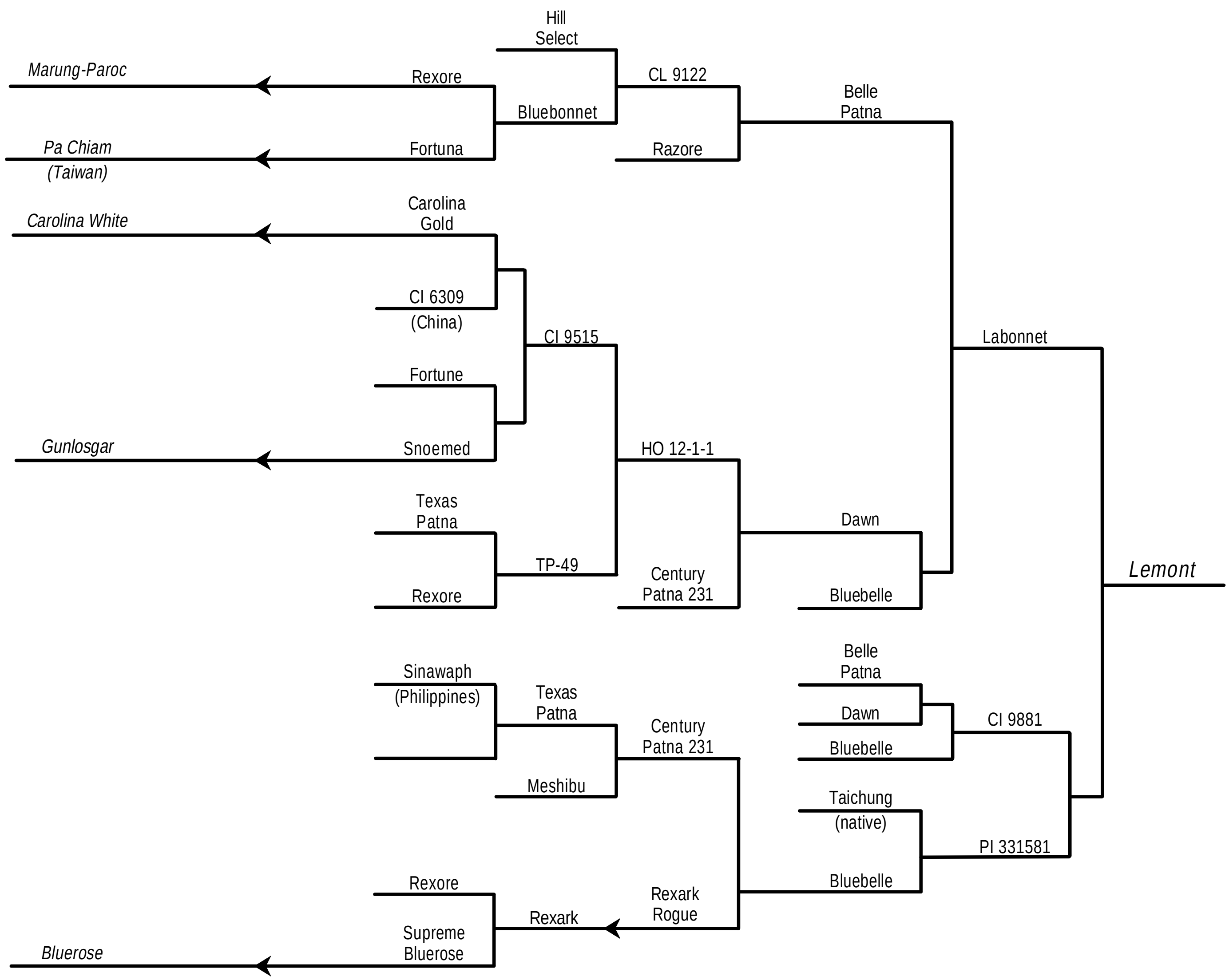
Sources: Economic Research Service. Data for crop yield, crop, and seed prices paid or received by farmers derived from USDA, *Agricultural Statistics* (seed prices normalized by crop price). Annual rate of growth in normalized seed price and crop yield is average between 1975 and 1992. Data for private research investment derived from Kalton, Richardson, and Frey (1989).

the private sector. Since the passage of the Patent Policy Act in 1980 (P.L. 96-517, also known as the Bayh-Dole Act), scientists conducting research supported by Federal funds have been allowed to own and license patents for their inventions. The intent of the legislation was to speed the rate at which basic scientific discoveries made at universities are developed into commercial technologies. Sometimes, it takes considerable additional investment to make a new invention into a commercially viable product. Firms may be unwilling to make these investments unless they have an exclusive license to the invention (Kitch, 1977). The law allows universities to own patents on discoveries made in federally funded research. Universities may then license their inventions to firms for commercialization. Patent licenses can be an important source of new revenue for the universities. However, patenting by universities could adversely affect the free exchange of information and materials among scientists as universities compete to be the first to achieve a new invention. Universities might be diverted into activities that are not compatible with their historical mission, which is "to protect and foster an environment conducive to free inquiry, the advancement of knowledge, and the free exchange of ideas" (Giamatti, 1982, p. 1278).

Empirical evidence on whether Utility Patents for agricultural biotechnology have curtailed scientific development is limited and mostly anecdotal. Surveys of agricultural scientists suggest that this may be more of a concern among researchers in the public sector than in the private sector. Public sector plant breeders have invested greater resources than their private sector counterparts in identifying major new traits and developing advanced breeding stock (Ruttan, 1982; Shands, 1995). Private seed companies have channeled more resources to incorporating advanced germplasm into their breeding lines and developing finished varieties (Ruttan, 1982). In a 1989 survey, 84 percent of directors of 49 State agricultural experiment stations thought that using patents in public research programs would adversely affect free exchange of plant germplasm between public and private breeders. Seventy-three percent thought that the use of patents in public research programs would adversely affect the free access and availability of undeveloped germplasm from international sources (Brooks, 1989). A 1991 survey of 90 agricultural research firms elicited their opinions about the effects of intellectual property rights on private plant-breeding programs (Pray, Knudson, and Masse, 1993). About 25 percent of respondents thought the availability of Utility Patents would reduce the flow of scientific information from government researchers and other firms. Thirty-five percent of respondents thought that exchange of germplasm would be curtailed. On the other hand, several respondents thought Utility Patents would serve to increase germplasm and information exchange, particularly among private sector firms. With patent protection, firms may be less inclined to rely on trade secrets to protect intellectual property. Twenty-five percent thought information would be more forthcoming from other firms, and 21 percent thought their competitors would be more likely to share germplasm. About 18 percent said that Utility Patents would

Figure 10

Pedigree of rice cultivar Lemont, indicating ancestors used to develop variety[1]



[1]Lemont is the most important rice variety currently grown in the United States.
Source: Economic Research Service. Data derived from Plowman (1993).

increase the flow of information and germplasm from government researchers to private companies. One limitation of this survey is that few biotechnology firms were included (only 5 of the 90 firms in the sample held Utility Patents).

There are several ways in which the patent process can be modified to reduce the likelihood of unduly restricting scientific development. One option is to have a broad research exemption for Utility Patents (Plowman, 1993). However, Karp (1991) maintains this would frustrate the reward and prospect functions of patents and seriously undermine the value of the patent system. A second option would be to require compulsory licensing of patents, based on a reasonable licensing fee (Tandon, 1982). A limitation of this option is the difficulty of establishing what is a reasonable fee. A third option would be to narrow the scope of patent claims (Merges and Nelson, 1990; Ko, 1992). This puts a heavier burden on the patent examiner, but there is some evidence that this is already occurring with animal patents (Lerner, 1994). A fourth option would be to leave the patent system as it is but encourage patent-pooling and cross-licensing. When exchanging germplasm, many seed companies and some universities use “material transfer agreements,” which specify the terms of exchange.

These agreements typically require the recipient to use the material for research purposes only and not to transfer it to third parties. If the exchanged germplasm contributes to a new variety the recipient wishes to sell commercially, then the recipient and the supplier must negotiate a profit-sharing arrangement. Another version of patent-pooling and cross-licensing is a corn research consortium established in 1995 by the USDA, several State agricultural experiment stations, and about 20 private plant breeding companies. Under this agreement, the participants agreed to share breeding crosses (although not inbred lines) to promote the development of major new traits in the corn germplasm pool used for breeding finished varieties (Shands, 1995). Although firms have an incentive to license their patented technologies to one another, as a practical matter, these arrangements often involve high negotiation and transaction costs, particularly for major innovations. As a result, such arrangements are often not successful (for references to empirical studies on the transaction costs of patent-pooling and cross-licensing, see footnotes 146-148, p. 874, in Merges and Nelson, 1990).

Market Failure, Regulation, and Innovation

Market prices provide signals that guide private firms in their resource allocation and investment decisions. When prices for goods reflect their scarcity value to society, producers have an incentive to allocate resources in a socially beneficial manner. Sometimes, however, market forces fail to adequately convey societal values for natural resources or consumer preferences for products. The prices farmers pay for pesticides, for example, account for the resources used in pesticide manufacturing, but do not reflect environmental or health costs that may result from pesticide use. Food products may lack certain desirable characteristics, like improved nutrition, if consumers do not have adequate knowledge about them. Even if consumers were willing to pay more for products with such attributes, firms would have little economic incentive to develop them unless they could convey that information to consumers. Without additional incentives, the private sector will tend to undersupply new products and technologies when demand is not fully reflected in market prices.

Regulations are sometimes used to correct for inefficiencies that arise when market prices do not reflect social costs or values adequately. Regulations influence not only the production and supply decisions of firms. They also affect firms' R&D investment decisions. While regulations can help address market failures, they may also have detrimental impacts on the economy. They may significantly raise industry costs, reduce incentives to invest in R&D, and adversely affect market structure.

Regulation of Agricultural Biotechnology and Chemical Pesticides

New agricultural technology may have unintended consequences for the environment and human health. It has been known for some time that the application of some chemical pesticides to crops may adversely affect health and damage ecosystems. More recently, the arrival of biotechnology has raised concerns about potential environmental and health risks posed by genetically modified organisms. These concerns have led to increased Federal regulation of the agricultural chemical and biotechnology industries.

Agricultural biotechnology is currently regulated by Animal and Plant Health Inspection Service (APHIS) of USDA, the Food and Drug Administration (FDA), and the Environmental Protection Agency (EPA). APHIS regulates the field testing of genetically modified plants and organisms to guard against unintended environmental harm. Between 1987 and June 1993, 470 field tests of such organisms were conducted under the standards set forth by APHIS (table 14). As experience with field testing increased, these regulations were partially eased. In 1994, APHIS authorized the field testing of genetically modified varieties of corn, cotton, potatoes, soybeans, tobacco, and tomatoes without a permit if certain eligibility criteria and performance standards were met (although testers still must notify APHIS). Prior to commercialization, companies must also ensure that a genetically modified food product complies with State and Federal marketing statutes. These include State seed certification laws, the Food, Drug, and Cosmetic Act (FDCA), and the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). The FDA, under authority granted through the FDCA, may regulate food products that may have been significantly altered by using plant biotechnology. The EPA may regulate plants that have pesticidal properties under authority granted through FIFRA (Office of Technology Assessment, 1992).

Regulation increases development costs and may delay the commercialization of new biotechnology products. On the other hand, some scientists consider these regulations insufficient for assessing the potential environmental risks posed by genetically modified organisms. While the APHIS regulations governing experimental testing appear to have been adequate for small-scale field trials, the information gathered from them may be deficient for evaluating the environmental risks of large-scale commercial use (Rissler and Mellon, 1993). Uncertainty and lack of consistency in the regulatory process can be impediments to the commercial viability of research investments in agricultural biotechnology.

Chemical pesticides have also been subject to increased regulation. Amendments to FIFRA enacted in 1972, 1978, and 1988 required companies to test new and existing pesticides for chronic and acute toxicity to humans and effects on fish and wildlife. The EPA was authorized to cancel or suspend pesticides that posed unreasonable environmental or health risks (Hatch, 1982).

In a recent study, Ollinger and Fernandez-Cornejo (1995) examined the effect of pesticide regulations on innovation in the agricultural chemical industry. The study found that these regulations significantly increased product development costs. Between 1972 and 1987, the cost of developing new pesticide products rose from $20.4 million to $54.2 million (constant 1982 prices). Much of this increase was to meet new regulatory requirements, such as evaluating chronic toxicity and assessing environmental effects on fish and wildlife. Between 1972 and 1991, regulatory costs rose from 18 percent to 60 percent of total R&D spending for agricultural chemicals (table 17). The study also found that regulations reduced the number of new chemical pesticide products available for use on minor crops. New pesticide registrations for vegetables, fruits, and nuts (minor-use pesticides) fell from 62 during 1972-76 to 15 during 1985-89. However, new registrations for major crops (corn, soybean, wheat, cotton, and sorghum) remained almost unchanged.

Although the regulations increased development costs and reduced product innovation, they also resulted in the development of pesticides with reduced environmental risks. These new pesticide products were often less toxic to nontarget species and would degrade more rapidly in the environment (Ollinger and Fernandez-Cornejo, 1995).

An unintended consequence of the pesticide regulations was their effect on the structure of the U.S. pesticide industry. Higher regulatory costs forced some companies to exit the industry. Regulations often favor larger and

Table 17—Structure and innovation in the agricultural chemical industry

Year	Firms[1] Small	Firms[1] Large	Four-firm concentration ratio	Foreign firm market share[2]	New product registration for major firms[3]	Share of total R&D for: Product development	Share of total R&D for: Reregistration and testing
	Number	*Number*	*Ratio*	*Ratio*	*Number*	*Percent*	*Percent*
1972	16	17	0.496	0.18	12	82	18
1973	17	17	.501	.16	4	81	19
1974	17	17	.484	.20	11	82	18
1975	18	18	.487	.20	12	80	20
1976	18	18	.478	.21	7	67	33
1977	18	18	.441	.20	1	69	31
1978	18	18	.421	.22	0	71	29
1979	18	18	.407	.21	9	70	30
1980	16	18	.394	.21	9	71	29
1981	16	18	.378	.21	5	73	27
1982	15	18	.372	.21	7	70	30
1983	14	18	.392	.21	8	69	31
1984	10	19	.402	.23	7	72	28
1985	9	19	.385	.28	4	66	34
1986	8	18	.380	.29	8	61	39
1987	8	15	.454	.36	4	60	40
1988	8	15	.466	.38	4	59	41
1989	6	13	.483	.43	10	53	47
1990	n.a.	n.a.	n.a.	n.a.	3	45	55
1991	n.a.	n.a.	n.a.	n.a.	3	40	60

n.a. = Not available

[1]Companies in the sample introduced at least one new product between 1972 and 1989 or were among the top 20 companies by sales. [2]Includes production of foreign-owned plants in the U.S. plus imports by foreign owned companies. [3]Includes chemical pesticide registrations only. Major companies are firms ranked among the top 20 companies at least once between 1972 and 1991.

Source: Economic Research Service compiled from Ollinger and Fernandez-Cornejo (1995).

foreign-based companies over smaller domestic firms (Ollinger and Fernandez-Cornejo, 1995). The number of small pesticide companies in the U.S. market fell significantly after 1972 (table 17). Although the exit of some companies reduced the potential for innovation, the firms that remained tended to be those that were better able to operate in the more stringent regulatory environment.

The decline in new registrations of minor-use chemical pesticides has increased market opportunities for biological pesticides and genetically resistant crop varieties (Krimskey and Wrubel, 1992). A major environmental advantage of biological pest controls is that they often affect only one target species. However, they may be less effective than chemical pest controls in situations where crops are subject to multiple insect pests. Insect resistance is also a concern. A further constraint for some biological controls is that organisms that have been genetically modified for pest resistance are subject to the regulations governing biotechnology.

Food Standards and Product Quality

Consumer preferences for food products are based on product attributes such as taste, appearance, familiarity, and perceptions about nutritional value and safety. However, not all product characteristics are easily observable. Food grades and labels can be used to help consumers choose products by providing additional information on product quality. Labeling regulations may also affect the development of new products and processing methods with preferred attributes as firms respond to consumer demands for these characteristics.

USDA has authority over food inspections and has developed grading standards for many food products, such as meats, fruits and vegetables. USDA grading standards are voluntary, but producers, processors, and packers cannot use the USDA packaging label unless they adopt the USDA grading system. Grading systems are used to classify foods with dissimilar characteristics into groups with specific and more uniform food qualities (Office of Technology Assessment, 1992). Higher quality grades are priced accordingly.

A case study of the pork grading system showed that pork characteristics improved once the USDA grading system was put in place (Office of Technology Assessment, 1992). However, the study also found those grading standards can lag behind changes in consumer preferences. Consumer demand for leaner meat increased. However, grading standards continued to measure pork quality based on the firmness of the fat and lean muscle tissue and on the fat feathering in lean muscle (with more fat warranting a higher grade). As a result, new pork products with lower fat content would not yield a higher grade. This could discourage the development of leaner meat products unless new or alternative grading standards are adopted.

Food labeling is governed by the Food, Drug, and Cosmetic Act (FDCA) and by its 1990 amendment, the Nutrition Labeling and Education Act (NLEA). Under the FDCA, food producers have the option of labeling their products for advertising purposes voluntarily or to provide information to consumers about the attributes of a food product. The NLEA further requires producers to label all food and beverage products for nutritional content. FDA has regulatory authority over food labeling and may require companies to verify that these labels are not false or misleading. FDA can also require warning labels on products judged to have adverse health risks, such as those found on cigarette packages and alcoholic beverages.

Concerning genetically engineered foods, FDA decided against requiring a label simply stating that a food was “genetically engineered” since it would not provide substantive information to a consumer. The FDA determined that the safety of a food product should be judged based on its content and not by the process by which it was produced (Caswell, Fuglie, and Klotz, 1994).

Mandatory labeling requirements are designed to give consumers more comprehensive information about product quality and to provide an incentive to firms to develop new products with desirable characteristics. Zarkin and Anderson (1992) suggest that the new mandatory nutrition labels may induce producers to either reformulate existing products, develop new products, or change prices to increase sales.

In a study of the effects of food labeling, Ippolito and Mathios (1989) examined the effects of health claims for high-fiber cereals on consumer purchases and product innovation. Dietary fiber intake has been shown to reduce the risk of colon cancer. The study found significant increases in the consumption of high-fiber cereals and breads for certain segments of society because of health claim advertising. The growing demand for high-fiber cereals and the ability to make health claims on labels also induced cereal manufacturers to develop new high-fiber cereals. The increased focus on dietary fiber did not lead to changes in the sodium and fat content of high-fiber cereals, however. Moreover, companies are unlikely to invest in fundamental research to understand better the underlying links between diet, nutrition, and health (Caswell and Johnson, 1991). Public support for research may be necessary to expand knowledge in these areas.

Policy Implications

The private sector currently conducts more than $3.4 billion worth of food and agricultural research annually, much more than the public agricultural research system. These investments are driven by their perceived profit potential and are influenced by both market forces and government policies. Within the past 25 years, private agricultural research has moved beyond its traditional focus on food-product, mechanical, and chemical technologies to include biological technologies as well.

The ability of a private company to capture the gains from new technology is critical for encouraging private research investments. The strengthening of intellectual property rights for biological inventions provided an important stimulus for private investments in plant breeding and biotechnology. However, private incentives to invest in pre-technology research, such as the development of elite germplasm, are weak. Private investment in applied plant breeding also seems uneven across commodities, and is heavily oriented toward hybrid seed crops. Continued public support of applied plant breeding is likely to be necessary to sustain productivity growth for nonhybrid crops. Utility Patents with broad claims on biotechnology innovations have raised concerns that they may curtail longrun progress in biological science.

The regulatory environment also significantly affects the rate and direction of private research investments. Regulation of biotechnology field testing and pesticides has raised development costs for biological and chemical technologies. While these regulations reduce private incentives to invest in research, they also help direct research toward new products with desirable attributes, such as pesticides with less mammalian toxicity and less environmental persistence. Grading standards and labeling systems for food products can also encourage firms to develop new products with desirable characteristics, such as improved nutrition. However, standards and systems are unlikely to induce the private sector to undertake fundamental research on health and nutrition.