Roles of Private and Public Sector R&D in Crop Seed Have Shifted

A prominent change in the seed industry over the last century has been the increasing role of private sector efforts in R&D. Not only have private R&D expenditures increased dramatically in absolute levels, but they have also increased relative to public levels. As private sector R&D expenditures have risen, the types of R&D activity pursued and the choice of crops for research have also changed. With the shift of more R&D activity to the private sector, the process by which the seed industry changes has itself transformed.

Returns to R&D Spending on Plant Breeding

Annual returns to R&D spending on plant breeding exceed 30 percent according to most estimates, although estimates vary widely. Griliches (1958) estimates the returns to public agricultural research for hybrid corn to be 35-40 percent during the period 1940-55. Sundquist et al. (1981) estimate those returns to be 115 percent in 1977. Griliches also finds returns to R&D on hybrid sorghum to be 20 percent during 1940-57. Other studies show returns to cash grains range from 31 to 85 percent (Fuglie et al., pp. 30-31). However, Huffman and Evenson (1993, pp. 245-46) report that returns to public sector crop research (45-62 percent) during 1950-82 are lower than returns to private sector research (90 percent) (table 23).

These estimates of returns to R&D investment may fail to incorporate the positive externalities generated by plant breeding research among and between countries. Foreign research in plant breeding benefits from positive spillovers arising from U.S. agricultural research just as U.S. researchers benefit from transfers of genetically diverse materials from research institutions and firms abroad. As a result, consumers in the United States and foreign countries frequently benefit from the increased quality and lower prices offered by new varieties cultivated, imported, or exported in the international economy (Fuglie et al., 1996, p. 28; Fernandez-Cornejo and Shumway, 1997; Maredia and Byerlee, 1999; Schimmelpfennig and Thirtle, 1999; Schimmelpfennig et al., 2000).

Public R&D

Historically in the United States, the public sector has maintained a central role in agricultural R&D. The establishment of the U.S. Department of Agriculture (1862) and the passage of key legislation, such as the Morill Land-Grant College Act (1862), the Hatch Act (1887), and the Smith-Lever Act (1914), expanded this role. The Morill Act established colleges and universities in U.S. States and territories that were dedicated to instruction in agriculture and engineering sciences, and, in 1890, were given further support with Federal funding under the second Morill Act. The Hatch Act provided further support to State-level research by establishing State agricultural experiment stations (SAES) to collaborate with land-grant institutions and to strengthen scientific research in agriculture. The

Table 23—Estimated returns to crop research in U.S. agriculture, various years

Commodity	Period	Annual return	Study
		Percent	
Hybrid corn	1940-55	35-40	Griliches, 1958
Hybrid sorghum	1940-57	20	Griliches, 1958
Cash grains	1969	47	Bredahl and Peterson, 1976
Crops	1959-64	110	Huffman, 1977
Crops	1964	55	Evenson and Welch, 1979
Cash grains	1969	31-57	Norton, 1981
Cash grains	1974	44-85	Norton, 1981
Maize	1977	115	Sundquist, Cheng, and Norton, 1981
Wheat	1977	97	Sundquist, Cheng, and Norton, 1981
Soybeans	1977	118	Sundquist, Cheng, and Norton, 1981
Crops - public sector, applied R&D	1950-82	45	Huffman and Evenson, 1993
Crops - public sector, pre-tech R&D	1950-82	62	Huffman and Evenson, 1993
Crops - private sector R&D	1950-82	90	Huffman and Evenson, 1993

Sources: Huffman and Evenson (1993), pp. 245-246; Fuglie et al. (1996), p. 30; Alston and Pardey (1996), pp. 204-206.

Smith-Lever Act extended this collaboration to include Federal, State, and county agencies through the establishment of the Cooperative Agricultural Extension Service (Fuglie et al., 1996, p. 2). Combined with resources from the USDA and other cooperating government agencies, these legislative acts supported a wide range of public initiatives in agricultural R&D.

One rationale for public investment in agricultural R&D is to address specific market failures. R&D can enhance yields, lower costs, and provide other benefits to both producers and consumers. The incentive for firms to undertake R&D arises from the ability of firms to capture some of the value created from successful innovation. However, the ease of replicating successful R&D undermines the ability of firms to appropriate the returns to their R&D investments (King, 2001). When a competitor can replicate R&D results without incurring the R&D costs, the competitive advantage to firms investing in R&D is not sustainable. The inability of firms to appropriate the returns to their R&D investments results in a market failure, in that productivity- and wealth-enhancing improvements are not attempted.

Other market failures include negative externalities and risk aversion or financial market failures (Beach and Fernandez-Cornejo, 1994). Negative externalities may arise where the social marginal costs of agricultural R&D exceed the private marginal benefits; for instance, when the broad social desire to improve a certain agricultural process is greater than firms' ability to generate such improvements profitably, resulting in underproduction and deadweight losses to society. Risk aversion and financial market failures may occur when private returns from R&D investments over the long term are discounted by investors at a rate higher than the desirable social rate of return.

Modern agricultural R&D includes large amounts of investment from both the public and private sectors (Alston and Pardey, 1996, pp. 29-30). Total public sector expenditure on agricultural R&D, which includes both Federal and State spending, was $3.1 billion in 1996 (table 24). Private sector R&D exceeded $4 billion in the same period (table 25).

Private Sector R&D

The development of commercially viable hybrid corn in the 1930s, the PVPA and subsequent rulings, and other forms of property rights protection led to significant changes in research expenditure patterns and played a key role in the development of new plant varieties. These technological and institutional changes over the past century improved appropriability, increasing incentives for private investment in agricultural R&D, resulting in a larger role in research for private firms.

Real private sector expenditure in agricultural R&D increased by 224 percent from 1960 to 1996 (table 25). Over the same period, real public sector agricultural R&D increased by 97 percent. In addition to the higher relative increase, annual private sector R&D expenditures have exceeded public expenditures every year since 1982. Whereas private sector efforts accounted for slightly less than half of total R&D expenditures from 1960 to 1970, they accounted for 58.7 percent of the total in 1996.

Expenditures on plant breeding and agricultural chemicals were the main areas of increased private sector R&D. From 1960 to 1995, real plant breeding expenditures increased by $514 million (1996 dollars), while R&D on agricultural chemicals increased by $1.392 billion. The growth of R&D in agricultural chemicals primarily reflects the increasing use of herbicides (USDA, 1997, p. 117) and compliance with regulations (Ollinger and Fernandez-Cornejo, 1995).

The dramatic increase in private sector plant breeding R&D expenditures came while public expenditure in that area changed very little in real terms. On the whole, private spending on plant breeding has steadily increased since 1960 as the seed industry increased in size and extent of commercialization. Private sector R&D expenditure has shifted over this period, in percentage terms, from farm machinery and food and kindred products to agricultural chemicals and plant breeding research.[11] These changes in expenditures have been accompanied by structural change in the industry. First, intense merger and acquisition activity in the last three decades led to the formation of large seed conglomerates that allowed once smaller, individually owned, seed companies to take advantage of the strategic R&D relationships and economies of scale of their parent companies. Second, new entrants into the seed industry between 1982 and 1994 increased the

[11] It is worth noting that that the increasing proportion of expenditure on agricultural chemicals greatly exceeds the increase in plant breeding, as shown in table 25. This is attributed to the fact that research in agricultural chemicals has long been dominated by the private sector, while plant breeding was traditionally the domain of public sector investment and only beginning to attract private investment during the earlier years of this period (Heisey, 1999, p. 19).

Table 24—Public agricultural research and development

Year	Biological efficiency expenditure					Non-commodity biotech & biometry expenditure					Pesticides & herbicides expenditure				
	USDA[1]	SAES[1]	Total	Total	Share of public R&D expenditure	USDA[2]	SAES[2]	Total	Total	Share of public R&D expenditure	USDA[3]	SAES[3]	Total	Total	Share of public R&D expenditure
	Million current dollars			*Mil. 1996 dollar*	*Percent*	*Million current dollars*			*Mil.1996 dollar*	*Percent*	*Million current dollars*			*Mil.1996 dollar*	*Percent*
1960	4.79	29.14	33.93	228.17	14.30	NA	NA	NA	NA	NA	11.60	16.43	28.02	188.43	11.81
1961	5.22	30.99	36.21	236.44	14.32	NA	NA	NA	NA	NA	12.84	17.26	30.10	196.57	11.91
1962	5.69	32.95	38.64	242.75	14.46	NA	NA	NA	NA	NA	13.40	18.96	32.37	203.33	12.11
1963	6.20	35.04	41.24	248.68	14.49	NA	NA	NA	NA	NA	14.42	20.45	34.87	210.27	12.25
1964	6.76	37.27	44.02	255.85	13.67	NA	NA	NA	NA	NA	16.72	23.14	39.86	231.63	12.38
1965	7.37	39.63	47.00	262.28	13.15	NA	NA	NA	NA	NA	19.60	25.82	45.42	253.49	12.71
1966	8.03	42.14	50.17	266.73	12.85	NA	NA	NA	NA	NA	20.25	30.26	50.51	268.53	12.94
1967	8.75	44.82	53.57	269.43	13.13	NA	NA	NA	NA	NA	20.98	32.92	53.90	271.10	13.21
1968	9.77	46.29	56.06	266.00	12.95	NA	NA	NA	NA	NA	20.42	38.44	58.87	279.32	13.60
1969	10.26	49.96	60.21	267.74	13.18	NA	NA	NA	NA	NA	22.17	40.68	62.85	279.46	13.75
1970	9.69	46.55	56.24	232.26	11.41	6.44	19.70	26.14	107.96	5.30	19.95	37.91	57.86	238.96	11.74
1971	9.74	49.81	59.55	232.37	11.19	7.08	20.41	27.48	107.25	5.16	22.35	40.48	62.83	245.18	11.81
1972	12.69	52.16	64.86	241.62	10.34	9.43	22.67	32.10	119.59	5.12	31.12	43.15	74.27	276.69	11.84
1973	13.64	54.46	68.10	239.10	10.15	10.93	25.27	36.19	127.07	5.40	30.68	48.82	79.51	279.14	11.85
1974	13.96	59.66	73.62	238.94	10.10	11.07	26.70	37.77	122.58	5.18	31.85	56.27	88.12	285.97	12.08
1975	15.60	68.89	84.50	254.80	10.26	12.35	27.74	40.09	120.90	4.87	33.96	63.67	97.62	294.40	11.85
1976	23.85	88.10	111.95	317.96	12.46	18.90	39.66	58.56	166.31	6.52	51.69	89.93	141.62	402.23	15.76
1977	20.96	89.55	110.51	301.77	10.71	17.96	35.59	53.54	146.21	5.19	47.40	79.40	126.80	346.24	12.29
1978	24.44	96.01	120.45	310.43	10.41	27.78	39.23	67.01	172.70	5.79	56.30	88.29	144.58	372.63	12.50
1979	27.49	101.70	129.19	309.61	10.36	26.71	43.20	69.91	167.55	5.61	62.41	98.60	161.01	385.87	12.91
1980	26.58	117.05	143.62	316.38	10.50	33.69	50.75	84.43	186.00	6.18	65.84	114.72	180.56	397.74	13.21
1981	34.02	126.34	160.35	323.09	10.49	37.91	55.45	93.36	188.10	6.11	75.56	132.95	208.50	420.10	13.64
1982	33.38	135.83	169.20	316.40	10.31	36.59	62.36	98.94	185.02	6.03	76.10	144.74	220.84	412.96	13.45
1983	36.68	138.96	175.64	310.66	10.31	39.84	70.64	110.48	195.40	6.48	79.20	150.41	229.61	406.11	13.48
1984	36.64	142.75	179.40	300.50	10.14	38.52	75.53	114.05	191.04	6.45	76.11	161.24	237.36	397.58	13.42
1985	44.55	153.05	197.61	314.03	10.25	47.72	90.03	137.75	218.90	7.14	88.12	173.12	261.24	415.16	13.55
1986	52.14	163.19	215.33	324.88	10.69	43.75	100.43	144.18	217.54	7.16	87.57	184.78	272.34	410.91	13.52
1987	56.84	164.75	221.59	315.19	10.26	38.29	105.58	143.87	204.65	6.66	94.82	193.81	288.63	410.56	13.36
1988	66.92	168.89	235.81	322.90	10.25	44.01	114.17	158.18	216.59	6.87	103.43	201.83	305.26	418.00	13.27
1989	70.58	180.00	250.58	325.41	10.25	33.81	122.18	155.99	202.58	6.38	105.63	216.56	322.19	418.40	13.17
1990	69.98	194.07	264.05	325.71	10.16	24.12	126.96	151.08	186.36	5.81	115.21	228.54	343.75	424.03	13.23
1991	75.70	199.36	275.06	325.74	9.89	27.26	132.69	159.95	189.42	5.75	131.05	244.63	375.68	444.90	13.51
1992	79.26	201.85	281.11	322.47	9.65	24.35	133.00	157.34	180.50	5.40	134.57	259.73	394.30	452.32	13.54
1993	80.16	205.83	286.00	313.97	9.63	25.39	137.58	162.97	178.91	5.49	135.03	270.47	405.50	445.16	13.65
1994	79.98	210.68	290.66	308.87	9.34	25.63	145.42	171.05	181.77	5.50	138.99	277.58	416.56	442.67	13.39
1995	74.21	211.50	285.71	294.59	9.02	22.71	142.47	165.18	170.32	5.21	143.71	295.96	439.67	453.34	13.87
1996	69.09	198.10	267.20	267.20	8.49	16.14	139.05	155.19	155.19	4.93	141.52	303.91	445.42	445.42	14.15

See footnotes at end of table.

--Continued

Table 24—Public agricultural research and development--Continued

Year	Production mechanization expenditures					Total public agri. R&D expenditures		
	USDA[4]	SAES[4]	Total	Total	Share of public R&D expenditure	Total[5]	Total[5]	Agric. R&D deflator[6]
	Million current dollars			*Mil. 1996 dollars*	*Percent*	*Million current dollars*	*Mil. 1996 dollars*	
1960	NA	NA	NA	NA	NA	237.3	1,595.7	0.1487
1961	NA	NA	NA	NA	NA	252.8	1,650.6	0.1531
1962	NA	NA	NA	NA	NA	267.3	1,679.3	0.1592
1963	NA	NA	NA	NA	NA	284.7	1,716.6	0.1658
1964	NA	NA	NA	NA	NA	322.0	1,871.5	0.1721
1965	NA	NA	NA	NA	NA	357.3	1,994.4	0.1792
1966	NA	NA	NA	NA	NA	390.5	2,075.9	0.1881
1967	NA	NA	NA	NA	NA	408.1	2,052.4	0.1988
1968	2.37	3.76	6.13	29.09	1.42	432.7	2,053.3	0.2107
1969	2.72	4.33	7.05	31.34	1.54	457.0	2,032.0	0.2249
1970	1.85	4.40	6.24	25.78	1.27	492.8	2,035.3	0.2421
1971	2.97	4.65	7.63	29.76	1.43	532.2	2,076.8	0.2562
1972	3.62	4.47	8.09	30.13	1.29	627.1	2,336.2	0.2684
1973	3.86	4.95	8.81	30.93	1.31	670.7	2,354.9	0.2848
1974	3.93	5.39	9.32	30.26	1.28	729.2	2,366.7	0.3081
1975	4.06	5.67	9.72	29.32	1.18	823.5	2,483.4	0.3316
1976	5.74	7.62	13.36	37.95	1.49	898.4	2,551.6	0.3521
1977	4.82	6.30	11.13	30.38	1.08	1,031.7	2,817.2	0.3662
1978	5.25	7.00	12.25	31.56	1.06	1,157.1	2,982.1	0.3880
1979	5.02	7.27	12.29	29.46	0.99	1,247.2	2,989.1	0.4173
1980	5.48	7.91	13.39	29.49	0.98	1,367.2	3,011.8	0.4540
1981	6.21	7.36	13.57	27.33	0.89	1,528.6	3,079.8	0.4963
1982	5.63	7.97	13.61	25.44	0.83	1,641.6	3,069.6	0.5348
1983	6.22	8.12	14.34	25.36	0.84	1,703.6	3,013.1	0.5654
1984	6.10	7.79	13.89	23.27	0.79	1,769.0	2,963.1	0.5970
1985	6.50	8.96	15.46	24.57	0.80	1,928.0	3,063.9	0.6293
1986	4.32	8.67	12.99	19.60	0.64	2,014.8	3,039.9	0.6628
1987	3.32	9.19	12.51	17.80	0.58	2,160.5	3,073.2	0.7030
1988	3.22	9.77	12.99	17.78	0.56	2,301.2	3,151.0	0.7303
1989	2.67	10.37	13.04	16.93	0.53	2,445.8	3,176.2	0.7700
1990	3.08	10.26	13.35	16.46	0.51	2,598.3	3,205.1	0.8107
1991	3.40	9.56	12.96	15.35	0.47	2,780.5	3,292.8	0.8444
1992	3.24	8.99	12.23	14.03	0.42	2,913.2	3,341.8	0.8717
1993	3.36	9.32	12.68	13.92	0.43	2,970.9	3,261.5	0.9109
1994	3.46	9.98	13.44	14.28	0.43	3,111.5	3,306.6	0.9410
1995	3.24	9.64	12.88	13.28	0.41	3,168.8	3,267.3	0.9698
1996	2.88	9.03	11.91	11.91	0.38	3,148.0	3,148.0	1.0000

NA = not available. SAES = State Agricultural Experiment Station.

[1] Research problem area code 304 and 307 in CRIS (USDA, CSREES, CRIS, 1993). Source: "Inventory of Agricultural Research" for fiscal years 1968-96 (USDA, CSREES, CRIS, various years). For 1960-67, total public expenditures on biological efficiency and pesticides/pest management estimated by linear interpolation.

[2] Research problem area code 318 in CRIS (USDA, CSREES, CRIS, 1993). Source: "Inventory of Agricultural Research" for fiscal years 1968-96 (USDA, CSREES, CRIS, various years). For 1960-67, total public expenditures on biological efficiency and pesticides/pest management are estimated by linear interpolation.

[3] Research problem area codes 204-209 in CRIS (USDA, CSREES, CRIS, 1993). Source: 1960-67: USDA and SAES expenditure on pesticides and herbicides are linear interpolations of data based on total SAES R&D expenditure derived from the rate of growth of total SAES R&D expenditure assumed to be consistent with the annual rate of growth in Alston and Pardey (1996, Table 2-A3, 76); 1968-96: "Inventory of Agricultural Research" for fiscal years 1968-96 (USDA, CSREES, CRIS, various years).

[4] Research problem area code 305 and 308 in CRIS (USDA, CSREES, CRIS, 1993). Source: "Inventory of Agricultural Research" for fiscal years 1968-96 (USDA, CSREES, CRIS, various years). For 1960-67, total public expenditures on biological efficiency and pesticides/pest management are estimated by linear interpolation.

[5] Total agri. R&D expenditures are not the sum of the four categories of R&D presented, and includes other categories not shown here. Source: 1960-69: data are based on rates of change from Alston and Pardey (1986, p. 76), and Huffman & Evenson (1993, pp. 95-96); 1970-96: "Inventory of Agricultural Research" for fiscal years 1970-96 (USDA, CSREES, CRIS, various years).

[6] Source: Klotz-Ingram (2000).

Table 25—Private agricultural research and development

Year	Plant breeding expenditure			Agricultural chemicals expenditure			Farm machinery expenditure			Food & kindred products expenditure			Veterinary pharmaceuticals expenditure			Total private agric. R&D expenditure		
	Total[1]	Total	Share of private R&D	Total[1]	Total	Share of private R&D expenditure	Total[1]	Total	Share of private R&D expenditure	Total[1]	Total	Share of private R&D expenditure	Total[1]	Total	Percent of private R&D expenditure	Total[1]	Total	Agric. R&D deflator[2]
	Million current $	*Mil. 1996 dollars*	*Percent*	*Million current $*	*Mil. 1996 dollars*	*Percent*	*Million current $*	*Mil. 1996 dollars*	*Percent*	*Million current $*	*Mil. 1996 dollars*	*Percent*	*Million current $*	*Mil. 1996 dollars*	*Percent*	*Million current $*	*Mil. 1996 dollars*	
1960	6.00	40.35	2.91	27.00	181.56	13.11	75.00	504.34	36.41	92.00	618.66	44.66	6.00	40.35	2.91	206.00	1,385.26	0.1487
1961	6.00	39.18	2.83	38.00	248.14	17.92	65.00	424.45	30.66	92.00	600.76	43.40	11.00	71.83	5.19	212.00	1,384.36	0.1531
1962	6.00	37.69	2.61	42.00	263.84	18.26	70.00	439.73	30.43	98.00	615.62	42.61	14.00	87.95	6.09	230.00	1,444.82	0.1592
1963	7.00	42.21	2.86	45.00	271.33	18.37	76.00	458.25	31.02	102.00	615.02	41.63	15.00	90.44	6.12	245.00	1,477.24	0.1658
1964	8.00	46.49	2.93	48.00	278.96	17.58	79.00	459.12	28.94	118.00	685.77	43.22	20.00	116.23	7.33	273.00	1,586.57	0.1721
1965	9.00	50.23	2.79	64.00	357.19	19.81	96.00	535.78	29.72	131.00	731.12	40.56	23.00	128.36	7.12	323.00	1,802.68	0.1792
1966	11.00	58.48	3.18	77.00	409.36	22.25	100.00	531.63	28.90	130.00	691.13	37.57	28.00	148.86	8.09	346.00	1,839.46	0.1881
1967	12.00	60.36	3.38	72.00	362.14	20.28	102.00	513.04	28.73	134.00	673.99	37.75	35.00	176.04	9.86	355.00	1,785.57	0.1988
1968	17.00	80.67	4.34	78.00	370.12	19.90	96.00	455.53	24.49	165.00	782.94	42.09	36.00	170.82	9.18	392.00	1,860.07	0.2107
1969	22.00	97.82	5.21	85.00	377.96	20.14	99.00	440.21	23.46	182.00	809.27	43.13	34.00	151.18	8.06	422.00	1,876.44	0.2249
1970	26.00	107.38	5.60	98.00	404.72	21.12	89.00	367.55	19.18	206.00	850.74	44.40	45.00	185.84	9.70	464.00	1,916.23	0.2421
1971	29.00	113.17	5.95	109.00	425.37	22.38	90.00	351.22	18.48	211.00	823.42	43.33	48.00	187.32	9.86	487.00	1,900.49	0.2562
1972	32.00	119.21	6.30	104.00	387.44	20.47	93.00	346.46	18.31	227.00	845.67	44.69	52.00	193.72	10.24	508.00	1,892.51	0.2684
1973	39.00	136.92	6.76	113.00	396.73	19.58	120.00	421.31	20.80	243.00	853.14	42.11	62.00	217.67	10.75	577.00	2,025.78	0.2848
1974	45.00	146.05	6.73	136.00	441.38	20.33	131.00	425.16	19.58	283.00	918.47	42.30	74.00	240.16	11.06	669.00	2,171.22	0.3081
1975	50.00	150.78	7.05	169.00	509.64	23.84	138.00	416.15	19.46	273.00	823.26	38.50	79.00	238.23	11.14	709.00	2,138.06	0.3316
1976	55.00	156.21	6.72	200.00	568.05	24.45	168.00	477.16	20.54	308.00	874.80	37.65	87.00	247.10	10.64	818.00	2,323.32	0.3521
1977	58.00	158.38	6.08	243.00	663.55	25.47	221.00	603.47	23.17	348.00	950.27	36.48	84.00	229.37	8.81	954.00	2,605.04	0.3662
1978	69.00	177.83	6.39	290.00	747.40	26.88	249.00	641.73	23.08	385.00	992.24	35.68	86.00	221.64	7.97	1,079.00	2,780.85	0.3880
1979	81.00	194.13	6.73	312.00	747.74	25.91	295.00	707.00	24.50	420.00	1,006.58	34.88	96.00	230.08	7.97	1,204.00	2,885.53	0.4173
1980	97.00	213.68	6.67	395.00	870.14	27.17	363.00	799.65	24.97	488.00	1,075.01	33.56	111.00	244.52	7.63	1,454.00	3,202.99	0.4540
1981	105.00	211.56	7.15	469.00	944.95	31.93	278.00	560.12	18.92	492.00	991.29	33.49	125.00	251.85	8.51	1,469.00	2,959.78	0.4963
1982	118.00	220.65	7.15	527.00	985.45	31.92	281.00	525.45	17.02	596.00	1,114.47	36.10	129.00	241.22	7.81	1,651.00	3,087.24	0.5348
1983	138.00	244.08	7.69	584.00	1,032.93	32.53	290.00	512.93	16.16	636.00	1,124.90	35.43	147.00	260.00	8.19	1,795.00	3,174.85	0.5654
1984	154.00	257.96	7.53	624.00	1,045.22	30.50	311.00	520.94	15.20	803.00	1,345.05	39.25	154.00	257.96	7.53	2,046.00	3,427.13	0.5970
1985	179.00	284.47	8.26	683.00	1,085.42	31.52	304.00	483.11	14.03	842.00	1,338.10	38.86	159.00	252.68	7.34	2,167.00	3,443.78	0.6293
1986	204.00	307.79	8.79	691.00	1,042.57	29.77	307.00	463.20	13.23	940.00	1,418.25	40.50	179.00	270.07	7.71	2,321.00	3,501.88	0.6628
1987	222.00	315.78	9.75	682.00	970.10	29.94	292.00	415.35	12.82	891.00	1,267.39	39.11	191.00	271.69	8.38	2,278.00	3,240.31	0.7030
1988	245.00	335.48	9.53	938.00	1,284.41	36.48	295.00	403.95	11.47	871.00	1,192.67	33.88	221.00	302.62	8.60	2,571.00	3,520.50	0.7303
1989	283.00	367.51	10.31	979.00	1,271.36	35.65	320.00	415.56	11.65	921.00	1,196.04	33.54	243.00	315.57	8.85	2,746.00	3,566.05	0.7700
1990	314.00	387.33	10.57	1,127.00	1,390.21	37.93	360.00	444.08	12.12	925.00	1,141.03	31.13	245.00	302.22	8.25	2,971.00	3,664.86	0.8107
1991	342.00	405.01	10.78	1,228.00	1,454.25	38.69	382.00	452.38	12.04	946.00	1,120.30	29.80	276.00	326.85	8.70	3,174.00	3,758.80	0.8444
1992	400.00	458.86	12.47	1,062.00	1,218.28	33.10	394.00	451.98	12.28	1021.00	1,171.24	31.83	331.00	379.71	10.32	3,208.00	3,680.07	0.8717
1993	453.00	497.31	13.04	1,389.00	1,524.86	39.99	369.00	405.09	10.62	995.00	1,092.32	28.65	267.00	293.12	7.69	3,473.00	3,812.71	0.9109
1994	470.00	499.46	13.10	1,356.00	1,440.99	37.80	377.00	400.63	10.51	1084.00	1,151.94	30.22	300.00	318.80	8.36	3,587.00	3,811.82	0.9410
1995	524.00	540.29	13.64	1,419.00	1,463.12	36.94	436.00	449.56	11.35	1146.00	1,181.63	29.84	316.00	325.82	8.23	3,841.00	3,960.41	0.9698
1996	554.00	554.00	12.35	NA	NA	NA	487.00	487.00	10.86	NA	NA	NA	359.00	359.00	8.00	4,486.00	4,486.00	1.0000

NA = not available.

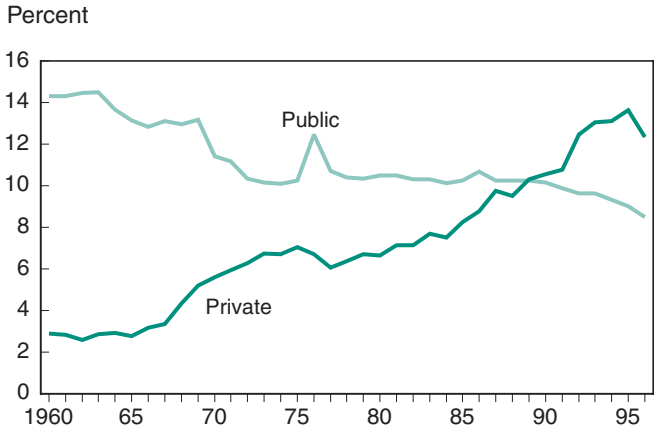
[1] Source: 1960-92: Klotz, Fuglie, and Pray (1995, p. 26); 1993-1997: Klotz, Fuglie and Pray (1995, updated July 1998). [2] Klotz-Ingram, Private Communication (2000).

number of firms engaged in private plant breeding throughout the United States from 269 to 329 (table 26). This trend in the private sector resulted in a 1,300-percent real increase in private R&D plant breeding expenditures between 1960 and 1996.

As the emphasis of R&D shifted, the share of public sector R&D expenditures on plant breeding research remained relatively unchanged at about 10 percent between 1970 and 1990, but the share declined in the 1990s (fig. 13). Public spending on biological efficiency (used as a proxy for public spending on plant breeding) decreased as a share of total public agricultural R&D expenditures, reaching 9 percent ($291 million) of total public sector agricultural R&D in 1994 (figs. 13-14).[12] This decrease occurred despite evidence suggesting that the rate of return on public research remains positive, and that such areas as pre-commercial agricultural research continue to require government support (Fuglie et al., 1996, pp. 29-31). On the other hand, the share of private sector research spent on plant breeding increased, reaching 13 percent ($470 million) of total expenditures on private agricultural R&D in 1994 (table 25) (Klotz et al.).

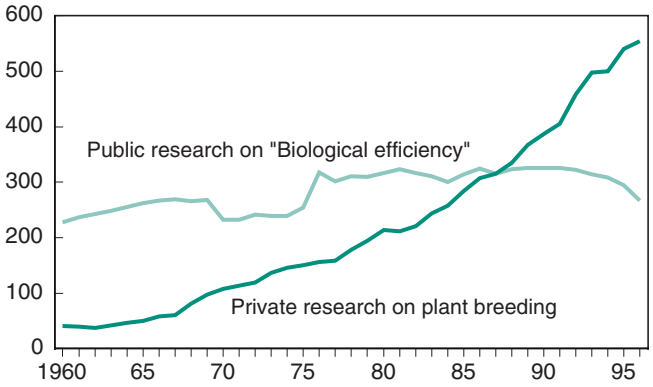
[12] We approximate public sector spending on plant breeding with USDA and SAES expenditures on improving biological efficiency for fruits and vegetables and field crops. Improvement of biological efficiency research is described in research problem areas 304 and 307 of the *Manual of Classification of Agricultural and Forestry Research*, as research on "the ability of agriculture to meet the feed, food, and fiber needs of the American people and provide vital amounts of these commodities for exports" (USDA, 1993, p. 71). The specific areas of research contained in this category of the *Manual* relevant to plant breeding are (i) the identification of superior germplasm and breeding and selection of improved varieties, and (ii) the genetic and biological determinants of biological efficiency. These research areas are adequate to examine trends in public sector expenditure on plant breeding, and to make comparisons with private sector expenditures.

Figure 13
Plant breeding as a share of total agricultural R&D expenditures



Source: Data source provided in tables 24 and 25.

Figure 14
Public and private research expenditures on plant breeding



"Biological efficiency" includes breeding and selection of improved plant varieties.

Source: Data source provided in tables 24 and 25.

Table 26—Private sector firms engaged in plant breeding, major field crops

Crop	1982		1989		1994	
	Number of companies	Share of companies	Number of companies	Share of companies	Number of companies	Share of companies
		Percent		*Percent*		*Percent*
Corn	66	24.5	75	27.6	91	27.7
Soybeans	26	9.7	34	12.5	38	11.6
Cotton	13	4.8	11	4.0	35	10.6
Wheat	21	7.8	11	4.0	27	8.2
Others	143	53.2	141	51.8	138	41.9
Total	269	100.0	272	100.0	329	100.0

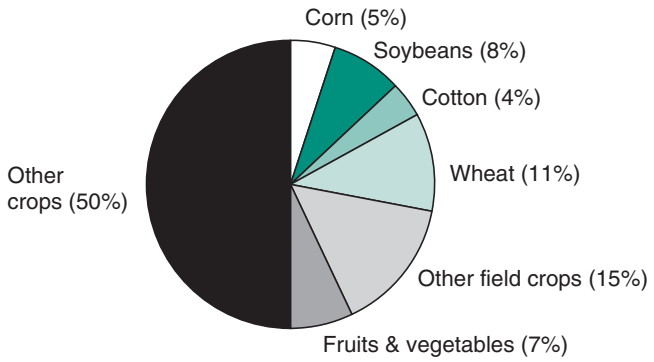
Source: Companies and expenditures for 1994: Frey (1996, p.19); companies and expenditures for 1982 and 1989: Kalton et al. (1990, p. 24).

Private and public research do not always emphasize the same areas. The emphasis of the private sector on pure line field crops (fig. 15, table 26) suggests that one role for the public sector is to carry out research in otherwise neglected crops. Private sector research has expanded to include cultivar development on hybrid crops and pre-breeding activities; meanwhile, public plant breeding research has focused on basic germplasm and applied plant genetics. (Heisey et al., 2001). So even as private firms engage in R&D that once was performed mostly by the public sector, important roles still exist for both public and private R&D.

A breakdown of expenditures on plant breeding R&D by specific private firms provides additional insight into the magnitude and growth of private sector research (table 27). Large firms, such as ICI, Sandoz, and Pioneer, each spent between $38 million and $57 million on plant breeding in 1988. As a share of seed sales, these figures range from 6.3 percent (Pioneer) to 23.2 percent (ICI). The seed industry considers 5 to 7 percent of sales to be the minimum requisite investment in R&D to maintain competitiveness (James, 1997, p. 6). Other large firms, such as Ciba-Geigy, DeKalb, Limagrain, KWS, and Upjohn, spent between $16 million and $27 million each on plant breeding R&D in 1988, and, when measured as a share of sales, each of these firms also exceeded the minimum requisite investment levels in R&D. By 1996, after new rounds of mergers and acquisitions, the upper bounds of R&D expenditures by large firms had increased significantly: Pioneer spent $133 million on seed R&D, a 2.5-fold increase relative to 1988, followed closely by Novartis with $122 million. Even Cargill, a smaller player in the market in terms of annual seed revenue, spent $37 million on seed R&D in 1996. As a share of sales, these expenditure levels again exceeded the industry estimates of minimum spending necessary to sustain competitiveness in the seed market.

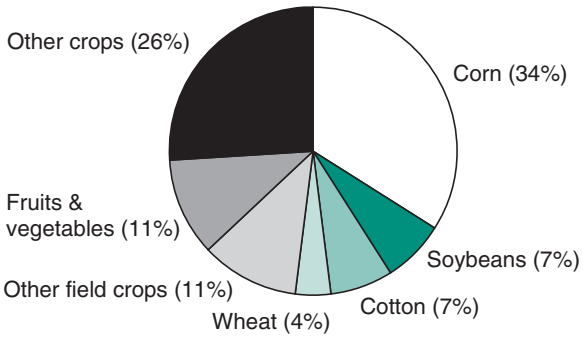
Figure 15
Research effort by crop, 1994

A--Public sector research effort (staff years) in biological efficiency



Source: Calculated from the number of SY given in table 32 first column.

B--Private industry research effort (staff years) in plant breeding



Source: Data source provided in table 31.

Plant Breeding Research Patterns by Crop

The changing focus of public and private sector R&D expenditures in plant breeding has also been associated with changes in research expenditure on specific crops. Historically, public sector expenditures on plant breeding have been allocated to basic and applied research on new varieties of field crops, while private sector expenditures have focused on the development of new plant varieties for home garden and horticultural crops (Fuglie et al., 1996, p. 53).

With the development of commercially viable hybrids in the 1930s, corn was the first crop subject to the rapid shift from public to private R&D sector expenditures in plant breeding. Private seed companies accounted for 40 percent of total R&D spent on corn in 1960 and more than 60 percent in 1984 (table 28). The shift of R&D expenditures from the public to the private sector occurred more recently with soybeans, and may be partly credited to the PVPA (Fuglie et al., 1996, p. 53). In 1960, less than 1 percent of R&D expenditures on soybean improvement came from the private sector (table 29). By 1984, this share had risen to almost a quarter of the total (public and private) R&D spent on soybeans. Among private R&D expen-

Table 27—Plant breeding R&D expenditures by company

Company	1986 Plant breeding			1988-89 Plant breeding					1996 Seed		
	Conventional breeding R&D	Plant biotechnology R&D	Total plant breeding R&D	Conventional breeding R&D	Plant biotechnology R&D	Total plant breeding R&D	Seed sales (fiscal 1989)	R&D as share of seed sales	Seed R&D	Annual revenue	R&D as share of revenue
	Million current dollars			*Million current dollars*				*Percent*	*Mil. current dollars*		*Percent*
Aventis Cropscience											
Rhone-Poulenc	2	3	5				125				
AgrEvo											
Novartis									122	970	12.6
Zeneca											
Advanta									53	470	11.3
ICI	11	15	26	21	17	38	164	23.2			
Sandoz	16	7	23	41	16	57	473	12.1			
Ciba-Geigy	9	13	22	9	17	26	125	20.8			
DowElanco											
Dow AgroSciences											
DuPont				0	20	20					
Pioneer	30	5	35	46	7	53	840	6.3	133	1,600	8.3
Monsanto	1	15	16	1	15	16					
DeKalb/Pfizer	19	6	25	16	6	22	205	10.7	41	387	10.6
Cargill[1]							250		37	250	14.8
Limagrain				22	5	27	335	8.1	60	660	9.1
KWS				18	5	23	151	15.2	47	350	13.4
Enimont				0	15	15					
Seminis									47	380	12.4
Shell	9	3	12	19	3	22					
Upjohn				24	3	27	270	10.0			

[1] Cargill's international seed business was purchased by Monsanto, while its U.S. seed business was purchased by AgrEvo.

Sources: 1986: Grossman et al. (1988, p. 13), 1988-89: Fox (1990, p. 42-43), 1996: James (1997, p. 6).

ditures on major crops, the share of R&D spent on soybeans by the 14 largest seed firms grew the fastest, from 1 percent in 1970 to 11 percent in 1980 (table 30). Public varieties of wheat and, to a lesser degree, cotton have been important sources of new seed for farmers. In addition, the public sector has continued to be the primary source of R&D investment and variety development for many small grains, such as oats, barley, and other minor field crops (Fuglie et al., 1996, pp. 53-55; Heisey, 1999, p. 19).

Table 28—Research expenditures on crop improvement for corn, public and private

Expenditure type sector/type	1960	1965	1970	1975	1979	1984
			Million 1984 dollars			
Research expenditures - breeding:						
Private sector	11.0	13.4	18.8	28.9	43.6	59.2
Public sector	16.5	18.5	21.2	26.0	27.5	36.8
Total public and private	27.5	31.9	40	54.9	71.1	96
			Percent			
Share of total:						
Private	40.0	42.0	47.0	52.6	61.3	61.7
Public	60.0	58.0	53.0	47.4	38.7	38.3

Source: Huffman and Evenson (1993, p. 159).

Table 29—Research expenditures on crop improvement for soybeans, public and private

Expenditure type sector/type	1960	1965	1970	1975	1979	1984
			Million 1984 dollars			
Research expenditures - breeding:						
Private sector	0.01	0.2	1.0	5.9	9.5	13.2
Public sector	9.79	10.9	14.7	23.9	40.6	41.9
Total public and private	9.80	11.1	15.7	29.8	50.1	55.1
			Percent			
Share of total:						
Private	0.10	1.8	6.4	19.8	19.0	24.0
Public	99.90	98.2	93.6	80.2	81.0	76.0

Source: Huffman and Evenson (1993, p. 165).

Research Patterns in Terms of Scientist Years

Measuring the number of scientist years (SY) and funding per scientist (holding Ph.D. or M.S. degrees) allocated to specific areas of research offers additional insights into the public and private R&D effort on plant breeding. Across all crop varieties, the number of SY engaged in private plant breeding of major crops increased by 114 percent (from 701 to 1,498) between 1982 and 1994, while funding per scientist year had an apparent increase of 38 percent from $164,000 to $226,000 in current dollars over the same period (table 31), a 28-percent decrease in real terms. The distribution of SY between different crops has closely followed the allocation of R&D expenditures in dollar terms for both the public and private sectors (fig. 15). For instance, the private sector provided 94 percent of the total 545 SY allocated to corn breeding research in 1994, a fact that reflects the private sector's dominance in corn research. For such crops as cotton and soybeans, for which the public sector still plays a role in plant breeding and germplasm research, the private sector provided 77 percent (cotton) and 65 percent (soybeans) of the total SY allocated to plant breeding research in 1994 (table 32). Private sector research on wheat is even more limited: 41 percent of the total SY allocated to wheat breeding research came from the private sector in 1994.

A cost comparison of public and private R&D on plant breeding per scientist year for 1994 shows that, on average, expenditures in plant breeding were higher in the public sector ($286,840 per SY) than in the private sector ($225,898 per SY) (table 33). However, public R&D expenditures were lower than expenditures of the larger private firms ($290,000 per SY), likely due to

Table 30—Private research and development expenditures of the 14 largest seed firms, by year and crop

Year	Expenditures	Corn	Soybeans	Alfalfa	Wheat	Cotton
	Million current dollars			*Percent*		
1970	3.40	79	1	9	7	4
1972	3.94	77	2	8	9	5
1974	5.59	75	6	7	8	4
1976	8.39	73	7	6	11	3
1978	10.26	71	10	6	9	4
1980	12.13	71	11	7	9	3

Source: Butler and Marion (1985), p. 31.

the more complex nature of plant breeding R&D (including the use of biotechnology techniques, which is expensive, Kalton el al., 1989) carried out by both public sector and large firms. Overall, the private sector employed more than twice as many SY as the public sector (1,498 versus 743), and total private sector expenditures in plant breeding ($338 million) exceeded those of the public sector ($213 million) in 1994.

Table 31—Number of firms and scientist years (SY) engaged in private plant breeding for major field crops

Crop	1982				1989*				1994			
	Number of firms	Share of firms	Scientist years	Share of SY	Number of firms	Share of firms	Scientist years	Share of SY	Number of firms	Share of firms	Scientist years	Share of SY
		Percent		*Percent*		*Percent*		*Percent*		*Percent*		*Percent*
Corn	66	24.54	255	36.38	75	27.57	371	34.77	91	27.66	510	34.05
Soybeans	26	9.67	52	7.42	34	12.50	86	8.06	38	11.55	101	6.74
Cotton	13	4.83	28	3.99	11	4.04	17	1.59	35	10.64	103	6.88
Wheat	21	7.81	42	5.99	11	4.04	47	4.40	27	8.21	54	3.60
Others	143	53.16	324	46.22	141	51.84	546	51.17	138	41.95	730	48.73
Total	269		701		272		1,067		329		1,498	
Dollars ($Mil.)	114.95				272				338.462			
Dollars ($)/SY	163,980				306,306				225,898			

* 1989 figures for million dollars per SY are based on the average of figures for 1988 and 1990.

Source: Companies and Expenditures for 1994: Frey (1996), p. 19; SY by crop, Frey (1996), pp. 36-38; Companies and expenditures for 1982 and 1989: Kalton et al. (1990), p. 24.

Table 32—Number of scientist years (SY) devoted to plant breeding, public and private, by crop, 1994

Crop/Crop category	Public sector		Private sector		Total	
	Number of SY employed	Share of total for the crop	Number of SY employed	Share of total for the crop	Number of SY employed	Share of total SY
		Percent		*Percent*		*Percent*
Corn	35	6.48	510	93.52	545	24.72
Soybeans	55	35.01	101	64.99	156	7.07
Cotton	31	22.94	103	77.06	134	6.09
Wheat	76	58.63	54	41.37	130	5.91
Other cereal crops	77	35.48	139	64.06	217	9.84
Other grain legumes	26	50.98	25	49.02	51	2.31
Other fiber crops	2	100.00	0	0.00	2	0.09
Forage	71	58.20	51	41.80	122	5.53
Fruit vegetable	46	21.60	167	78.40	213	9.66
Other crops	287	45.27	348	54.89	634	28.75
Total	706		1,499		2,205	

Source: Frey (1996), pp. 6-11.

Table 33—Public and private research in plant breeding, scientist years (SY), and cost, 1994

Sector/Institution	Number of companies	Total number of SY	Cost per SY	Dollar input per sector/institution
			Dollars	*Million current dollars*
Private	329	1,498	225,898	338.5
Public	NA	743	286,840	213.2
ARS/USDA	NA	177	300,000	53.1
SAES	NA	530	293,500	155.5
Plant materials center	NA	36	125,000	4.5
Total	NA	2,241		551.6

* Average cost. Cost varies with company size, ranging from $148,000 for the smallest firm size category to $290,000 for the larger firms (Frey, 1996, p.19)
NA = not available. SAES = State Agricultural Experiment Station.

Source: Frey (1996, p. 19).