Chapter 4

Technology Transfer and the Competitiveness of U.S. Agriculture

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New technologies have bolstered the remarkable gains in agricultural productivity that the United States has enjoyed since World War II. To a large degree, technology is the foundation of the U.S. position as the world's leading exporter of agricultural products. In recent years, however, poor export performance has led to questions about whether the United States can maintain its edge in agricultural science and technology. This chapter examines the international transfer of agricultural technology, emphasizing the transfer of U.S. technology to other countries, including competitors.

In general, although this country continues to dominate the field of agricultural technology, other nations have begun to close the gap. Technology transfer from the United States has played an important role in this process, and should continue to do so in the future. Over the next decade, the United States' strategic advantage in agricultural technology may be reduced. Of course, the introduction of crop biotechnologies into commercial use will enhance the U.S. advantage over other nations; however, because international diffusion of biotechnology can occur rapidly, U.S. farmers may enjoy cost advantages for a shorter period of time than has been the case with technological innovation in the past.

'Unless otherwise noted, the material in this chapter is drawn from an OTA contract report entitled "The Potential for Transfer of U .S. Agricultural Technology, " by Robert E.Evenson, Jonathan Putnam, and *Carl Pray, 1985.*

AGRICULTURAL TECHNOLOGY TRANSFER

In general, transfer of agricultural production technologies is more difficult than that of other manufacturing technologies. This process is affected by economic conditions and policies in the receiving nation, natural resources, and climate. Agriculture's biological nature often negates the possibility of "direct transfer" to another country or region without adjusting for local growing conditions; for example, plant varieties must be adapted to specific soil types. As a result, "adaptive transfer" *is more* common. Diffusion of scientific findings or techniques—''pretechnology science transfer' '—represents another important process. This may lead to new inventions in other countries, or may support efforts to "adapt" technologies. Also, the transfer of technical and scientific capacity among nations, as in the training of foreign graduate students in the United States, constitutes a significant channel for the transfer of agricultural technology.

Patent Information

Patent registration data provide imperfect but useful information about invention activity, and about the direction and pace of technology transfer between countries. One drawback of patent data is that inventors may not wish to disclose trade secrets in patent documents, tending to underestimate the actual number of inventions. International comparisons of patent data present other difficulties. For example, about 90 percent of all patent applications are granted in France, compared to **35** percent in West Germany; a greater degree of innovation maybe needed in West Germany to gain patent protection. Evaluation of patents awarded in a broad range of countries reduces this problem. Finally, certain agricultural inventions—chemicals and chemical processes, for example—are excluded from patent protection in such major agricultural nations as India, Under these circumstances, a foreign technology that can be imported constitutes an inexpensive alternative. In this situation, however, foreign firms may be reluctant to transfer technology, and fewer incentives exist to import and adapt foreign innovations.

Three sources of agricultural patent information demonstrate trends in the international diffusion of technology, as described below.

U.S. Crop Variety Patents

The Plant Variety Protection Act of 1970 led to a marked increase in the number of crop varieties registered for patent protection in the United States. With the exception of patents for such widely grown forage grasses as fescue, bluegrass, and perennial ryegrass, foreign firms have not been particularly active in this area. In contrast, private U.S. firms have acquired many patents for an array of minor crops, as well as for major export crops like field corn, cotton, wheat, and soybeans (see table 4-1). Although the private sector has dominated corn breeding over the years, the growing number of private patents for wheat and soybean varieties suggests a significant shift in the locus of inventive activity. The public sector—U. S. Government, other national governments, and international research and development institutions—has traditionally dominated the invention and transfer of soybean and wheat varieties. Now, many U.S. companies with foreign subsidiaries, or with joint ventures for research and marketing, are positioned to play a major role in this process. Also, in addition to its impact on U.S. markets, the increase in private sector patents may affect avenues and rates of international germplasm transfer for export crops.

Foreign Patents Granted by the United States for Agricultural Technology

Foreign firms that plan to transfer or produce technologies in the United States—directly, through subsidiaries, or via joint ventures—are likely to seek U.S. patent protection. U.S. patent office data indicate that foreign entities obtained between 24 and 52 percent of all patents in each of seven agricultural technology fields and in postharvest technology (PHT) between 1980 and 1984 (see table 4-2). Foreign patent activity is greatest in threshing equipment, fertilizers, and biotechnology, which claimed shares of 46, 44, and 52 percent of all patents, respectively. This suggests that these areas have the highest potential for technology transfer to the United States. The proportion of U.S. patents granted to foreign firms increased from the 1975-79 period to 1980-84 in five technology fields—planters and diggers, harvesters, threshers, animal husbandry, and fertilizers.

In contrast, the proportion of patents received for these technology fields by the U.S. Government did not change significantly between 1975-79 and 1980-84. Nor did the percentage of patents granted to U.S. citizens rise or fall dramatically, except for a decline in the field of planter and digging machinery and an increase in threshing equipment. In fact, the actual number of patent applications increased over the decade in only three other technology fields—harvesting equipment, biotechnology, and PHT,

International Patents for Agricultural Technology

One way to gauge the potential for technology transfer is to examine international patent activity. Foreign patents protect property rights for products that firms plan to market or license in other nations. International patent data for 7 nations and 13 technology fields between 1978 and 1984 indicate that the United States is a leading exporter of agricultural and postharvest technology. During that period, for example, U.S. inventors were granted 6,555 patents for agricultural chemical technologies other than fertilizers. One-half of these patents were granted in this country, and one-half in the six other nations examined—the United Kingdom, France, West Germany, Japan, Canada, and Brazil. In other words, U.S. inventors obtained a foreign agricultural chemicals patent abroad for every one they received domestically.

U.S. inventors show an even greater degree of international patent activity in biotechnology fields. Inventors in the United States obtained 115 U.S. patents for mutation and genetic engineeer-

Table 4-l.—Plant Patents in the United States, 1970-84

Variety	Total 1970-90	Total 1981-84	The Netherlands 1970-90	The Netherlands 1981-84	United Kingdom 1970-90	United Kingdom 1981-84	Other 1970-90	Other 1981-84	Public 1970-90	Public 1981-84
Agrotriticum	4	0	0	0	0	0	0	0	0	0
Alfalfa	11	17	0	0	0	0	0	1	7	0
Aster, china	10	1	0	0	0	0	0	0	0	0
Barley	14	7	0	1		0	0	0	2	0
Beans, field	3	9	0	0	0	0	0	0	2	2
Beans, garden	80	26	2	9	0	0	0	0	0	0
Beans, lima	5	3	0	0	0	0	0	0	0	0
Bentgrass	1	1	0	0	0	1	0	0	1	0
Bluegrass	11	14	5	4	0	0	0	1	0	1
Broccoli	1	2	0	0	0	0	0	0	0	0
Buckwheat	0	1	0	0	0	0	0	0	0	0
Cauliflower	6	6	3	6	0	0	0	0	0	0
Celery	0	3	0	0	0	0	0	0	0	0
Clover, all	3	3	0	0	0	0	0	0	2	
Corn, field	5	17	0	0	0	0	0	0	0	0
Corn, pop	1	2	0	0	0	0	0	0	0	0
Corn, sweet	3	0	0	0	0	0	0	0	0	0
Cotton	82	33	0	0	0	0	0	0	0	0
Cowpea	2	3	0	0	0	0	0	0	2	1
Eggplant	1	1	0	0	0	0	0	0	0	0
Fescue, all	12	26	5	9	1	3	0	1	5	1
Lettuce	43	6	0	0	1	0	0	0	0	0
Marigold	21	8	0	3	0	0	0	0	0	0
Muskmelon	6		0	0	0	0	0	0	2	
Nasturtium	9	;	0	0	0	0	0	0	0	0
Oat	12	4	0	0	0	0	0	0	7	1
Onion	10	12	0	0	0	0	0	0	0	4
Orchardgrass	2	1	1	1	0	0	0	0	0	0
Pea, garden	92	52	0	2	0	1	0	0	0	0
Peanut	8	2	0	0	0	0	0	0	2	0
Pepper	0	3	0	0	0	0	0	0	0	0
Pumpkin	4	1	0	0	0	0	0	0	0	0
Radish	1	3	0	0	0	0	0	0	0	0
Rice	9	3	0	0	0	0	0	0	0	0
Rye	2	0	0	0	0	0	0	0	1	0
Ryegrass, annual and other	4	8	1	2	3	0	0	0	0	1
Ryegrass, perennial	13	21	4	8	1	0	1	2	1	0
Safflower	5	0	0	0	0	0	0	0	0	0
Sainfoin	2	0	0	0	0	0	0	0	1	0
Soybeans	170	139	0	0	0	0	0	0	27	16
Squash	5	2	0	0	0	0	0	0	1	
Sunflower	1	5	0	0	0	0	0	0	0	0
Sweetpea	6	0	0	0	0	0	0	0	0	0
Tobacco	11	5	0	0	0	0	0	0	0	0
Tomato	0	13	0	0	0	0	0	0	0	2
Trefoil Birdsfoot	1	1	0	0	0	0	0	0	1	1
Triticale	0	3	0	0	0	0	0	0	0	0
Turnip	0	1	0	0	0	0	0	0	0	0
Vetch, common	0	4	0	0	0	0	0	0	0	4
Watermelon	6	7	0	0	0	0	0	0	1	0
Wheat, common	84	39	0	0	0	0	0	0	27	9
Wheat, Durum and other	5	4	0	0	0	0	0	0	0	0
Zinnia	3	0	0	0	0	0	0	0	0	0
Others (minor grasses and flowers)	14	11	1	1	0	1	0	0	3	2
Totals	—	—	22	45	7	6	1	5	107	50

SOURCE Robert E Evenson, Jonathan Putnam, and Carl Pray, "The Potential for Transfer of US Agricultural Technology" contract report prepared for the Office of Technology Assessment, 1985

Table 4-2.—U.S. Patents Granted in Agricultural Technology Fields

	Earthworking equipment	Planters, diggers	Harvesting equipment	Threshing equipment	Animal husbandry	Fertilizers	Biotechnology	Postharvest technology
Patents granted								
1975-79	554	128	339	83	807	1,251	493	2,866
1980-84	451	120	418	96	786	1,085	527	2,340
Ratio, 1980-84/1975-79	0.82	0.94	1.23	1.16	0.97	0.87	1.06	0.82
Percent U.S. corporation								
1975 -79	38	25	50	55	24	58	40	52
1980-84	36	33	48	35	24	52	42	49
Percent U.S. Government								
1975 -79	00	02	00	00	01	01	03	03
1980-84	01	02	00	01	01	02	02	01
Percent US individual								
1975 -79	27	36	26	12	58	03	03	12
1980-84	30	28	24	18	51	02	04	13
Percent foreign origin								
1975-79	35	35	24	32	17	38	54	32
1980-84	34	38	28	46	24	44	52	27

SOURCE: Robert E. Evenson, Jonathan Putnam, and Carl Pray, "The Potential for Transferor US Agricultural Technology," contract report prepared for the Office of Technology Assessment, 1985

ing technologies, as opposed to 350 in this field in the six other countries. U.S. inventors received 183 patents in Japan for mutation and genetic engineering, more than at home.

Table 4-3 shows that the United States is a net exporter to these other nations in each of the 13 technology fields, and is a net exporter to most of the countries individually. U.S. patent activity abroad is most pronounced in the biotechnology fields, agricultural chemistry, and postharvest technologies.

Table 4-4 indicates what types of technology are most readily transferred among these seven countries. It shows the ratio of the total number of patents granted in a field in all countries to the patents granted in origin countries in the same field. For example, the seven countries granted 23,814 patents in agricultural chemistry, which was the largest number in any field; 13,397 of these were obtained by inventors in their own country. The ratio of total-to-origin patents was 1.78; a total of 78 agricultural chemical patents were received in the six foreign nations for every 100 received in the home nation. Once again, biotechnology and agricultural chemicals represented the fields with the greatest relative degree of transfer. For mutation and genetic engineering technologies, slightly more international patenting activity occurred than patenting activity within countries of origin, for a ratio of 2.12.

Further analysis of international patent data for these countries reveals that:

- The United States imports a significant amount of agricultural chemistry and fertilizer technology from West Germany.
- Canada and Brazil stand out as substantial net importers of agricultural technology. The Canadians produce a great many inventions, but import even more from the United States. The Brazilians patent relatively few inventions while maintaining significant imports, primarily from the United States.
- In most fields, U.S. patents are outnumbered by those of Japan, which:

  > . . . is overall a net exporter although it imports in several fields [and] outproduces the two traditional invention economies, France and the U. K., in all fields except agricultural chemicals. Japan is also an exporter of some biotechnology and will probably become a large exporter in the future.

- Biotechnology inventions that enter the United States could become a significant factor in the growth of domestic agricultural productivity. Because this country represents a large, relatively affluent market, in which the adoption of new technologies proceeds rapidly, it tends to attract emerging biotechnology. All other things being equal, lower production costs that result from biotechnology will benefit U.S. farmers, and domestic and foreign consumers.

Table 4-3.—Indices of International Trade in 13 Agricultural Technology Fields, 1978-84: Trade Index for Patents by Country; U.S. Trade Index for Patenting Activity With United States

							Biotechnology				Postharvest		
	Earthworking —planting	Harvesting machinery	Animal husbandry	Fertilizer	Agricultural chemistry	Mutation genetic engineering	Micro-organism tissue culture	Enzyme	Apparatus	Meat dairy	Fruit	Grain	Food preservation
Trade index[a]													
United States	0.24	0.25	0.09	0.36	0.54	2.69	0.74	0.62	1.05	0.671	0.373	0.620	0.401
United Kingdom	0.26	-0.18	0.11	-0.27	0.60	1.42	0.97	1.04	1.38	0.39	1.58	0.613	0.563
France	0.38	0.27	0.04	0.07	0.82	-1.61	0.73	1.23	0.98	0.135	0.215	0.704	0.140
West Germany	0.34	0.09	0.22	0.35	0.86	0.232	0.38	0.08	0.23	0.352	0.245	0.288	0.215
Japan	2.22	3.23	0.07	0.00	0.29	0.413	0.09	0.05	0.11	0.110	0.186	0.015	0.007
Canada	1.64	-1.53	1.56	-1.46	-6.84	-0.15	7.30	6.54	7.33	2.91	0.90	3.86	3.75
Brazil	0.31	-0.48	0.66	2.90	19.10	41.0	6.00	5.75	2.04	5.10	1.39	2.47	
United States trade[b]													
United Kingdom	0.025	0.016	0.029	0.046	0.067	0.513	0.149	0.077	0.129	0.115	0.109	0.109	0.069
France	0.015	0.032	0.044	0.041	0.045	0.252	0.072	0.051	0.122	0.062	0.109	0.099	0.029
West Germany	0.019	0.026	-0.016	0.03	0.074	0.261	0.052	0.000	0.035	0.013	0.036	0.037	0.012
Japan	−0.019	−0.01	0.016	0.061	0.220	1.356	0.201	0.179	0.248	0.178	0.081	0.051	0.067
Canada	0.187	0.144	0.074	0.137	0.126	0.104	0.195	0.195	0.241	0.220	0.054	0.241	0.160
Brazil	0.051	0.041	0.021	0.101	0.159	0.286	0.072	0.051	0.059	0.082	0.190	0.081	0.060

[a]Trade index = (patents granted abroad to foreign inventors − patents granted at home to foreign inventors) / patents granted at home to national inventors

[b]U.S. trade = (patents obtained by U.S. inventors in country − patents obtained by country's inventors in U.S.) / U.S. patents granted to U.S. inventors

SOURCE: Robert E. Evenson, Jonathan Putnam, and Carl Pray, "The Potential for Transfer of U.S. Agricultural Technology," contract report prepared for the Office of Technology Assessment, 1985.

Table 4-4.—Total Origin Patents and Patents Granted in 13 Agricultura Technology Fields, 1978-84

							Biotechnology				Postharvest		
	Earthworking —planting	Harvesting machinery	Animal husbandry	Fertilizer	Agricultural chemistry	Mutation genetic engineering	Micro-organism tissue culture	Enzyme	Apparatus	Meat dairy	Fruit	Grain	Food preservation
Total origin patents	2,393	1,570	1,388	1,774	13,397	565	894	1,098	1,412	3,967	468	2,006	6,608
Total granted patents	3,563	2,190	1,907	2,696	23,814	1,200	1,691	1,770	2,321	6,481	716	3,002	8,176
Transfer index[a]	1.49	1.39	1.37	1.52	1.78	2.12	1.89	1.62	1.64	1.63	1.53	1.50	1.24

[a]Ratio of total patents granted in all countries to origin patents.

SOURCE: Robert E. Evenson, Jonathan Putnam, and Carl Pray, "The Potential for Transfer of U.S. Agricultural Technology," contract report prepared for the Office of Technology Assessment, 1985.

Indirect Transfer of Agricultural Technology

Because of its biological basis, agriculture—more than most production processes—reacts to local conditions. As a result, direct international transfer of agricultural technologies is not a common occurrence. For example, foreign use of wheat germplasm developed in the United States demands a high degree of adaptation. Even within the United States, technologies that have proven successful in some areas require a measure of adaptation to agro-climatic conditions in others. As a result, a considerable amount of international technology transfer takes on the form of scientific information, knowledge, and techniques. This section addresses the process of scientific transfer, for agricultural and postharvest technology.

Patent Citations

Patent applications in the United States contain "citations" of scientific literature, which help to distinguish an invention proposed for patent protection. Patent citations capture the process of adaptive technology transfer, providing "a kind of pedigree of the intellectual or technical parentage" for an invention.

Table 4-5 provides the number and origins of patent citations in eight agricultural and postharvest technology (PHT) fields for two periods, 1975-79 and 1980-84. Over the 10-year timeframe, the percentage of citations of foreign literature increased in every field:

> In the early period, 29.1 percent of all patents were granted to foreigners (foreign patents of U.S. ownership are not included), while 17.5 percent of all cites were to foreign patents. In the second period, 32.2 percent of all patents were granted to foreigners while 23.6 percent of all cites were to foreigners. Thus the citation data are consistent with a growing foreign role in U.S. [agriculture and postharvest] invention and with the recognition that foreign invention is a growing part of the intellectual structure of [those] inventions.

Scientific Publications

As noted earlier, many inventions relevant to agriculture and postharvest technology are not patented. However, another way to evaluate adaptive transfer of agricultural science and technology, and the United States' standing in that process, is to examine scientific publications in these fields. Among 24 major agricultural nations and in 10 "traditional" agricultural technology fields, the United States ranked first in scientific publications between 1978 and 1982; U.S. publications totaled 289,061 over this period. The United Kingdom, with 100,135 publications, and India, with 89,750 publications, placed second and third. Significantly, India ranked second in the areas of plant breeding, plant pathology, crop science, and soil science.

Between the two periods examined, 1973-77 and 1978-82, the United States maintained its standing among these countries, although the total number of U.S. publications dropped by 22 percent in animal nutrition and by 3 percent in plant breeding. Publications grew significantly in four scientific fields between the timeframes: veterinary medicine, 59 percent; soil science, 40 percent; entomology /hematology, 39 percent; and animal breeding, 31 percent (see table 4-6).

The United States gained in the 24-nation share of publications in 6 of the 10 fields—animal breeding, weed science, plant breeding, plant pathology, crop science, and soil science—lost share in 3—animal nutrition, entomology /hematology, and veterinary medicine, and held steady in dairy science (see table 46). India is the only other country to demonstrate significant gains in terms of world literature share in the agricultural sciences.

Comparing U.S. distribution of publications by field with that of other countries provides another indication of technology transfer. Statistical correlation shows that the structure of U.S. literature resembles that of 12 other countries, assuming a correlation coefficient greater than 0.900: Canada, Australia, the United Kingdom, France, West Germany, The Netherlands, Switzerland, East Germany, Mexico, Argentina, Japan, and Israel, The diffusion of technology, and of scientific knowledge and methods in particular, appears to occur most easily between the United States and these nations. Correlations are also close with New Zealand, Poland, and Egypt.

Table 4-5.– U.S. Patents Granted in Agricultural Technology Fields

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Ratio, 1980-84/1975-79	0.82	0.94	1 23	1 16	097	087	106	082
Percent foreign orlgln								
1975-79	35	35	24	32	17	38	54	32
1980-84	34	38	28	46	24	44	52	27
CItatIons/patent								
1975-79	952	1701	571	1319	1567	753	1264	708
1980.84	1162	2045	746	1354	1683	943	1311	968
Percent foreign cttes (Indirect)								
1975-79	17	10	20	08	03	20	15	13
1980-84	14	09	21	11	06	20	18	17
Percent foreign cites (direct)								
1975-79	12	12	05	03	01	05	02	05
1980-84	15	18	10	05	03	11	03	08

SOURCE Robert E Evenson Jonathan Putnam and Carl Prav The Potential for Transfer of U S Agricultural Technology contract report prepared for the Office of Technology Assessment 1985

Table 4-6.—Total Publications in 24 Countries for 10 Applied Agricultural Science Fields and U.S. Share, 1973-77 and 1978-82

Scientific field	Total publications 1978-82	U.S. share	Total publications 1973-77	U S share	Ratio 1978-82/1 973-77
Animal breeding ...	39,680	+ 0.216	30,435	0.182	1.31
Animal nutrition . . .,	30,616	– 0.240	39,164	0.255	078
Crop science ., . . ., ...	47,424	+0.189	41,722	0.160	1,14
Dairy science ., ., ., . .	43,440	0.163	35,882	0.163	1 18
Entomology /hematology	46,113	–0.194	33,126	0.233	139
Plant breeding . ., . . .	48,786	+0, 178	50,204	0.161	097
Plant pathology ... . . .,	29,260	+o.168	28,030	0137	1,04
Soil science . . .	50,658	+ 0.203	36,096	0,167	1.40
Veterinary medicine ., ...	191,965	– 0154	121,319	0.189	1 59
Weed science . . .	19,492	+ 0.328	141361	0,303	1 0 9

+ Gain in share since 1973-77
– Loss in share since 197377

SOURCE Robert E Evenson Jonathan Putnam and Carl Pray The Potent (al for Transfer of U S Agricultural Technology contract report prepared for the Office of Technology Assessment 1985

The Role of International Agricultural Research Centers (IARCS)

An important recent development in international agriculture is the formation of International Agricultural Research Centers (IARCS). Thirteen IARCs now conduct a variety of agricultural research and development projects, specializing in productivity gains in tropical agriculture. The two most renowned centers, the International Maize and Wheat Improvement Center in Mexico (CIMMYT) and the International Rice Research Institute in the Philippines, played central roles in the development and dissemination of high yielding varieties of wheat and rice—the cornerstone of the "green revolution. " For these and other agricultural commodities, IARCS train large numbers of scientists of less developed countries (LDCS), disseminate genetic materials like new seed varieties, and release scientific information. "The IARCS function partly as a transfer station between work in the research centers in the developed countries and the LDCS. "

A recent study examined the effects of IARC activities on crop productivity for 10 crops in 25 developing countries,[2] and concluded that "IARC programs contributed positively to crop productivity improvement in maize, millets, sorghum,

[2]Robert E Evenson, The IARCS Evidence of Impact on National Research Extension and Productivity, ' study paper prepared for the Consultative Group of the World Bank, Washington, DC 1986

wheat, rice, beans, groundnuts, cassava and potatoes. " Moreover, the study reinforced the notion that growing conditions influence technology transfer for most crops:

> The IARC impact was higher in countries with gee-climatic conditions similar to those of the IARC host location. For cassava and rice little impact beyond the host countries was measured, showing less transfer potential. Only wheat showed high transferability outside the similar regions.[3]

Agricultural Research Capacity

Investment and personnel devoted to agricultural research indicate the dynamics of a nation's agricultural sector (see table 4-7). Between 1959 and 1980, worldwide expenditures for public agricultural research programs increased significantly, by 360 percent after inflation. The number of scientist-years committed to agricultural research more than tripled during the same period. Dramatic growth occurred during the first decade of this period; worldwide, research expenditures and personnel rose more rapidly between 1959 and 1970 than between 1970 and 1980.

Striking differences exist between different parts of the world in spending and employment patterns for agricultural research over the 20-year period. All regions spent more and employed more people in 1980 than they had in 1970 or 1959, but changes occurred in regional shares of worldwide investment and personnel. Eastern Europe and the Soviet Union together fell from about 28 percent of world expenditures in 1959 to 20 percent in 1980, and from 38 percent of world personnel to 35 percent. North America and Oceania dropped from 37 percent of world expenditures to 23 percent, and their personnel share declined from 18 to 9 percent. Western Europe and Asia gained significantly in percentage share. Africa held steady, although its proportion of research personnel did rise slightly. The largest expansion of research capacities occurred in developing countries:

> Research spending increased by a multiple of 5.8 in developing countries in Latin America, 6.9

[3]Ibid.

Table 4-7.—Agricultural Research Expenditures and Scientist-Years, by Region, 1959-80

Region/subregion	Expenditures (000s constant 1980 U.S.$)			Manpower (scientist-years)		
	1959	1970	1980	1959	1970	1980
Western Europe	274,984	918,634	1,480,588	6,251	12,547	19,540
Northern Europe	94,718	230,135	409,527	1,818	4,409	8,027
Central Europe	141,054	563,334	871,233	2,888	5,721	8,827
Southern Europe	39,212	125,165	208,828	1,545	2,417	2,636
Eastern Europe and U.S.S.R,	568,284	1,282,212	1,492,783	17,701	43,709	51,614
Eastern Europe	195,896	436,094	553,400	5,701	16,009	20,220
U.S.S.R.	372,388	846,118	939,383	12,000	27,700	31,394
North America and Oceania	760,466	1,485,043	1,722,390	8,449	11,688	13,607
North America	668,889	1,221,006	1,335,584	6,690	8,575	10,305
Oceania	91,577	264,037	386,806	1,759	3,113	3,302
Latin America	79,556	216,018	462,631	1,425	4,880	8,534
Temperate South America	31,088	57,119	80,247	364	1,022	1,527
Tropical South America	34,792	128,958	269,443	570	2,698	4,840
Caribbean and Central America	13,676	29,941	112,941	491	1,160	2,167
Africa	119,149	251,572	424,757	1,919	3,849	8,088
North Africa	20,789	49,703	62,037	590	1,122	2,340
West Africa	44,333	91,899	205,737	412	952	2,466
East Africa	12,740	49,218	75,156	221	684	1,632
Southern Africa	41,287	60,752	81,827	696	1,091	1,650
Asia	261,114	1,205,116	1,797,094	11,418	31,837	46,656
West Asia	24,427	70,676	125,465	457	1,606	2,239
South Asia	32,024	72,573	100,931	1,433	2,569	5,691
Southeast Asia	141,469	521,971	734,694	7,837	13,720	17,262
China	54,166	502,491	643,555	1,250	12,250	17,272
World total	2,063,553	5,358,595	7,390,043	47,163	108,510	138,039

SOURCE Robert E. Evenson, Jonathan Putnam, and Carl Pray, "The Potential for Transfer of U S Agricultural Technology, " contract report prepared for the Office of Technology Assessment, 1985 in Asia and 3.6 in Africa. Scientist man-year multiples were 6.0 in Latin America, 4.1 in Asia and 4.2 in Africa. This is in contrast to spending and personnel multiples for public sector agricultural research in the U.S. of 1.9 and 1.4 respectively. The major competitors, Canada, Australia, Argentina and Brazil, had spending multiples of 2.4, 4.0, 2.1 and 1.4, respectively.

Further analysis of world expenditures and personnel devoted to agricultural research shows that between 1959 and 1980, research expenditures in developing countries grew at a faster pace than agricultural extension expenditures as a percentage of the value of agricultural products. As a result, the intensity of research and extension are now approximately equal in developing countries. This reorientation signifies a more sophisticated and balanced capability for adaptive research within the developing world than that which existed two decades ago.

Capacity Transfer: Foreign Students Trained in the United States

One of the most significant avenues for transfer of technology, and of scientific knowledge and technique in particular, has been the training of scientists from developing countries in the United States and other developed nations. Table 4-8 indicates the total number of U.S. doctoral degrees awarded in agricultural and related fields between 1960-64 and 1975-79; during this period, over 7,500 such degrees were awarded to foreign students. In most fields, foreign students represent a growing share of degree recipients-over 40 percent in agronomy, which includes crop breeding and soil science, veterinary medicine, agricultural engineering, agricultural economics, and general agriculture. In contrast, in the related and important field of genetics, the percentage of foreign Ph.D. recipients over this period fell from 48 percent in 1960-64 to 25 percent in 1975-79. In the 1975-79 interval, approximately 16 percent of foreign students with temporary visas planned to remain in the United States for postdoctoral studies. The majority of these planned to obtain employment in either education or government.

TECHNOLOGY TRANSFER AND MAJOR EXPORT CROPS

Important differences exist in the avenues of international technology transfer for three major U.S. export crops: corn, wheat, and soybeans. In some cases, as with hybrid corn seed, indirect technology transfer takes place through multinational companies. For other crops and technologies, such as soybean varieties, direct transfer from the United States to other countries has occurred via public research entities or international research centers. For all three crops, an accelerated pace of agricultural technology transfer has resulted from worldwide improvements in public and private research capacity over the past few decades, especially in the developing world. Moreover, the international exchange of scientific knowledge and trained scientists are important routes for the diffusion of technology that affects corn, wheat, and soybean productivity.

Technology transfer brings many benefits to agricultural production and trade. U.S. farmers gain from certain technology imports, although transfer generally flows toward agricultural producers in other nations—including international competitors. Because technology transfer tends to lower the price of crops throughout the world, it facilitates consumption. In a number of cases, U.S.-based multinational firms have the lead in a particular technology, and can profit through technology exports, or through production and sales via subsidiaries or joint ventures in other countries. U.S. farmers may benefit from such transactions indirectly, since many U.S. firms reinvest profits in domestic research and development. Finally, agricultural technology transfer that boosts income in other countries may translate into increased trade with the United States.

Table 4-8.—Total Number of Ph.D. Degrees Awarded in 20 Fields Associated With Agriculture and Home Economics and the Proportion of Degrees Awarded to Non-U.S. Citizens With a Temporary Visa[a]

	1960-64		1965-69		1970-74		1975-79	
Fields	Total	Percent foreign	Total	Percent foreign	Total	Percent foreign	Total	Percent foreign
Agronomy, including soils and soil science	711	28.0	873	36.8	1,150	38.1	1,060	43.5
Horticulture	237	27.8	334	33.5	321	34.9	321	34.0
Forestry	66	9.1	172	15.1	249	19.3	304	26.1
Entomology	444	25.2	651	21.8	823	20.8	685	25.1
Phylopathology	385	30.4	561	29.6	468	29.3	410	31.9
Physiology-plant	96	27.1	262	29.4	287	25,5	183	28.4
Physiology-plant and animal[b]	160	13.1	—				—	
Animal husbandry, animal science, and nutrition	573	15.7	649	27.6	651	26.5	667	28.4
Veterinary medicine	96	26.0	184	23.9	196	37.3	152	44.1
Physiology-animal	163	8.6	509	14.3	732	12.8	590	12.6
Agricultural engineering	97	21.6	181	19.9	309	31.1	235	45.5
Agricultural economics[d]	—	—	92	30.4	794	33.4	742	42,7
Food science and technology	—	—	—		373	30.8	510	35.1
Agriculture and food chemistry	160	40.0	223	27.4	160	20.6	42	33.3
Fish and wildlife	65	13.8	90	7.8	204	10.3	255	11.4
Agriculture (general and other)	116	27.6	314	33.1	519	31.3	383	40.2
Nutrition and/or dietetics[c]	—	—	—	—		.	283	7
(Other) home economics		22.7	150	21.3	133	16.5	269	
Subtotal	(3,497)	(23.6)	(5,035)	(28.0)	(7,274)	(27.9)	(7,887)	?
Biochemistry	696	17.8	1,099	19.4	1,140	15.5	1,019	?
Genetics	296	48.0	418	35.2	444	30.5	372	25.3
Totals	4,489	23.3	6,662	26.5	8,858	26.4	8,478	29.4

aForeign is defined as a Ph D recipient of a US university who has a temporary visa
bin fiscal year 1962, "Physiology" was broken out into "Animal Physiology" and "Plant Physiology"
c"Animal Science" was added as a field in fiscal year 1973 Field was changed to 'Animal science and Animal Nutrition" In fiscal year 1977
dAdded as a field in fiscal year 1969.
e"Nutrition" dropped as afield in fiscal year 1960 "Nutrition and/or Dietetics" added as a field in fiscal year 19

SOURCE Robert E Evenson, Jonathan Putnam, and Carl Pray, "The Potential for Transfer of US Agricultural Technology, " contract report prepared for the Off Ice of Technology Assessment, 1985

International Transfer of Corn Technology

As much as any other U.S. crop, technological change has altered postwar corn production. Conventional plant breeding, more frequent and more efficient use of nitrogen fertilizer, and assorted "production management technologies" should continue to increase corn yields through the end of the century. Even greater potential for increasing corn yields may lie in biotechnologies that will enter commercial markets by the mid-1990s. Plant growth regulators for corn could have the largest impact of any biotechnology, followed by photosynthetic enhancement, breeding techniques like cell and tissue culture, and biological nitrogen fixation. Developments in pesticide and fertilizer technologies will play important roles as well.

How rapidly and by what routes might these technologies be transferred to other nations, eluding U.S. competitors? As befits the U.S. position as the world's top producer and trader of corn, this country generally leads in corn technology. In particular, U.S. companies figure critically in the development and dissemination of chemicals and biotechnology. U.S. and multinational firms either operate subsidiaries or participate in joint ventures in every major corn producing nation:

> Pioneer Overseas Corporation, Cargill, and DeKalb / Pfizer have subsidiaries or joint ventures in all of our major competing countries. These subsidiaries or joint ventures all have some research capacity. Northrup-King and Funk Seeds have subsidiaries in all of these areas except Thailand where Funk is just starting a research program. All of the major seed companies are active in Europe.

Moreover, U.S. companies play a crucial role in the development of hybrid corn seed. Most corn produced in the United States comes from hybrid seed developed by these firms, although inbred varieties that result from public sector research often serve as one of the hybrid parents. To the extent that productivity-boosting corn technology will center around seed, U.S. and European multinationals will be the main channels for direct and rapid transfer.

Genetic material, research methods, and basic knowledge may be transferred rapidly and directly by these companies. For example, a hybrid, high-yield corn seed that is rich in carbohydrates, resists certain diseases, or has other similar traits, could be transferred by a private U.S.-based multinational to Argentina, Europe, and South Africa, and could enter commercial use within a relatively short time—perhaps several years. These countries possess temperate climates similar to that of the United States, and offer large, accessible, and lucrative markets. Furthermore, governments often encourage and assist such transfer, particularly those of developing countries like Argentina and Brazil.

Hybrid corn seed developed for temperate climates would probably need to undergo biological adaptation before entering such tropical countries as Brazil and Thailand. As a result, new knowledge in general, and new research methods in particular, are critical forms of genetic technology transfer to these nations. Moreover, the CIMMYT and State-sponsored research efforts play a more important role than private companies in transferring genetic material to the tropics.

Even if new corn hybrids are not transferred directly, many U.S. seed companies contribute to plant breeding programs in competing nations, which may lead to new, higher yielding, locally developed corn hybrids within the next few years. Programs of this type have already increased corn yields in Argentina and Brazil over the past decade. Transfers may occur in the reverse direction as well; germplasm collected in tropical countries has been an important and controversial source of genetic material for corn breeding programs in the United States.

In addition, multinational companies could facilitate the transfer of chemical technologies for corn production, and for pesticides and plant growth regulators in particular. These firms conduct most of the important research and development for corn pesticides and corn hormones. Two European chemical companies, Ciba-Geigy and Shell, market corn herbicides in the United States and maintain significant product development programs. These firms also "have extensive sales, production and research programs in Latin America and Asia. " Similarly, U.S. companies that dominate corn herbicides and insecticides "have major sales programs in Europe and South America, They also have applied research and development programs in many countries. "

Market characteristics and the security of property rights influence the pace at which U.S. companies introduce new agrichemicals to agricultural competitor nations; the cost of building a production plant or distribution network for a new product is weighed against the size of the market and the availability, cost, and efficacy of competing products. A number of large, lucrative markets for agrichemicals, such as Australia, Canada, and Europe, do possess mature chemical industries that can replicate new technologies. However, strong patent protection in these nations should allow U.S. firms to market new products rapidly. Patent protection is not as secure in other countries, but not all U.S. chemical companies perceive the risk of infringement in the same way. For example:

> Argentina has a patent system but has not signed the Paris convention on patents and so one company, which is very concerned about patent rights, stated their reluctance to introduce their newest chemicals there. Most other companies did not appear to have particular concerns about Argentina.

Similarly, Thailand's new and as yet untested patenting system could affect transfer of agrichemicals: "One major American company will not expand into Thailand or introduce new products there because it feels that it recently had a new product stolen by a Thai company. " However, "other companies are attracted to Thailand because the [pesticide] registration requirements are almost nonexistent and so companies can introduce a new product very quickly. "

Relatively lax registration requirements are common in developing countries, which benefits companies in developed nations that produce and market chemicals and uses of chemicals that have been banned or restricted in their home country. Also, insecticides and disease control agents, or "fungicides," are not widely used for corn production in developing countries, and appear to be prime candidates for technology transfer. Broad spectrum herbicides represent another possibility for transfer to the developing world.

International Transfer of Wheat Technology

International competitiveness in wheat production has become a sensitive issue to the United States, in the wake of recent declines in the U.S. share of the world wheat market. International developments in wheat production technology have an important effect on this market. Conventional plant breeding programs, which formed the basis for the "green revolution" in wheat production during the past two decades, will continue to produce high-yield wheat varieties—perhaps the most important source of productivity improvement over the next 5 to 10 years. Improved management techniques, combined with new plant varieties, will facilitate the multiple-cropping of wheat and other crops, effectively extending wheat's already wide geographic range. Wheat growth regulators, which may enter the market within the next decade, should boost yields moderately, as may the development of hybrid wheats. The United States occupies an important position in the development and dissemination of these technologies.

In contrast with corn, the breeding and transfer of wheat germplasm is dominated by the public sector. Many programs are sponsored by national governments and by CIMMYT, which played a key role in the "green revolution. " In the United States, varieties developed by public research comprise more than **90** percent of all wheat acreage.

Direct regional and international transfer of wheat varieties is rare, due to varying growing conditions and, in some cases, different preferences for specific types of wheat. Even within the United States, for example, wheat varieties remain site-specific: soft white wheats are suited to some areas, and hard red winter wheats are suited to others. Moreover:

> . . . each country has to produce its own varieties using the characteristics of germplasm from around the world. If the country does not have local capacity to do research it cannot use the qualities in the germplasm like disease resistance or, in the future, biological nitrogen fixation.

Even where varieties are transferred to other regions, preferences and grading standards for specific types of wheat can cause delays. The "era" variety of wheat produced yield increases of up to **25** percent when released in Minnesota in 1970, but Canada did not adopt this crop until recent years because of stringent standards imposed by that country's wheat board. Release of a high yielding, rust-resistant wheat variety developed by CIMMYT was delayed in Australia because its red grain was unacceptable to Australian millers. Rather, Australian scientists employed the CIMMYT germplasm to develop a white-grained wheat, which spread rapidly; by 1978, about one-third of Australia's wheat area was planted with CIMMYT-based varieties. Argentine wheat production also benefited from CIMMYT research and plant materials; approximately 60 percent of Argentina's wheat acreage is planted with CIMMYT-based varieties.

As a result, although the transfer of wheat varieties and germplasm is indirect, promising biological traits may be utilized by experienced scientists. The rate of transfer depends on the nature of the individual trait. Concerning the process of transfer:

> Breeders from government institutions in the U.S. and other developed countries regularly exchange their genetic material. Breeders read about a new development in an academic journal, they write to the author for a sample of seeds and then try the seed under their conditions. They then incorporate the useful characteristics into their own commercial varieties.

Again, CIMMYT is a critical link in such exchanges. Other avenues of transfer include shipments of material from international wheat rust research nurseries, and through training programs that bring foreign scientists to the United States. Significantly, this country has also benefited from transfer of wheat germplasm and scientific information about wheat traits.

Apart from biotechnology breeding techniques, growth regulators may become the first form of biotechnology to be transferred among major wheat producing nations. Current research aimed at altering wheat's genetic proclivity to aluminum toxicity could lead to an important breakthrough for tropical wheat production, particularly in Brazil and other Latin American countries. In contrast, the international diffusion of other agrichemicals and of mechanical technologies holds a lower potential for increasing wheat yields, although wheat "fungicides' '—which are employed by European and North American farmers, and are developed and marketed by companies on both continents—may have an impact.

International Transfer of Soybean Technology

Through the turn of the century, conventional plant breeding should continue to be the main avenue for improving the productivity of soybean production throughout the world. In addition, higher yields, further improvements in the efficiency of biological nitrogen fixation, and more effective soybean pesticides are anticipated. On the other hand, emerging biotechnologies—with the possible exception of tissue cultures—and the advent of hybrid soybeans are not likely to have a direct impact on productivity in this century. Public research remains the fountainhead of soybean breeding, although private companies have developed and marketed their own varieties since the late 1970s.

Historically, international transfer of soybean varieties has been a salient feature of global production. The United States dominates production and trade today, but this country imported its first soybeans from China. Over the past two decades, soybean varieties developed in the U.S. public sector formed the foundation of the soybean industry of our closest competitor, Brazil, and played a key role in establishing the Argentine soybean industry, In contrast to the adaptive and indirect international transfers of corn and wheat varieties, "some soybean varieties . . . developed by . . . land grant universities in the Southern United States were grown commercially with no modification in Argentina and Brazil. " The Brazilian soybean boom of the 1970s also benefited from private sector transfers of soybean milling and marketing technology, via U.S.-based multinational corporations. Brazil now exports large amounts of soybean meal and oil, and has displaced some U.S. markets in Europe and Japan. Within the past several years, the Brazilian research system has matured, and now develops its own varieties—used in Argentina, Uraguay, and Paraguay, along with U.S. varieties. Still, about 80 percent of Argentina's soybean acreage is planted with U.S.-produced varieties, and the United States regularly exchanges soybean types with Canada.

Future improvements in soybean varieties, or desirable soybean characteristics, may be transferred or adapted directly and rapidly from the United States to Brazil. Varieties or traits adapted to the tropics will then be transferred to other Latin American countries, and perhaps to Africa and Asia. Important transfers could occur in the opposite direction, but this has not yet occurred.

In addition, transfer of soybean pesticides is a potential source of short-term productivity improvements to competitors. And, as is the case with corn and wheat, plant growth regulators combine considerable potential for productivity gains and technology transfer. However, this technology is not expected to be available to the marketplace until the end of the century.

INTERNATIONAL TRANSFER OF EMERGING AGRICULTURAL TECHNOLOGIES

An OTA document published in 1986[4] identified technologies likely to be introduced to U.S. agriculture over the next 20 years. OTA contractors used that information to assess the potential for transfer of these technologies to other nations, as discussed below,

[4] U.S. Congress, Office of Technology Assessment, *Technology, Public Policy, and the Changing Structure of American Agriculture*, OTA-F-285 (Washington, DC. U.S. Government Printing Office, March 1986).

The technologies were grouped into 44 separate fields, and rated for their potential to increase productivity, for the ease and direction of transfer, for impacts on competitors and importers, and for other characteristics. The ratings were assigned based on a variety of factors, including patent information, research and development activity, and technology transfer data. Sources included interviews with U.S. companies, publications, technology characteristics—a number of which are in the form of scientific knowledge, not specific products—and contractors' experiences. This qualitative rating scheme does not attempt to specify the pace of transferor adoption; as noted above, the actual transfer and adoption in recipient countries depends on such considerations as costs and government policies.

Table 4-9 lists the technology fields that have at least a medium (M) potential for producing productivity gains over the next 20 years and at least a medium (M) potential for transfer to other countries. Of the 44 fields examined, 29 received such a rating. The table also identifies leading research nations for each field; the United States is among the top four for all technologies. Eleven agricultural technology fields received a rating of "M+" or greater for the potential for transfer from the United States: entomology-nematology; general, wheat, and soybean pesticides; regulation of animal growth and development; environment and animal behavior; meat PHT; mutations and genetic engineering; micro-organisms/tissue culture technologies; enzymes; and biotechnolog y equipment and apparatus. Of the 12 crop technologies,

Table 4-9.—Technology Fields With At Least Medium Productivity and Transfer Potential

Leading field	Leading centers	Transfer potential: General	Transfer potential: From U.S.
Crop Technologies:			
1. Plant Breeding	U. S., India, U. S. S. R., U.K.	L	L-M
2. Entomology -hematology	U. S., U. K., India, U.S.S.R.	M +	M +
3. Pesticides-general	U. S., W. Germany, Japan, France	H –	H –
Corn	U. S., IARC, U. S. S. R., Argen.	L –	M
Wheat	U. S., IARC, India, U.S.S.R.	M –	M +
Soybeans	U. S., Brazil, Argentina, India	M –	M +
Rice	IARC, India, Japan, U.S.	M –	L
4. Genetic engineering	Japan, U. S., U. K., W. Germany	H –	M
5. Enhance photosynthesis		M	M
6. Plant growth regulation	U. S., Japan	M	M
7. Plant disease control	U. S., U. K., India, U.S.S.R.	M –	M
8. Biological N Fix.		M	M
Animal technologies:			
1. Animal husbandry	U. S., W. Germany, France, U.K.	L-M	M
2. Animal breeding	U. S., U. K., India, W, Germany	M	M
3. Regulating animal growth and development		M	M +
4. Animal disease control	U. S., U. K., India, W. Germany	M	M
5. Animal reproduction	U. S., U. K., W. Germany, Austral	M	M
6. Environment and animal behavior		M +	M +
General mechanical and managerial technologies:			
1. Communication/information	U.S.	M	M
2. Monitor/control plant	U.S.	M	
3. Monitor/control animals	U.S.	M	
Postharvest (PHT) and biotechnologies:			
1. General PHT	Japan, U. S., W. Germany, France		M
2. Meat PHT	Japan, U. S., W. Germany, France	M +	M +
3. Fruit PHT	France, U. S., Japan, W. Germany	M	M
4. Grain PHT	U. S., W. Germany, Japan, U. K., France	M	M
5. Mutations and genetic engineering	Japan, U. S., U. K., W. Germany	H	H
6. Micro-organisms/tissue culture	Japan, U. S., W. Germany, France	H –	H –
7. Enzymes	Japan, U. S., W. Germany, France	M +	H
8. Biotechnology equipment	Japan, U. S., W. Germany, France	M +	H

NOTE Number of technology fields examined 44 Fields this table 29, Number of fields Where transfer from U.S is at least M + 11

SOURCE Robert E. Evenson, Jonathan Putnam, and Carl Pray, "The Potential for Transfer of U S Agricultural Technology," contract report prepared for the Office of Technology Assessment, 1985.

only 2—plant breeding and rice pesticides—were assigned less than a medium (M) potential for transfer from the United States to other countries, It is important to note, however, that most products associated with conventional plant breeding are not directly transferable, except in the case of soybeans.

OTA contractors rated the potential impact of the transfer of these technologies to U.S. export competitors on a similar scheme, although the results do not appear in tabIe 4-9. Ten of the technology fields shown in the table have at least medium (M) potential to increase productivity in competitor nations. In this respect, crop technologies were the most sensitive: they comprised **8** of the 10 fields with medium (M) or greater potential productivity impacts for U.S. competitors.

CONCLUSIONS

Compared to many other industries—manufacturing, for example—technology transfer in agriculture proceeds at a slow rate, in part because of its varied biological nature, and in part because much agricultural production remains the province of millions of small-scale farmers slow to adopt new technologies, Over the past two to three decades, however, the pace of international transfer of agricultural technology has increased. Developing countries have improved their capabilities in conventional agricultural science; at the same time, developed countries, such as West Germany, France, and Japan, have established sophisticated, competitive agricultural input industries. Substantial public investments have been made in agricultural research and extension activities. It is not surprising that the United States, a leader in most aspects of agricultural technology, occupies a central role in technology transfer through direct trade, scientific research and training, and agricultural development programs.

Between now and the end of the century, the rest of the world—including export competitors—will match the United States in many aspects of agricultural technology and development, and will absorb a wide range of innovations and knowledge more easily and rapidly. It is unlikely that the United States will lose its preeminence in all aspects of agricultural science and technology, or even in most. Still, many emerging agricultural technologies in the United States appear to be transferable to other countries via private companies and public agencies, including important biotechnologies that may provide the next spurt in productivity for plant and animal agriculture. As a result, U.S. farmers may not enjoy the fruits of early adoption of new technology for as long as they have in the past; their absolute advantage in the production of many agricultural goods, which is rooted in technology, could diminish over the next *10* years, depending on how much emphasis the United States places on agricultural research.