Introductions and Trials of New Varieties Are Increasing Over Time

The emergence of the private sector marks a significant shift in agricultural R&D. Decisions about R&D made in a competitive environment are likely to differ from those made in a public sector setting, where most R&D traditionally has taken place. Therefore, the amount of R&D, the emphasis of research, and other aspects of R&D are likely to change. In addition, public research priorities may change in response to R&D efforts undertaken by private firms: Public institutions may pursue initiatives that complement private efforts as well as research areas that the private sector neglects. Measures of plant breeding research output further highlight the shift in emphasis from public to private R&D.

PVP Certificates

Plant variety protection certificates approved by USDA's PVPO are similar to patents issued for crop varieties. PVP certificates are intended to benefit both consumers and producers of improved crop varieties. Individual and corporate consumers benefit from the improved quality of agricultural goods that they use directly for consumption purposes or as inputs to the production of goods, such as livestock and medicine. And to the extent that new varieties increase productivity and supply, consumers also stand to gain from decreases in price. Seed producers, on the other hand, benefit from the exclusive rights they secure over the purity, breeding, marketing, distribution, and sales of improved varieties, allowing them to obtain a return on their investment of research and development resources (USDA, AMS, 2000).

Estimates of the time involved in producing new varieties in a breeding program range from 10 to 15 years to produce a marketable product (tables 34-35).[13] On an annual basis, a small breeding program was estimated to cost approximately $250,000 in the late 1980s, a sum adequate to cover the costs of a chief breeder, a staff of three or four, equipment, facilities and land (McMullen, 1987, p. 58). Even where larger firms realize economies of scale and scope in producing multiple varieties, the estimated development costs of a new variety range between $2.0 million and $2.5 million for the same period (McMullen, 1987, pp. 58-60). Given the magnitude of these investments, it is unlikely that plant breeders would have made this type of R&D investment without property rights protection.

The number of PVP certificates issued by the PVPO provides a useful indicator of the results of plant breeding research efforts. Research findings differ in showing the PVPA's effect on creating private sector incentives in research. Butler and Marion (1985, p. 79) conclude that during the 1970s, the PVPA resulted in "modest private and public benefits at modest private and public costs." Perrin et al. (1983), on the other hand, conclude that the act led to increased private investment in plant breeding for soybeans and other nonhybrid seed crops. These competing conclusions highlight the significance of time lags between R&D investment and the release of a new variety. For many varieties, this lag is often more than 10 years (table 35), implying that the economic returns to new R&D investments in plant breeding made in the 1970s were

Table 34—Stages and time required in plant breeding

Stage	Hybrid	Open-pollinated
	Years	
Recognition	0	0
Parent-line preparation	4-5	0-2
Initial crosses	5-6	0-3
Progeny selection	6-10	3-11
Crop evaluation	7-12	5-12
Testing the variety	7-15	6-15
Determination of a new variety	8-12	7-13
Market evaluation	8-13	8-14
Application for plan variety protetection	8-14	9-14
Multiplication from individual plants or ears	9-14	9-15
Certification	9-14	9-15
Market introduction	10-15	10-17
Market acceptance	12-18	12-19
Market growth	13-19	13-20
Obsolescence	20-25	20-25

Source: McMullen (1987b), p. 58.

[13] Amount of time depends on availability of source germplasm. Time can also be reduced when breeders can use more than one cycle per year (e.g., through Southern Hemisphere shuttle breeding).

Table 35—Research time required for developing new seed varieties, major field crops

Crop	Time required			Number of varieties[1]	
	From date of cross to date of determination	From date of determination to application date	Total	Cross to date of determination	Date of determination to application
	Years				
Corn	5.5	2.0	7.5	4	6
Soybean	6.2	3.0	9.2	64	75
Cotton	8.0	4.2	12.2	27	57
Wheat	8.0	2.8	10.8	36	56
Rice	6.0	2.8	8.8	5	12
Average/total[2]	7.9	3.2	11.1	253	391

[1] Applicants are required to list the date of variety determination and date of application when submitting protection applications but they are not required to list the date the cross was made. For this reason, there are fewer varieties listed in the "Cross to date of determination" column.
[2] Average and total include other field crops and vegetables not shown here.

Source: McMullen (1987), p. 60, using data from Asgrow Seed Company.

not fully captured in the studies by Butler and Marion and Perrin et al. (Fuglie et al., 1996, p. 38).

The number of PVP certificates issued by the PVPO has grown rapidly since the 1970 PVPA after accounting for the time lag in plant breeding R&D (tables 36-37). This growth indicates the PVPA's positive effect on generating private sector incentives for plant breeding R&D. The increases were most marked for soybeans and corn, which together account for more than half of all certificates issued for field crops. By the end of 2002, 2,584 certificates were issued for varieties of U.S. origin for the four major field crops, including 1,078 for soybeans, 648 for corn, 568 for wheat, and 290 for cotton (table 37).

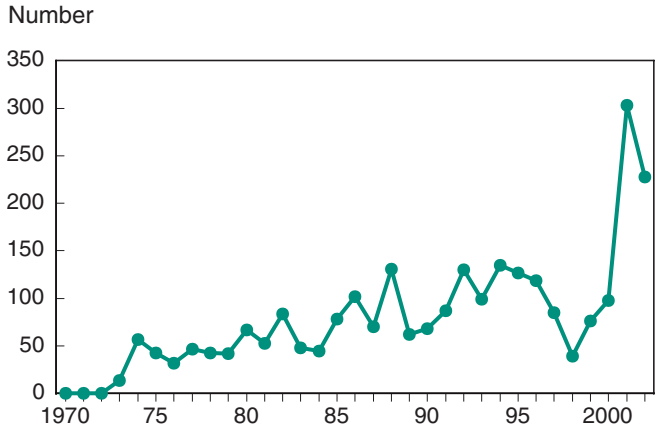
The majority of PVP certificates—about 84 percent—are held by the private sector. Among PVPs for major crops, the private sector owns close to 100 percent of corn certificates, 87 percent of cotton certificates, 84 percent of soybean certificates, and 68 percent of wheat certificates. Figure 16 captures the growth in PVP certificates issued for U.S. private and public entities for corn, soybeans, cotton, and wheat between 1970 and 2002.

Agricultural Biotechnology R&D

A driving force behind some of the increase in private sector R&D has been the introduction of modern biotechnology to agriculture. Biotechnology, broadly defined, is the application of biological science to affect living things. Under this broad definition, the entire endeavor of agricultural experimentation over thousands of years of human history might be considered "biotechnology." But the 20th century discovery of DNA and subsequent scientific advances have ushered in a new period of biological research. The application of genetic science to plants and animals in light of these discoveries is the sense in which this report employs the word "biotechnology."

The emergence of modern biotechnology is consistent with the more recent focus on plant breeding in private sector agricultural R&D (tables 25-26; figs. 13-14). In addition to techniques of modern biotechnology, the creation of new plant varieties with useful agronomic properties requires significant knowledge of plant breeding. In this sense, plant breeding and biotechnology are complementary. Moreover, the commercial success of GE crop varieties typically requires that biotechnology-derived trait enhancements are incorpo-

Figure 16
Number of PVP certificates issued for corn, soybeans, cotton, and wheat



Source: Data source provided in table 37.

Table 36—Plant variety protection certificates issued for new crop varieties, field crops

Crop	Number of certificates issued							Share of certificate ownership	
	1971-74	1975-78	1979-82	1983-86	1987-90	1991-94	Total	Private	Public
								Percent	
Soybeans	34	69	132	150	114	162	661	0.84	0.16
Corn	0	1	6	50	104	161	322	1.00	0.00
Wheat	12	52	59	30	74	87	314	0.68	0.32
Cotton[1]	24	35	41	38	34	39	211	0.87	0.13
Subtotal for major crops	70	157	238	268	326	449	1,508	0.85	0.15
Barley	0	12	2	22	6	35	77	0.82	0.18
Beans, field	0	1	5	18	10	28	62	0.77	0.23
Oats	0	10	6	0	9	8	33	0.36	0.64
Rice	0	8	4	2	5	15	34	1.00	0.00
Sorghum	0	0	0	0	2	31	33	1.00	0.00
Canola	0	0	0	2	8	15	25	0.72	0.28
Safflower	0	3	2	1	5	6	17	0.88	0.12
Other field crops	0	16	15	13	18	13	75	0.85	0.15
Subtotal for other crops	0	50	34	58	63	151	356	0.80	0.20
Total field crops	70	207	272	326	389	600	1,864	0.84	0.16

[1] Figures for PVP certificates issued for cotton varieties given here may vary from figures presented elsewhere in this report due to PVPO revisions and updates to PVP certificate listings.

Source: Fuglie (1996), p. 38.

rated into successful cultivars. Acquisition of firms with established varieties by companies with the ability to improve varieties using biotechnology is one possible rationale for recent consolidation in the U.S. seed industry.

The rapid commercial success of GE varieties provides a preliminary measure of the technical success of the R&D efforts.[14] The number of field releases of plant varieties for testing purposes provides an ex-ante measure of R&D output.[15]

Field Releases

The process by which new GE varieties of organisms are released into the environment is regulated and monitored by USDA's Animal and Plant Health Inspection Service (APHIS). Private companies and public institutions proposing tests of such organisms in the environment either notify APHIS of their intent, in accordance with APHIS's field release notification procedures, or submit an application for a field release permit (referred to here as an application). If an APHIS review of the application (notification or permit application) establishes that there are no significant environmental risks associated with a release, a notification is acknowledged or a field permit is issued (referred to here as an "approval"), thereby allowing the breeder to pursue testing. Between 1987 and June 2001, APHIS received over 7,600 applications for field releases of GE varieties. Of these applications, APHIS approved the field release of more than 6,700 new varieties (table 38). Also significant is the annual growth of field release applications during this period: applications received annually by APHIS increased from just 9 in 1987 to a high of 1,206 in 1998 (fig. 17). Although some applications were denied or withdrawn, a significant majority—almost 90 percent—were approved by APHIS (table 39, fig. 18).

The majority of applications for field releases received from private companies and public institutions are for testing improved varieties of major crops. By mid-2001, applications received included more

[14] Ex-ante, two important factors suggested a profitable market, justifying the time and expense of improving seed through biotechnology R&D. First, the seed market for U.S. field crops is very large. Second, genetically engineered seeds, selling at a price premium over conventional seeds, are not substantially more expensive to produce after R&D and regulatory approval are complete.

[15] Another measure of research output is the number of patents, which can also provide an indication of concentration of research assets (Brennan et al., 2000). Considering the two major crops, corn and soybeans, the three top firms, DuPont/Pioneer, Monsanto/DeKalb and Novartis/Syngenta, held 46 percent of the biotech patents or patent applications as of 1996-97 (table 51).

Table 37—PVP certificates issued for major field crops[1]

Calendar year issued	Corn					Soybeans					Cotton	Wheat	All major field crops
	Private origin	Public origin	Total U.S.	Foreign origin	Total	Private origin	Public origin	Total U.S.	Foreign origin	Total	Total U.S.	Total U.S.	Total
						Number							
1970	0	0	0	0	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	10	3	13	0	13	0	1	14
1974	0	0	0	0	0	21	1	22	0	22	24	11	57
1975	0	0	0	0	0	8	5	13	0	13	14	16	43
1976	0	0	0	0	0	14	0	14	0	14	7	11	32
1977	3	0	3	0	3	21	1	22	0	22	5	17	47
1978	0	0	0	0	0	20	2	22	0	22	9	12	43
1979	0	0	0	0	0	19	2	21	0	21	11	10	42
1980	6	0	6	0	6	30	13	43	0	43	12	6	67
1981	1	0	1	0	1	30	2	32	0	32	10	10	53
1982	2	0	2	0	2	32	7	39	0	39	10	33	84
1983	3	0	3	0	3	33	1	34	0	34	11	0	48
1984	11	0	11	0	11	23	4	27	0	27	7	0	45
1985	8	0	8	0	8	37	11	48	0	48	8	14	78
1986	29	0	29	0	29	42	2	44	0	44	13	16	102
1987	15	0	15	1	16	36	5	41	0	41	11	2	70
1988	33	0	33	0	33	34	14	48	0	48	8	42	131
1989	19	0	19	0	19	12	3	15	0	15	0	28	62
1990	37	0	37	0	37	10	0	10	0	10	15	6	68
1991	35	0	35	0	35	33	4	37	0	37	14	1	87
1992	54	0	54	1	55	47	17	64	1	65	1	9	130
1993	36	0	36	5	41	6	0	6	0	6	4	48	99
1994	29	0	29	0	29	42	12	54	0	54	20	32	135
1995	22	0	22	0	22	58	15	73	0	73	6	26	127
1996	35	0	35	5	40	33	5	38	0	38	7	34	119
1997	30	0	30	10	40	24	4	28	0	28	4	13	85
1998	22	0	22	0	22	13	1	14	0	14	0	3	39
1999	26	0	26	0	26	16	4	20	0	20	0	30	76
2000	18	1	19	0	19	43	9	52	0	52	0	27	98
2001	88	4	92	3	95	124	10	134	0	134	10	64	303
2002	79	2	81	0	81	43	7	50	2	52	49	46	228
Total	641	7	648	25	673	914	164	1,078	3	1,081	290	568	2,612

[1] Figures for PVP certificates issued may vary from figures presented elsewhere due to PVPO revisions and updates to PVP listings.

Source: Strachan (2003).

Table 38—Applications for field releases received by APHIS, by crop and year[1]

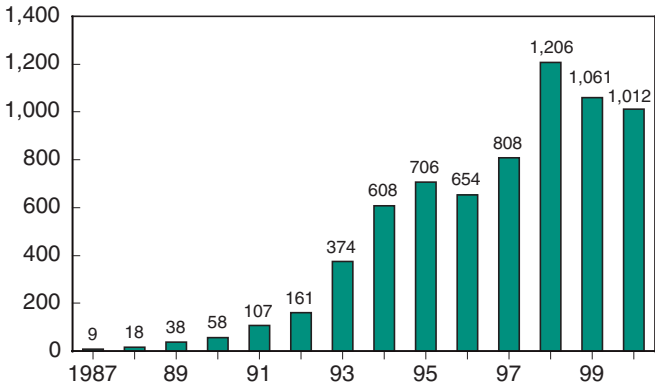
Crop	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total (1987-2001)[1]
								Number								
Corn	0	0	0	3	15	44	134	262	348	279	406	563	385	420	468	3,327
Soybeans	0	0	4	5	6	36	68	69	62	52	55	85	68	51	40	601
Cotton	0	1	5	11	17	4	23	43	63	33	50	47	53	79	52	481
Wheat	0	0	0	0	0	0	0	3	4	12	16	20	39	65	50	209
Other	9	17	29	39	69	77	149	231	229	278	281	491	516	397	246	3,058
Total	9	18	38	58	107	161	374	608	706	654	808	1,206	1,061	1,012	856	7,676

[1] Includes field release notifications received by APHIS, and field release permits either issued, withdrawn, or denied by APHIS, between June 16, 1987, and July 9, 2001.

Source: Virginia Polytechnic Institute (2001).

Figure 17

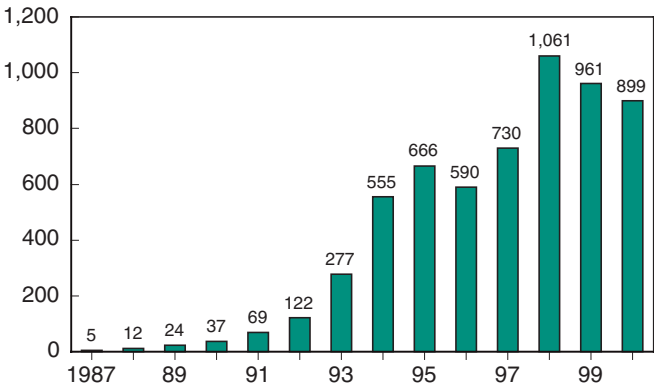
Total number of field release applications, by year



Source: Data source provided in table 38.

Figure 18

Total number of field release approvals, by year



Source: Data source provided in table 39.

than 3,327 for corn varieties, 761 for potatoes, 601 for soybeans, 532 for tomatoes, 481 for cotton, and 209 for wheat (table 40). APHIS classifies each variety according to the variety's unique genetic characteristic, or phenotype, which distinguishes it from other varieties. Field release applications received by APHIS between 1987 and 2000 included varieties with such characteristics as herbicide tolerance (27 percent), insect resistance (25 percent), product quality usually associated with added value output traits (17 percent), virus resistance (9 percent), and agronomic properties (6 percent) (table 41). A small share of the applications for field releases also contain multiple or "stacked" traits, such as herbicide tolerance and insect resistance.

The breakdown of the number of applications for field releases by company is provided in table 42. Much more detail, by year and for each of the major crops —corn, soybeans, cotton, and wheat—is shown in tables 43-47.

Table 39—Status of field release notifications and permits[1]

Year	Received	Approved	Delayed approval	Denied	Withdrawn	Void	Pending	Total
				Number				
1987	9	5	4	0	0	0	0	18
1988	18	12	6	0	0	0	0	36
1989	38	24	14	0	0	0	0	76
1990	58	37	21	0	0	0	0	116
1991	107	69	38	0	0	0	0	214
1992	161	122	28	0	11	0	0	322
1993	374	277	29	0	68	0	0	748
1994	608	555	38	6	9	0	0	1,216
1995	706	666	14	2	18	5	0	1,411
1996	654	590	35	8	20	0	0	1,307
1997	808	730	13	33	28	3	0	1,615
1998	1,206	1,061	25	108	10	2	0	2,412
1999	1,061	961	25	46	22	6	0	2,121
2000	1,012	899	36	57	16	1	2	2,023
2001	856	777	0	25	13	1	39	1,711
Total[2]	7,676	6,785	326	285	215	18	41	15,346

[1] From June 16, 1987, to July 9, 2001.

[2] The total number of field releases approved by APHIS includes 961 permits issued and 6,156 notifications acknowledged. Acknowledgments are given under the APHIS notification procedure, while issued refers to release permits issued by APHIS. For most purposes, there is no difference in these two categories, and together, they equal the number of field releases approved by APHIS.

Source: Virginia Polytechnic Institute (2001).

Table 40—Number of applications for field releases, by crop[1]

Crop	2000		1987-2001	
	Number	*Percent*	*Number*	*Percent*
Corn	420	41.5	3,327	43.3
Potatoes	70	6.9	761	9.9
Soybeans	51	5.0	601	7.8
Tomatoes	25	2.5	532	6.9
Cotton	79	7.8	481	6.3
Wheat	65	6.4	209	2.7
Tobacco	15	1.5	202	2.6
Rapeseed	16	1.6	177	2.3
Rice	19	1.9	134	1.7
Beet	22	2.2	121	1.6
Melons	13	1.3	140	1.8
Other	217	21.4	991	12.9
Total	1,012	100.0	7,676	100.0

[1] From June 16, 1987, to July 9, 2001. Includes field release notifications received by APHIS, and field release permits either issued, withdrawn, or denied by APHIS between June 16, 1987, and July 9, 2001.

Source: Virginia Polytechnic Institute (2001).

Table 41—Share of applications for field releases received by APHIS, by trait

Trait	2000	1987-2001[1]
	Percent	
Agronomic properties	6.5	6.0
Bacterial resistance	1.3	1.2
Fungal resistance	5.5	5.5
Herbicide tolerance	30.1	27.4
Insect resistance	26.0	25.3
Marker gene	5.4	3.8
Nematode resistance	0.2	0.2
Product quality	11.5	17.3
Virus resistance	6.1	9.1
Other	7.3	4.4
Total[1]	100.0	100.0

[1] From June 16, 1987, to June 25, 2001. Note that certain products contain multiple or "stacked" traits and are thus included separately under each appropriate trait.

Source: Virginia Polytechnic Institute (2001).

Table 42—Status of notifications and field release permits by company, 1987-2001[1]

Company/ institution	Acknowledged[2]	Issued[2]	Pending	Denied	Withdrawn	Void	Total
				Number			
Monsanto	2,142	155	11	68	47	6	2,429
Pioneer	535	55	2	31	22	1	646
AgrEvo	312	14		14	4		344
DuPont	305	15			1		321
ARS	130	42	1	12	8	3	196
DeKalb	172	9		8	3		192
Calgene	90	74		2	8	1	175
Semnis Vegetable Seed	144	18	2	3	1		168
DNA Plant Tech	74	15			2		91
Northrup-King	69	11		3	5		88
University of Idaho	66	14		6	1	1	88
Upjohn	10	63			12		85
Aventis	72	4	1		8		85
Iowa State University	69	5		7	2		83
Asgrow	49	26		1	5		81
Novartis Seeds	74	3		2			79
ProdiGene	50	22	2	1	1		76
Stine Biotechnology	71			4			75
Rutgers University	59	12		4			75
Cargill	54	11		1	5		71
Dow	56	2	4				62
Agracetus	57	3		1			61
Agritope	47	6		6	1		60
Zeneca	47	2	1	7	1		58
Frito Lay	36	18		2	2		58
Other	1,366	362	17	102	76	6	1,929
Total	6,156	961	41	285	215	18	7,676

[1] From June 16, 1987, to July 9, 2001.

[2] Acknowledgments are given under the APHIS notification procedure, while issued refers to release permits issued by APHIS. For most purposes, there is no difference in these two categories, and together, they equal the number of field releases approved by APHIS.

Source: Virginia Polytechnic Institute (2001).

Table 43—Field release approvals for corn, by company[1]

Crop	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
								Number							
Monsanto					1	7	47	72	63	32	105	94	147	248	816
Pioneer					4	11	20	45	57	78	106	114	54	5	494
DuPont							12	67	63	14	17	19	7		199
AgrEvo							2	2	12		5	131	26		178
DeKalb				2	1	6	6	27	29	41	26	33	1		172
Northrup-King						3	6	10	42	10					71
ProdiGene											2	6	24	24	56
Novartis Seeds											12	22	7	12	53
Iowa State University									1	1	4	15	16	14	51
Stine Biotechnology											3	9	21	14	47
Plant Genetic Systems										4	42				46
Cargill					1	2	3	2	10	6	7	8	2		41
Holdens					2	4	3	5	14	7	2				37
Ciba-Geigy					2	3	4	5	10	12					36
Stanford University											7	4	12	13	36
Garst/ICI					1	2	2	4	3	5	5	8	3		33
Mycogen							1	2	1	1	6	8	11		30
Dow							1	1	2		1		6	18	29
Limagrain								1		10	6	6	1	4	28
Asgrow							1	4	6	3	3				17
Agracetus								1	5	5	3		1		15
NC+Hybrids									3	6	3	3			15
University of Minnesota									1	2	3	4	5		15
University of Arizona										1	1	5	3	4	14
Aventis														13	13
Golden Harvest Seeds									2	5	1	3	2		13
Rogers/Rogers NK							1	4	2	6					13
Rhone-Poulenc											1	3	6		10
Wyffels Hybrids										6	4				10
Southern Illinois Univ.										2	2	1	3	1	9
Upjohn					2	3	2								7
Zeneca											1	2	3	1	7
Other				1	1	2	3	6	11	16	5	9	5	15	74
Total	0	0	0	3	15	43	114	258	337	273	383	507	366	386	2,685

[1] From June 16, 1987, to December 31, 2000. Field release approvals are either categorized as notifications acknowledged by APHIS under its notification procedure, or field release permits issued by APHIS. For most purposes, there is no difference in the two categories, and together, they equal the number of field releases approved by APHIS.

Source: Virginia Polytechnic Institute (2001).

Table 44—Field release approvals for soybeans, by company[1]

Crop	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
								Number							
Monsanto			4	4	3	22	13	12		1	6	20	38	21	144
DuPont							3	15	28	4	19	18	2	2	91
AgrEvo								6	16	16	8	13			59
Pioneer					1	4	11	16	5	3	7	7	2	2	58
Agracetus							1	4	9	13	2				29
Asgrow							1	6	2	9	5	6			29
Upjohn				1	2	5	7								15
Rhone-Poulenc											2	2	10		14
Aventis														10	10
DeKalb							2	1		2	1	3			9
Stine Biotechnology						1							1	6	8
Dairyland Seeds							2	3	1			1			7
Limagrain										1	1	3	1		6
University of Kentucky									1				2	2	5
AgriPro						1	2	1							4
Northrup-King						1	2	1							4
University of Illinois										2		2			4
Calgene												3			3
Iowa State University												1	1	1	3
Jacob Hartz							1	2							3
University of Georgia											1	1	1		3
University of Nebraska												1		2	3
FFR Cooperative							1	1							2
Ohio State University													2		2
Other							4					1			5
Total	0	0	4	5	6	34	50	68	62	51	52	82	60	46	520

[1] From June 16, 1987, to December 31, 2000. Field release approvals are either categorized as notifications acknowledged by APHIS under its notification procedure, or field release permits issued by APHIS. For most purposes, there is no difference in the two categories, and together, they equal the number of field releases approved by APHIS.

Source: Virginia Polytechnic Institute (2001).

Table 45—Field release approvals for cotton, by company[1]

Crop	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
								Number							
Monsanto			2	6	6		9	11	26	12	14	26	39	54	205
Calgene			2	4	9	4	4	4	4	5	11	1			48
Delta & Pine Land							2	11	13	6	4				36
AgrEvo											12	10	4		26
Dupont				1	2		2	8	7						20
Agracetus		1						1	5	7	1				15
Mycogen									2	1	2	4	3		12
Texas Tech University												5	3	4	12
Aventis														9	9
Dow														8	8
All-Tex								2							2
ARS										1			1		2
Boswell										1	1				2
Jacob Hartz									2						2
Novartis Seeds														2	2
United Agri Products								1	1						2
American Cyanamid							1								1
Bowdoin College														1	1
Brownfield								1							1
Chembred								1							1
Dunn								1							1
Miles							1								1
Northrup-King			1												1
SeedCo								1							1
Williams Seed								1							1
Other															0
Total	0	1	5	11	17	4	19	43	60	33	45	46	50	78	412

[1] From June 16, 1987, to December 31, 2000. Field release approvals are either categorized as notifications acknowledged by APHIS under its notification procedure, or field release permits issued by APHIS. For most purposes, there is no difference in the two categories, and together, they equal the number of field releases approved by APHIS.

Source: Virginia Polytechnic Institute (2001).

Table 46—Field release approvals for wheat, by company[1]

Crop	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
								Number							
Monsanto								2	3	7	6	13	27	52	110
University of Idaho										1	3	3	3	3	13
Montana State Univ.												1	4	3	8
Novartis Seeds											2	1	3	1	7
ARS									1	2		1		1	5
Applied Phytologics														2	2
AgrEvo								1							1
Syngenta														1	1
Cargill														1	1
Other															0
Total	0	0	0	0	0	0	0	3	4	10	11	19	37	64	148

[1] From June 16, 1987, to December 31, 2000. Field release approvals are either categorized as notifications acknowledged by APHIS under its notification procedure, or field release permits issued by APHIS. For most purposes, there is no difference in the two categories, and together, they equal the number of field releases approved by APHIS.

Source: Virginia Polytechnic Institute (2001).

Table 47—Field release approvals for corn, soybeans, cotton, and wheat, by company, 1987-2000[1]

Corn		Soybeans		Cotton		Wheat	
Company	No.	Company	No.	Company	No.	Company	No.
Monsanto	816	Monsanto	144	Monsanto	205	Monsanto	110
Pioneer	494	DuPont	91	Calgene	48	University of Idaho	13
DuPont	199	AgrEvo	59	Delta & Pine Land	36	Montana State Univ.	8
AgrEvo	178	Pioneer	58	AgrEvo	26	Novartis Seeds	7
DeKalb	172	Agracetus	29	DuPont	20	ARS	5
Northrup-King	71	Asgrow	29	Agracetus	15	Applied Phytologics	2
ProdiGene	56	Upjohn	15	Mycogen	12	AgrEvo	1
Novartis Seeds	53	Rhone-Poulenc	14	Texas Tech University	12	Syngenta	1
Iowa State University	51	Aventis	10	Aventis	9	Cargill	1
Stine Biotechnology	47	DeKalb	9	Dow	8	Other	0
Plant Genetic Systems	46	Stine Biotechnology	8	All-Tex	2		
Cargill	41	Dairyland Seeds	7	ARS	2		
Holdens	37	Limagrain	6	Boswell	2		
Ciba-Geigy	36	University of Kentucky	5	Jacob Hartz	2		
Stanford University	36	AgriPro	4	Novartis Seeds	2		
Garst/ICI	33	Northrup-King	4	United Agri Products	2		
Mycogen	30	University of Illinois	4	American Cyanamid	1		
Dow	29	Calgene	3	Bowdoin College	1		
Limagrain	28	Iowa State University	3	Brownfield	1		
Asgrow	17	Jacob Hartz	3	Chembred	1		
Agracetus	15	University of Georgia	3	Dunn	1		
NC+Hybrids	15	University of Nebraska	3	Miles	1		
University of Minnesota	15	FFR Cooperative	2	Northrup-King	1		
University of Arizona	14	Ohio State University	2	SeedCo	1		
Aventis	13	Other	5	Williams Seed	1		
Golden Harvest Seeds	13	Delta Pine & Land	1	Other	0		
Rogers/Rogers NK	13	Michigan State University	1				
Rhone-Poulenc	10	Midwest Oilseeds	1				
WyFFels Hybrids	10	Land O' Lakes	1				
Southern Illinois University	9	Other					
Upjohn	7						
Zeneca	7						
Other	74						
Total	2,685	Total	524	Total	412	Total	148

[1] From June 16, 1987, to December 31, 2000. Field release approvals are either categorized as notifications acknowledged by APHIS under its notification procedure, or field release permits issued by APHIS. For most purposes, there is no difference in the two categories, and together, they equal the number of field releases approved by APHIS.

Source: Virginia Polytechnic Institute (2001).

Determination of Nonregulated Status

In the United States, once new varieties are successfully field tested and the research is fully documented, breeders may apply for a "determination of nonregulated status" from APHIS. This determination, once approved, allows the variety to be produced and sold commercially (USDA, APHIS, 2000). Out of the thousands of plant varieties approved for field release, APHIS had received 79 petitions for deregulation status as of mid-2001 (table 48). Of these 79 petitions, APHIS granted nonregulated status to a total of 53. These new varieties no longer fall under Federal regulation and can be planted freely throughout the United States.

Of the varieties granted nonregulated status by APHIS, 18 are corn varieties, 12 are tomatoes, 5 are soybeans, and 5 are cotton. Thirty-six of percent of these nonregulated varieties have herbicide-tolerance traits, 20 percent have insect-resistance traits, and 19 percent have traits to improve product quality (table 49).

Adoption of Crop Biotechnology Products

Successful transfer of a targeted trait to an elite strain may take plant breeders many crop generations. Superior hybrid corn varieties, for example, were introduced in the early 1930s after more than 25 years of research. Once development is complete, adoption of these crops takes time as well. The share of corn acreage planted with hybrid corn in the U.S. grew from about 1 percent of total corn planted in 1933 to more than 95 percent by 1960 (fig. 2). The speed of adoption might depend on the success of marketing efforts, the ability of growers to adapt farming practices to take advantage of the new varieties, and the superiority of the new varieties to existing varieties. The speed of adoption of corn hybrids differed by region because plant breeders had to produce varieties compatible with local growing conditions (Griliches, 1957).

By comparison, both the development and the adoption of genetically engineered field crop varieties were even more rapid than the adoption of hybrid corn varieties. The relative speed with which new varieties can be developed using modern biotechnology gives biotechnology an advantage over other techniques. Notwithstanding, first-generation biotechnology products were commercially available for farmers in the mid-1990s after about 15 years of research and development. Following their release in 1996, U.S. farmers rapidly adopted GE crops with herbicide-tolerant and insect-resistant traits (fig. 3).

Table 48—Crops no longer regulated by USDA, 1987-2001[1]

Crop	Petitions submitted	Petitions approved	Share of petitions approved
	Number	*Number*	*Percent*
Corn	23	18	33.96
Tomato	23	12	22.64
Potato	23	5	9.43
Soybeans	23	5	9.43
Cotton	23	5	9.43
Other	23	8	15.09
Total	79	53	100.00

[1] From June 16, 1987, to June 25, 2001.

Source: Virginia Polytechnic Institute (2001).

Table 49—Crops no longer regulated by USDA, by trait, 1987-2001[1]

Trait	Petitioned	Approved	Share approved
	Number	*Number*	*Percent*
All crops:			
Agronomic properties (AP)	8	6	9.38
Herbicide tolerance (HT)	29	23	35.94
Insect resistance (IR)	22	13	20.31
Stacked (HT, IR)	5	4	6.25
Product quality (PQ)	18	12	18.75
Virus resistance (VR)	9	6	9.38
Total	91	64	100.00
Corn:			
Agronomic properties (AP)	3	3	16.67
Herbicide tolerance (HT)	8	7	38.89
Insect resistance (IR)	10	5	27.78
Stacked (HT, IR)	5	3	16.67
Total	26	18	100.00
Soybeans:			
Herbicide tolerance (HT)	5	4	80.00
Product quality (PQ)	2	1	20.00
Total	7	5	100.00
Cotton:			
Herbicide tolerance (HT)	3	3	60.00
Insect resistance (IR)	3	1	20.00
Stacked (HT, IR)	1	1	20.00
Total	7	5	100.00

[1] From June 16, 1987, to June 25, 2001.

Source: Virginia Polytechnic Institute (2001).

Concentration and Private Sector R&D

A relatively small number of firms are active in the field of crop biotechnology, particularly with respect to major field crops (tables 43-46). Only a few firms have secured approval for unregulated release of genetically modified crops, a number likely affected by recent merger and acquisition activity.

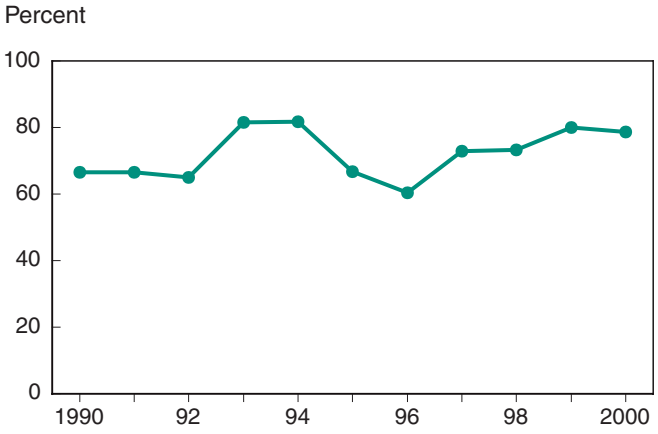
As Fulton and Giannakas (2002) observe, the relevant measure of market concentration is not always based on output markets (sales). To assess the impact of mergers focusing on innovative activity, the Federal Trade Commission is using innovation competition.

To construct a measure of concentration in innovation activity for the case of crop biotechnology, this report uses the regulatory approvals of GE varieties. In particular, this section adapts the CR4 measure used to quantify concentration in seed sales. Figures 19-21 show the percentage of field releases obtained by the leading four firms during 1988-2000. The top four firms control well over 50 percent of these approvals, suggesting concentration in R&D as well as potential barriers to entry for potential competitors. Note that much of the concentration reflects mergers and acquisitions among firms listed individually in the tables.

Based on the four-firm concentration ratio of approvals, corn seed remains the least concentrated industry relative to the other three crops. This finding is fairly consistent with earlier findings presented on the four-firm concentration ratio of corn in terms of sales. Moreover, the level of corn seed R&D concentration has remained relatively constant, at around 72 percent since 1990, which is also consistent with earlier findings. Soybean seed R&D remains highly concentrated in terms of field release approvals, although this concentration generally follows a downward trend. Again, this is fairly consistent with trends for the four-firm concentration ratio when measured in more conventional terms earlier. Cottonseed R&D, on the other hand, shows a trend toward increasing concentration, from 89 percent in 1993 to 96 percent in 2000, a finding also consistent with earlier market concentration measures.[16] Finally, the wheat seed industry remains highly concentrated, although this

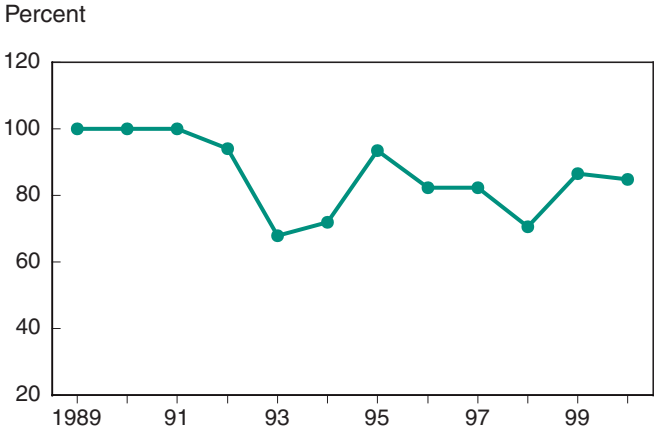
[16] Note, however, that few firms dominated cotton field release approvals by APHIS during the first 5 years (1988-92). Hence, the four-firm concentration ratio during this period was 100 percent. New firms entered the market and pursued R&D in subsequent years.

Figure 19
Four-firm concentration ratio in APHIS field release approvals for corn



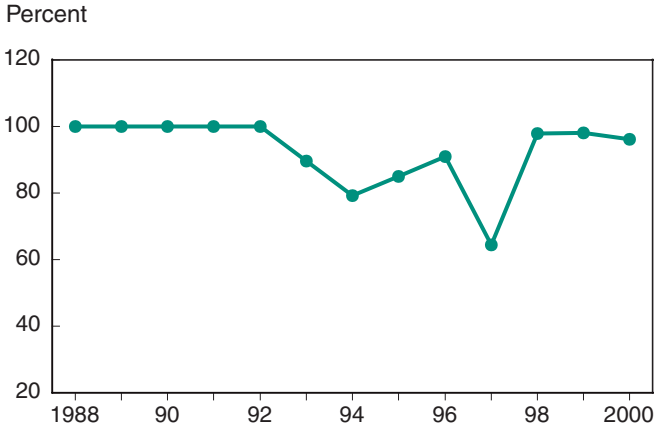
Source: Data source provided in table 43.

Figure 20
Four-firm concentration ratio in APHIS field release approvals for soybeans



Source: Data source provided in table 44.

Figure 21
Four-firm concentration ratio in APHIS field release approvals for cotton



Source: Data source provided in table 45.

may be due to the limited number of private firms operating in the sector; only two of the largest four institutions were private firms.

Between 1988 and 2000, Monsanto received approvals for over 1,200 new varieties of corn, soybeans, cotton, and wheat, making it the leader in product development, followed by other large companies such as DuPont/ Pioneer, and AgrEvo. The majority of the permits issued to leading companies have been for testing of new corn varieties, followed by soybeans and cotton (table 47). Similarly, out of the 53 approvals for nonregulated status given by APHIS, 28 were for varieties developed by Monsanto/ Calgene/Asgrow/DeKalb, 10 were for AgrEvo, and 3 were for DuPont/Pioneer (table 50). Thus, the largest two firms hold 70 percent of the nonregulated varieties.

Patent ownership shows a pattern of concentration similar to that evident in other R&D measures. Most of the biotech patents awarded to private sector firms are held by a small number of large companies. As of 1996/97, DuPont/Pioneer held the largest number of patents for corn and soybeans, followed by Monsanto (table 51) (Brennan et al., 1999, p. 167). As with regulatory approvals, the leading firms in the sector have received intellectual property rights not only through their R&D investment but also through recent mergers and acquisitions.

Table 51—Biotech patent ownership for corn and soybeans, by company

	Corn (1982-96)	Soybeans (up to 1997)	Corn and soybeans
	Number of patents held		
Aventis/Rhone-Poulenc-Agrochem	3	4	7
AgrEvo /PGS	4	3	7
Novartis/Syngenta	17	2	19
Zeneca	0	3	3
Dow Chemical/Mycogen	3	4	7
DuPont/Pioneer	28[1]	42[2]	70
Monsanto DeKalb	11[3]	23	34
Cyanamid	3	0	3
Others	69	49	118
Total	138	130	268

[1] Includes 21 from Pioneer.
[2] Includes 27 from Pioneer.
[3] Includes 4 from DeKalb.

Source: Derwent Biotechnology Abstracts, as reported in *GRAIN* (1996, 1997) and in Brennan et al. (2000).

Table 50—Status of petitions for deregulation, by company, 1987-2001[1]

Company/institution	Approved	Incomplete	Pending	Withdrawn	Void	Total
			Number			
Monsanto	16		2	8		26
AgrEvo	10			3		13
Calgene	9				1	10
DeKalb	2			1		3
DuPont	2			1		3
DNA Plant Tech	1			1		2
Agritope	1			1		2
Bejo	1			1		2
Zeneca		1		1		2
Cornell University	1			1		2
Asgrow	1					1
Aventis				1		1
Ciba-Geigy	1					1
Dow	1					1
Upjohn	1					1
Syngenta				1		1
University of Saskatchewan	1					1
Zeneca & Petoseed	1					1
Mycogen				1		1
Northrup King	1					1
Novartis Seeds	1					1
Pioneer	1					1
Plant Genetic Systems	1					1
Vector Tobacco			1			1
Total	53	1	3	21	1	79

[1] From June 16, 1987, to June 25, 2001.

Source: Virginia Polytechnic Institute (2001).