Agricultural Technology—The Potential Socio-Economic Impact

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This paper first briefly describes past and prospective developments in agricultural technology, then forecasts changes in agricultural productivity and structure from emerging technology. Much of the paper addresses the socio-economic implications of changes in agricultural technology.

Technology, defined as the means used to convert resources into things needed or desired, has profoundly altered agriculture and society over time. It has done so in three past revolutions. A fourth revolution is beginning.

Past Technological Revolutions

The first technological revolution featured the wheel and simple hand tools such as the hoe, sickle, and knife. Together with irrigation and domestication of plants and animals, it changed society from nomadic stone-age hunters and gatherers to tillers of the soil who accumulated learning and built institutions to serve their needs. The first revolution lasted for thousands of years and was still underway when the first white settlers came to America.

The second revolution in agricultural technology began with the industrial revolution in Britain during the late 18th century and in the United States about 1850. It featured cheap steel, railroads, the steam engine, steel plow, reaper, and a host of other animal-drawn implements. It made possible the extensive buy-sell activities and specialization of commercial agriculture, hence set in motion the urbanization process and with it the alienation of farmers who found the business cycle and other economic forces on which their economic fortunes rested to be inscrutible.

The third revolution was mechanical (e.g. the tractor), chemical (e.g. commercial fertilizers and pesticides), and biological (e.g. hybrid corn). It began about 1920 but was delayed by the Great Depression and World War II and is drawing to a close. Notable features included electrification, universal education, and application of science through research. Better medicines improved performance of animals and eliminated perennial killers of humans such as small pox. Transportation and communication were revolutionized. Application of science and industry to agriculture resulted in massive substitution of capital for labor. Millions of persons left farms. The demand for farm output in 1986 was met with essentially the same real volume of production inputs as was used in 1920!

Past revolutions teach four lessons perhaps applicable to future revolutions:

(1) The pace of technological change is accelerating although some subsequent projections for the emerging fourth revolution give little evidence thereof;

(2) The revolutions are occurring more frequently. A fifth revolution associated with nuclear fusion power may begin before the fourth revolution discussed below reaches full momentum;

(3) Modern revolutions originate from increasingly sophisticated science and are most successful with close cooperation between public basic research and private applied research and development; and

(4) The origins and control of technological revolutions increasingly originate outside of agriculture although they massively influence agriculture.

Emerging Technologies—The Fourth Revolution

The fourth revolution is in incipient stages. Its central features are the new biotechnology and the new electronics, the latter especially apparent in computers, fiber optics, lasers, and telecommunications. Like previous technologies, the fourth revolution has great capacity for both good and evil and ultimately will transform agriculture, America, and the world.

The New Biotechnology

The new biotechnology differs fundamentally from the old in engineering gene structure in laboratories rather than breeding only from the gene pool within a species. The field includes but is not limited to recombinant DNA and gene transfer, tissue culture, embryo transplants, and cloning.

Traditionally, the public intervened in markets to support basic research because marginal social benefits exceeded private (firms') benefits of basic and some applied science. Private firms could not recoup their investments in technology. Another reason why the public supported research is because technology developed therefrom is like construction and use of a bridge. Development costs of technology or a bridge are sunk costs; restricting use by

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charging to cover sunk costs when there is no current cost of another person or firm using the technology or bridge reduces the net social value of the investment.

Armed with new legal instruments, private firms now have major incentives to invest in agricultural biotechnology because they can appropriate revenue to recoup their investment (Buttel, p. 6). The Plant Variety Protection Act of 1970 extended patent-like protection to crop varieties. A 1980 U.S. Supreme Court decision established the legality of obtaining patents for novel life forms. While increasing incentives, patent protection will restrict use to paying customers of some technologies that would have been made more widely available if developed by public research.

Private firms undoubtedly will emphasize development of hybrid seeds and other technologies which cannot easily be reproduced by farmers. Thus the thrust of the new biotechnology will be more along the lines of past hybrid seed corn research than of wheat research. In the case of hybrid seed corn, land-grant universities have provided basic research and inbred lines. Private firms combined inbred lines to produce hybrids not reproducible by producers. This contrasts with wheat where land-grant universities provided both basic research and open varieties reproduced by farmers. Publicly supported research in the new biotechnology may develop open varieties reproducible by farmers in competition with hybrid lines.

Biotechnology research can emphasize different goals. It can develop input-saving technologies such as nitrogen fixation capability in grains. Or it can develop the more capital-intensive technologies such as vaccines and growth stimulants. It can develop beneficial plant varieties resistant to pesticides (herbicides and insecticides) so that more chemicals can be applied to kill pests. This would enhance sales of fertilizer and pesticides. Or it can develop plant varieties which resist pests and diseases; hence, would reduce the need for chemical pesticides. It can slant research towards capital-intensifying as opposed to cost-saving technologies.

Evidence to date indicates that grains developed for nitrogen-fixing capability will yield less than today's varieties. By saving nitrogen fertilizer, however, such plants might provide greater profit than conventional varieties. Widespread adoption could increase demand for land, raise land prices, raise erosion rates, and only modestly influence grain output. This pattern would be an exception to the more general tendency for the new biotechnology to increase output and to reduce the demand for land.

Whatever the research emphasis, biotechnologies are likely to move agriculture further in the direction it has gone in the past—towards more purchased, technologically-improved capital inputs. The result will be continued pressures for a lower ratio of prices received to prices paid by farmers, for continued adjustment of labor out of agriculture, and for fewer and larger commercial farms.

Biotechnology with its massive potential to restructure agriculture raises basic questions about the conflicts between research for people versus profit. When scientific results are treated as proprietary information, the result is to interrupt the free flow of information that is essential to successful basic research and development. A shortage of public support for science coupled with potentially high economic payoff from basic research encourages closer ties between academia and industry. With private firms increasingly "buying into" basic research in universities, the public will ask whether it is paying for research twice: once for university faculty and apparatus developing new products and again when private firms sell the products for economic gain. If private firms perform most of the applied research and development and if the public sector mainly provides basic research used by private firms to make a profit on applied technology, the public may increasingly question the role of public universities in agricultural research. This will be especially true for state funding which now overshadows federal funding for agricultural experiment stations. The result could be economic inefficiency due to underfunding of basic research with a high economic payoff to society.

This conclusion does not necessarily mean that technological change and productivity gains in agriculture will be slowed by greater patent protection and profit incentives in biotechnology. Incentives and funds provided private firms by ability to appropriate benefits may compensate for any loss of public funding for basic research. At any rate, high-payoff investments in research and knowledge have been the key to economic progress in the U.S. because another key to progress, a high savings rate, has been lacking. Both the public and private sectors must invest in development of technology to maintain satisfactory economic progress.

Although biotechnology may revolutionize the structure of agriculture, the form and substance of the output from such research is too dimly known at this time to provide hard and fast conclusions. The following are educated guesses.

Economies of Size and Farm Structure. Most biotechnogies are unlikely to be lumpy inputs which require farmers to make huge durable capital investments that must be spread over a large output to achieve low cost per unit of outputs. Biotechnologies are likely to be more scale neutral than many mechanical innovations. Bovine growth hormone, for example, can be used with profit on dairy herds of 20 cows or 200 cows. But because resources and output are now unevenly distributed among farms and because larger operations frequently are early adopters, the initial tendency of biotechnology will be to reinforce existing inequality among farms by size and managerial capability. Many biotechnologies will require more sophisticated management and higher cost per acre or animal unit than do current technologies. But new technologies will tend to reduce the cost per unit of output.

Size is an advantage in forward contracting which is likely to be widely practical in the future to reduce the risk under improved technology. Some biotechnologies will reduce risks arising from weather, disease, and pests. Risk has restrained growth of large farms. A reduction in uncertainty tends to benefit large farmers more than small farmers. Large operators will be freer to concentrate on organizing asset portfolios, marketing, and other forms of organizational management in which they have a comparative advantage over smaller-size operating units. Biotechnology on the whole is likely to further concentrate production on fewer, larger commercial farms.

The new biology will develop innovative food technology and food uses. This will mean more uses and potentially higher demand elasticities for farm products. Higher demand elasticities growing out of more diversified domestic uses of farm output and greater export markets will help producers to retain some economic benefits. Early adopters among farm operators will obtain net economic benefits from the new biotechnology. Some economic benefits of the new biotechnology will be retained by agribusiness firms, land owners, and innovative operators. But as in the past, the major beneficiaries of biotechnology will be consumers.

The initial impact of biotechnology will be largely to improve on conventional plants and animals. This technology is unlikely to change the basic organizational configuration of the farming industry. But an entirely different outcome could occur with a major breakthrough in development of single-cell protein processable into palatable foods at low cost. Such technology would turn "farming" into an industrial system where large factories turn petroleum and other feedstocks into processed foods. If feedstocks are made feasible from cellulose fiber such as wood through new biological technologies that break down cellulose into low-cost food ingredients, the outcome also could be a major restructuring of agriculture. Conventional agriculture would wither away. These outcomes are unlikely in the near future, however, because food and feed from petroleum or cellulose feedstocks cannot compete in cost or palatability with farm-produced food ingredients.

Available evidence to date indicates that biotechnology will have a "systems" impact. That is, biotechnologies will influence not only plant genetic composition but also the pesticide, fertilizer, and machinery input industries and food processing industries. Advantages will accrue to large corporate (perhaps multinational) conglomerates which have the resources and diversified industry structure most conducive to a systems approach to production and marketing. This is one reason why several seed companies have been purchased by multinational chemical firms with large capital resources to sustain a major research effort in biotechnology. Small, venture capital firms possessing a core of top scientists from universities will also play a key, innovative role in the new biotechnology, but the few existing firms are being acquired by large, diversified corporations.[1]

International Comparative Advantage. A distinguishing characteristic of higher generation technologies is the way they have developed. The first generation of hand tools emerged largely by chance from individual tinkerers; the second generation of machines required a little more organization in firms. The third generation of chemical, biological, and mechanical technologies required more sophisticated and organized science and industry but no more than could be handled by a single major firm or university. A distinguishing feature of the fourth revolution is that it is international in scope. Major pools of scientific talent now exist not only in developed countries but also in India, China, and other developing countries. But the developed countries have a special advantage in that they possess the financial resources to assemble the critical mass of the most talented scientists from throughout the world for making major breakthroughs. Of course, enough talent will remain in major developing countries to ensure that technology developed elsewhere will trickle down to them. Adaptation of technology developed elsewhere will remain a serious problem in subsaharan Africa, however.

Biotechnology offers promise of developing disease, pest, drought, cold, and salt-resistant varieties of special benefit to developing countries where chemicals such as fertilizers and pesticides are unprofitable. It will be especially helpful to develop open seed varieties and other low-cost biological inputs requiring minimal cash outlays for producers in developing countries. The public sector will play a key role in such research. The above considerations offer promise for reprieve from the dearth of attractive technologies needed for major food output advances in many third world countries, especially in Africa.

The result can be less world hunger and poverty. The break-throughs are likely to originate and be used first in developed countries. Disparities in income between developed and less developed countries will remain and might widen, because developing countries will be late adopters. But all nations can improve growth trajectories

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[1] *Vertical integration is apparent in biotechnology; conglomerate firms with direct agricultural applications are purchasing biotechnology firms frequently located in university communities and with ties to university scientists. In 1984, Lubrizol Corporation, an Ohio-based conglomerate one specialized in oil additives, purchased Agrigenetics Corporation, a Boulder, Colorado firm specializing in biotechnology to improve crops. Five years earlier, Lubrizol purchased a 25 percent share in Genetech, another biotechnology firm. In 1982 Lubrizol purchased a 28 percent equity in Sungene Technology, a Palo Alto, California biotechnology firm developing new sunflower varieties for oil; it also purchased Sigco Research, which specialized in hybrid sunflowers and Lynnville Seed Company which developed proprietary soybean seeds. Since 1975 and before being acquired by Lubrizol, Agrigenetics had purchased a dozen seed companies and was the seventh-largest producer of seed including hybrid corn.*

J. G. Boswell, the largest U.S. corporate farm, purchased Phytogen, a company researching alfalfa, cotton, and sunflower seed. W. R. Grace and Company, an agribusiness conglomerate, took a controlling interest in Cetus Corporation of Madison, Wisconsin, a biotechnology firm.

and have higher incomes and better diets through payoffs from investments in science and technology.

It is possible that the new biotechnology ultimately will allow most nations to make good on their quest for food self-sufficiency but that outcome and its implications for U.S. exports are too far in the future to anticipate with useful precision.

Aggregated Input Volume. Biotechnologies will reduce *aggregate* input costs and volume. They will displace conventional farm land and labor. By reducing cost of production, biotechnologies will help keep U.S. agriculture competitive in world markets. They also may expand demand through new products. They are likely to increase supply more than demand, hence aggregate resource demand and real prices of food will fall.

Soil Conservation and Environment. Although nitrogen-fixing capabilities in grains may increase demand for land, on the whole biotechnologies are likely to reduce the demand for land as improved capital inputs substitute for land. Also, biotechnologies will interact with mechanical and chemical technologies to make integrated pest management and conservation tillage practices more effective and profitable. On the whole, biotechnologies are likely to facilitate soil conservation and allow acres now in crops to be in grass and trees. Many acres will be converted to recreational, forest, and urban uses. To the extent that biotechnologies will reduce dependence on pesticides and fertilizers, such technologies will be more compatible than current technologies with an environmentally sound agriculture.

Local Impacts of Biotechnology. Much of the best biotechnology research is being done by universities for applications to humans. Knowledge from this research often will be transferred to farm animals. Early breakthroughs in biotechnology (in the form of new and improved vaccines, medicines, and growth hormones) initially will most influence livestock operations, but crop farms will not be far behind. Impacts will differ among types of farms and regions. Development of salt-tolerant varieties would have a major impact in coastal and irrigated areas whereas nitrogen fixing capabilities in grains could have the greatest impact in the Cornbelt and Great Plains. Drought resistant varieties would most impact the Great Plains and Mountain States. Pest resistance would especially benefit humid regions of the South. Cold-tolerant plants would most influence the North. But changes in any one region will be felt by other regions as product prices change.

Computer and Telecommunication Technologies

The "high technology" of computers and telecommunications for business applications are especially well suited for large farms (Tweeten, 1985). A personal computer with necessary software costs less than half as much as an automobile, hence is well within the means of the vast majority of farm families. But the continuing cost for cable, satellite, or telephone hookups to teletext information systems and for software to manage and operate systems is by no means inconsequential. The cost of time to first learn and then continue to make best use of the computer also is not minor. A higher proportion of large farms than of small farms will use microcomputers and telecommunication technology and use such technology more intensively in managing and marketing operations.

Computer and telecommunication technology for the most part does not increase farm output directly. It is an intermediate input, providing information which interacts with other inputs to increase efficiency by using less aggregate input or producing more output. A broader information base will help farmers secure inputs at lower cost and sell output at a higher price per unit. The larger a farm and hence the more input and output to influence, the more high technology potentially can contribute to efficiency. Large farms have an advantage in being able to afford hired, specialized skills and spread the costs and benefits over many units of output. Their chances are greater than chances on smaller farms to use microcomputers profitably.

Many part-time small farms and full-time family farms will be unable to spare family labor time or afford to hire extra labor to operate computers. Some part-time farm operators with considerable off-farm income will have discretionary income to purchase microcomputers, will have been exposed to computers in off-farm work, and will have the multiple-use potential to justify a purchase. Thus large and small (part-time) farms have some advantages over mid-size farms in adopting high technology.

Family-size farms have been efficient because the owner-operator has had a stake in the business. The result has been high levels of *operational management* apparent in getting the crop planted and harvested on time, being on hand when sows farrow at midnight, and the like. *Organizational management* (acquiring assets, managing investment portfolios, risk management, choosing enterprises based on careful forecasts, etc.,) requires sophisticated information systems, special expertise, and adequate scale for greatest success. In modern agriculture, organizational management is becoming important relative to operational management. The microcomputer and modern telecommunications can help the family farm whose traditional strength is operational management to compete efficiently with large industrial type farms able to purchase or hire organizational management. Other things equal, however, the farms able to apply high technology at low cost per unit will have the advantage. But the computer is likely to have much less impact on farm size and numbers than the tractor.

The advantage of microcomputers and telecommunications to large farms is unlikely to be decisive. High technology will not save poor managers and profligate spenders from financial ruin. Personal performance especially apparent in capacity of operators and their families to mentally process information and reach sound decisions along with dedication, initiative, and luck will far outweigh computer technology in determining success or failure of a farm whether large or small.

TABLE 1. Most Likely Projection of Total Number of U.S. Farms in Year 2000, by Sales Class.

Sales Class	Sales per farm	1982 % of all sales	1982 Number of farms (thousands)	1982 Percent of all farms	2000 Number of farms (thousands)	2000 Percent of all farms
Small and part-time	<$99,999	27.3	1,936.9	86.0	1,000.2	80.0
Moderate	$100,000-199,999	19.2	180.7	10.0	75.0	6.0
Large and very large	$200,000+	53.5	121.7	4.0	175.0	14.0
TOTAL		100.0	2,239.3	100.0	1,250.2	100.0

SOURCE: OTA, pp. 16, 17

Economic Trends

Economic implications of changing technology are apparent in projections in Table 1 and later tables. Table 1 from the Office of Technology Assessment (OTA) projects farm numbers will drop to 1.25 million in year 2000, an annual average rate of loss of 2.19 percent from 1982. The estimate runs counter to alternative estimates such as from Lin, Coffman, and Penn who project 1.75 million farms in year 2000, a drop of only 1.89 percent per year from 1974 and of 1.76 percent per year from 1990 to year 2000. In the face of harsh economic conditions, farm numbers fell only 1.88 percent annually from 1981 to 1986. It is difficult to believe that economic conditions will be so unfavorable (because of less generous commodity programs, technological advances, and other factors expanding supply relative to demand) that the pace of farm outmigration will quicken in the 1986-2000 period.

The OTA study projects a drop by 3.6 percent per year or a near halving of small and part-time farm numbers from 1982 to 2000. Tweeten (1984, p. 11) noted the near demise of full-time small farms, leaving small farm numbers to be dominated by growing numbers of part-time farmers. Hence the decline in small and part-time farms projected by OTA seems unduly large. I (1984, pp. 25, 26) projected that *commercial* farms will increase in size and decrease in numbers by approximately 2 percent per year in the 1980s and 1990s but projected little if any decline among small farms. The number of large farms will increase. In short, I anticipate a considerably larger number of farms by year 2000 than projected by OTA and or by a simple extension of growth rate trends of the 1950s and 1960s. Small farm numbers will be highly sensitive to changes in the definition of farms, however.

Yields

Table 2 shows for major crops past and projected yields, the latter from OTA for the 1982-2000 period. Given substantial current publicity pointing to accelerating productivity with the new biology, it is notable that the OTA projections depict a sharply slower yield growth rate for 1982-2000 than the actual rate of increase in yield per *harvested* acre for 1950-85. An exception is soybeans for which past and projected rates were comparable. It seems plausible that the major impact of the new biotechnology will not be felt by grains until after year 2000, but the pace of yield increments anticipated by OTA in Table 2 seems to be unduly low. Johnson and Wittwer (p. 46) project crop yield increases averaging only 1.07 percent annually from 1980 to 2030, an unduly low estimate.

Table 2. — Crop Yields and Yield Increases per Harvested Acre, 1950-1985

Crop	Actual 1950	1960	1970	1980	1985	1950-85	Projected (OTA) 2000
Corn — bu./A.	38.2	54.7	72.4	91.0	118.0		139
% annual increase		3.66	2.84	2.31	5.33	3.27	1.2[a]
Upland Cotton — lb./A.	269	446	439	402	628		554
% annual increase		5.19	-.16	-.88	9.33	2.45	.7[a]
Soybeans — bu./A.	21.7	23.5	26.7	26.5	34.1		37
% annual increase		.80	1.28	-.08	5.17	1.30	1.2[a]
Wheat — bu./A.	16.5	26.1	31.0	33.5	37.5		45
% annual increase		4.69	1.75	.78	2.28	2.37	1.3[a]

SOURCE: OTA and other sources.

[a] Projected rate of increase, 1982-2000.

OTA also projected productivity growth for livestock from 1982 to 2000 (Table 3). Measured by output per unit of feed or per animal unit, livestock productivity was projected to expand slowly—even more slowly than for crops. A notable exception to these trends was dairy (see also Kalter). Pounds of milk per pound of feed was projected to increase only .2 percent annually for the 1982-2000 period but milk per cow was projected to increase an average of 3.9 percent annually! Bovine growth hormone and other products of biotechnology were projected to double milk per cow. Given the slow increase in milk demand, cow numbers were expected to fall sharply. Except for dairy, the foregoing OTA projections, while probably overestimating reduction in farm numbers and underestimating yield gains, hardly point to a high-technology revolution before year 2000. Johnson and Wittwer not only seem pessimistic about yield gains but indicate "that within 50 years the United States may have to farm an additional 50 million to 60 million

Table 3. — Impact of Emerging Technology on Animal Production Efficiency in Year 2000

Enterprise	Actual 1982	Most likely 2000	Annual growth rate (percent)
Beef:			
Pounds meat per pound feed	0.07	0.072	0.2
Calves per cow	0.88	1.000	0.7
Dairy:			
Pounds milk per pound feed	0.99	1.03	0.2
Milk per cow per year (1,000 lb.)	12.30	24.70	3.9[a]
Poultry:			
Pounds meat per pound feed	0.40	0.57	2.0
Eggs per layer per year	243.00	275.00	0.7
Swine:			
Pounds meat per pound feed	0.157	0.176	0.6
Pigs per sow per year	14.400	17.400	1.1

SOURCE: OTA, p. 18.

[a]Annual growth rate 1980-85 = 1.8%
1964-85 = 2.3%

acres..." (p. 42).

The yield projections from OTA and from Johnson and Wittwer raise the serious issue of whether yields are plateauing, that is, increasing at a decreasing rate. Figures 1 to 4 help to resolve that issue. Many functional forms of regression equations were tried but the best fit to annual U.S. data for 1950-85 was achieved with the double logarithm form.[2]

The most notable conclusion from Figures 1 to 4 is that yield per planted acre of major crops and overall farm productivity increased in nearly a straight line from 1950 to 1985. In every case the *rate* of increase slowed but the annual absolute increments grew except for soybeans as apparent from the regression results below.

	Annual rate of increase (%)		Absolute annual increase	
	1950	1985	1950	1985
Corn (bu./A.)	4.30	2.53	1.40	2.57
Soybeans (bu./A.)	1.99	1.17	.36	.36
Wheat (bu./A.)	3.04	1.79	.46	.61
Total Productivity (1977 = 100)	2.41	1.42	1.45	1.62

In all cases except wheat, yield variability was larger in recent years than in earlier years. The graphs provide no evidence that excess capacity and financial stress in the 1980s are the result of a sudden surge of productivity apparent in higher crop yields (Figures 1-3) or overall output-input ratios (Figure 4).

[2]*In yield per planted acre = ln a + b ln T where time trend T was the last two digits of the current year. Several other origins for T were used but with less favorable results. The natural logarithm is designated ln.*

FIGURE 1. Actual and Predicted Yield per Planted Acre of Corn, U.S.

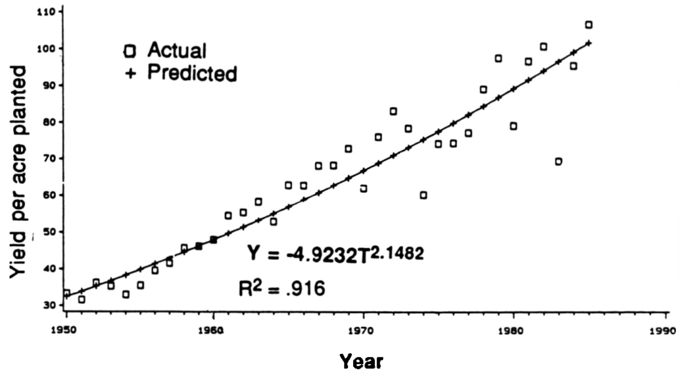

FIGURE 2. Actual and Predicted Yield per Planted Acre of Soybeans, U.S.

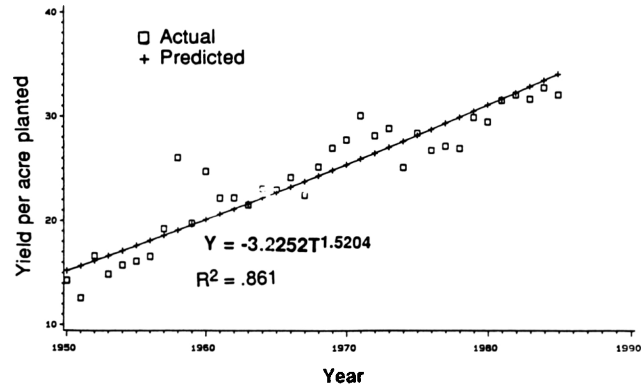

FIGURE 3. Actual and Predicted Yield per Planted Acre of Wheat, U.S.

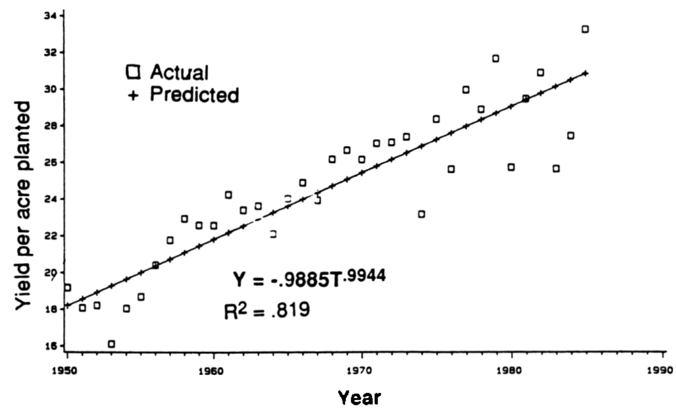

FIGURE 4. Actual and Predicted Productivity Index (Output per Unit of All Production inputs) for U.S. Agriculture.

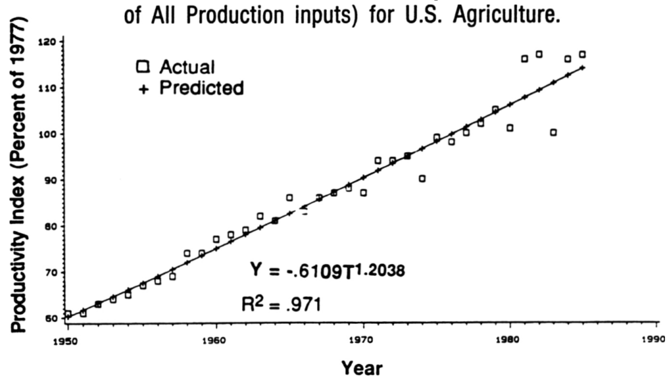

Table 4. Economic Outcomes for Farming Industry Under Different Growth Rates of POPR and Alternative Yearly Demand Shifts, 1982-2025

Year and POPR[a] Growth	Variable[a] PR	Qs	GFR	NFI	POPR	MP	VMP	IRR
	1910-14= 100	Bil. 1982 $	$ Bil.	$ Bil.	$ Bil.	1982 $	$	%
Actual								
1982	60.67	142.40	142.40	24.57	1.74	10.19	10.19	45.43
Projected: Annual Shift in Demand = 1.5%								
3%								
1995	58.12	186.95	179.10	25.01	2.60	5.55	5.31	25.51
2010	55.65	245.09	224.82	22.62	3.99	4.35	3.99	19.83
2025	53.20	320.86	281.40	16.50	6.21	3.60	3.15	15.66
5%								
1995	57.73	187.83	178.73	23.91	3.35	4.88	4.64	21.73
2010	54.63	249.05	224.27	18.80	6.96	2.88	2.59	12.02
2025	51.50	330.51	280.59	7.68	14.48	1.80	1.52	4.88
7%								
1995	57.35	188.69	178.37	22.84	4.36	4.33	4.09	18.66
2010	53.65	252.99	223.74	14.50	12.04	1.93	1.71	6.10
2025	49.88	340.25	279.75	1.20	33.21	0.93	0.75	-2.88
Projected: Annual Shift in Demand = 2.0%								
3%								
1995	60.51	190.40	189.90	32.96	2.59	6.29	6.27	29.22
2010	60.20	258.67	256.70	43.26	3.99	5.22	5.18	24.98
2025	59.70	351.53	346.29	56.02	6.12	4.48	4.41	21.73
5%								
1995	60.10	191.28	189.51	31.83	3.35	5.52	5.47	24.91
2010	59.10	262.85	256.07	39.18	6.96	3.43	3.34	15.98
2025	57.85	362.09	345.26	46.25	14.48	2.22	2.11	9.16
7%								
1995	59.71	193.03	189.13	30.22	4.36	4.88	4.80	21.43
2010	58.04	267.01	250.43	35.12	12.04	2.29	2.19	9.31
2025	56.03	372.76	344.26	36.43	33.21	1.13	1.04	0.44

SOURCE: Braha and Tweeten

[a]See text for variable definitions.

[3]*Estimates shown in Table 4 are not discounted.*

In short, past yield trends give evidence of weak form plateauing as rates of increase are slowing but not of strong form plateauing. The results suggest that a technological revolution brings higher rates of productivity growth than prior revolutions but the growth rate slows as a revolution matures. The U.S. is between revolutions, a difficult time for prediction, and of interest is whether the next decades will be characterized by diminishing productivity rates of the third revolution or by accelerating rates of the inchoate fourth revolution.

Alternative Projections

Tables 4 and 5 show more recent projections to 2025 under alternative investment rates in a high-technology environment. Variables are defined and briefly discussed below.

POPR: Production-oriented agricultural research and extension outlays, alternatively assumed to grow at rates of 3, 5, and 7 percent per year.

PR: Ratio of index of prices received to prices paid by farmers. The ratio falls in most scenarios but increases slightly if demand for farm output grows 2.0 percent per year and POPR grows 3 percent per year.

Qs: Quantity supplied of farm output. Growth of the variable depends on prices and productivity.

Table 5. Annual Growth Rates of Qs, GFR, NFI, and PIND Under Alternative Growth Rates in POPR Outlays for the Period 1982-2025

Annual Growth in POPR	Variable[a] PR	Qs	GFR	NFI	PIND
	Percent per year				
Shift in Demand = 1.5 percent					
3%	-0.30	1.86	1.56	-0.90	1.99
5%	-0.37	1.93	1.55	-2.61	2.12
7%	-0.44	1.99	1.55	-9.00	2.24
Shift in Demand = 2.0 percent					
3%	0.03	2.07	2.04	1.89	1.99
5%	-0.12	2.14	2.03	1.50	2.12
7%	-0.18	2.21	2.03	0.90	2.24

SOURCE: Braha and Tweeten

[a]See text for variables.

GFR: Gross farm income. Gross farm income is not influenced much by POPR because lower prices offset output growth with more rapid rates of increase in POPR.

NFI: Net farm income. Like other variables, NFI is in real terms and is maintained reasonably well beyond year 2000 if POPR increases 3 percent per year and demand increases 1.5 percent per year. High rates of increase in demand allow a much larger increase in POPR without reducing net farm income.

MP: Marginal product of POPR; the additional dollars of real farm output from $1 invested in agricultural research and extension.

VMP: Value of marginal product of POPR; the MP multiplied by product price. VMP is larger than MP when real product price increases after 1982.

IRR: Internal rate of return; the highest interest rate that could be paid on POPR outlays and just break even on the investment. IRR is 45 percent in 1982 and remains well above returns on alternative investments unless high rates of increase in POPR are associated with a low rate of increase in demand.

PIND: U.S. Department of Agriculture's index of productivity; aggregate output of crops and livestock per unit of production input, 1977 = 100.

In conclusion, farm economic conditions are highly sensitive to trends in demand and supply. If demand grows only 1.5 percent per year, a 3 percent annual growth in POPR is consistent with maintaining farm earnings to year 2000. If demand grows faster than 1.5 percent per year as seems likely, faster rates of growth in POPR are desirable to obtain productivity gains which benefit consumers and others.

Other Issues Raised by Emerging Technology

Does It Pay to Publicly Finance High Technology While Paying Farmers Not to Produce?

Despite some exceptions, on the whole third generation technological change has been a resounding success measured in purely economic terms. Recent estimates indicate an economic benefit-cost ratio of 5.0, i.e. each $1 billion invested in production-oriented agricultural research and extension (POPR) ultimately returned $5 billion in additional real output discounted to the present at a 10 percent rate (Braha and Tweeten).[3] Thus the approximately $2 billion of public funds spent annually on POPR return $10 billion. Net economic benefits discounted at 10 percent are estimated to be $7 billion in the short run and $8 billion in the long run. The investment is also equitable—low income consumers derive large benefits relative to costs because they spend a high proportion of their income for food and fiber. Farm commodity programs costing $15 billion (mostly transfer payments to remove 7 percent excess capacity to produce) cost $5 billion in foregone *real* goods and services annually in the short run and $1 billion in the long run. The net benefit of investing in POPR while simultaneously controlling production is $7 billion -$5 billion = $2 billion in the short run and $8 billion -$1 billion = $7 billion in the long run based on 1985 conditions. The long run impact of supply controls is less because producers learn to circumvent supply controls.

The *social* benefit-cost ratio which includes psychic and other intangible costs and benefits is far more difficult to appraise. It has been a matter of major disagreement among social scientists. A principal target has been mechanization technology, which more than any other is responsible for displacement of millions of farm people and the demise of hundreds of thousands of family farms. Fourth generation technologies will have less impact than those of the last half century in part because they will displace less labor and partly because small farms are increasingly dominated by part-time farmers. The latter farmers are resilient in the face of low farm returns and they are more influenced by what happens in the nonfarm sector than by farming technology. Compared to past decades, relatively few mid-sized family farmers remain to be displaced—the group most vulnerable to being displaced. Even if they all left agriculture (and they will not), numbers leaving would be a small fraction of the exodus in the past half century.

A key issue is that purely economic measures do not record the full psychic cost of change. Although few Americans indeed will spend their entire career in their initial occupation and no outcry against typical Americans changing jobs is apparent, the situation is different for farmers. Many established farm families experience unusual trauma when displaced, especially in the time immediately before and after departure. But adjustment pains diminish with time. Large numbers of farm families interviewed some time after moving to urban areas indicated they were better off for having made the transition (Tweeten and Brinkman, pp. 88-92). Only a small percentage went on welfare or became part of the urban social problem of crime, welfare dependency, drugs, and unemployment.

Through public policy, the exodus of family farmers could be stopped but at a considerable cost in terms of higher taxes and/or food and fiber prices. A strong case can be made for greater use of counseling, job training, and moving assistance to reduce the trauma of adjustment. Such efforts have failed in the past because farm groups have not supported them, because the efforts have been small in scope, and because political and administrative management of programs has been inadequate at best.

Several countries have comprehensive programs of job protection, unemployment compensation, and other social legislation to preserve the status quo. The result in major countries of Western Europe is the so-called "British Disease" or "Eurosclerosis" associated with moribund economies. High rigid price supports also have not effectively saved farms from changing technology in the Common Market. The number of farms declined on average by 2.5 percent per year in five countries: Germany (2.7 percent), France (2.1 percent), Netherlands (2.8 percent), United Kingdom (2.8 percent), and Denmark (2.5 percent) from 1960 to 1981. In contrast in the U.S. from 1959 to 1982 the number of farms declined on average by 2.17 percent per year.

The measurable differences in cultural and socio-psychological characteristics between farm and nonfarm people have diminished over time. Still, many Americans wish to preserve the family farm as a special part of their heritage just as they wish to preserve the Liberty Bell. It is not for social scientist as professionals to say whether the family farm should or should not be saved by special public measures in the face of changing technology. But social scientists can be helpful in pointing out costs and benefits of preserving family farms and in noting whether policies work or do not work to preserve such farms.

Gauging social consequences of technology is far more elusive than gauging economic consequences. Progress, which is viewed as desirable by most Americans, requires change which in turn produces winners and losers. Progress means gain and pain—although in most instances benefits are sufficiently great so that gainers can compensate losers and all are better off. The problem is that compensation is difficult or impossible under many circumstances. That is one reason why Americans often express ambivalence about progress.

Some observers see change as desirable (Kohls, pp. 4, 5):

> In the American mind, change is seen as an indisputably good condition. Change is strongly linked to development, improvement, progress, and growth.

[3] *Estimates shown in Table 4 are not discounted.*

...The belief that we can do anything and the belief that any change is good—together with an American belief that each individual has a responsibility to do the best he or she can do have helped Americans achieve some great accomplishments. So whether these beliefs are "true" is really irrelevant; what is important is that Americans have *considered* them to be true and have acted as if they were, thus, in effect, causing them to happen.

Maurice Dingman, Catholic Bishop of Des Moines, speaks for some other Americans when he calls technological change a mistake for rural America (pp. 3, 4):

...In our thinking we have accepted the alleged efficiency of the large farm conglomerate—an efficiency which has never been proven—permitting our policy to drive farm people from the land to the cities. Those who have advanced such claims have never included in their cost accounting the vastly increased expenditures required to meet the needs of these new urban poor. We should include the social and human cost resulting from the needless shift of population from the vacated farm homes to overcrowded cities and suburbs. They should include the ecological damage to soil, water, and food producted by attitudes and practices that treat agriculture as an industrial venture rather than a biological enterprise. Huge social costs have been the inevitable result of bad policy.

The shift from agriculture to agribusiness was ill-conceived and detrimental to the best interest of our country. The laissez-faire approach has allowed the harsh forces of uncontrolled competition to drive less prosperous farmers out of agriculture. The adaptive approach goes so far as to employ the power influence of government and educational institutions, including land-grant universities, to accelerate the migration of farm families from the land. This should not have been permitted. That policy has been immoral, unethical, unjust, disastrous, motivated by greed, destructive, leading inevitably...to conditions similar to Central America.

Social scientists cannot resolve these value conflicts. Some contend that the U.S. cannot remain a leader of the free world economically or morally without technological change to keep the nation at least abreast of the rest of the world. At the same time, the nation could do a better job than in the past with human resource and other investments to cushion adjustments and ease the pain of change. Current policies have not and will not preserve all family farms. If the family farm is truly a prized institution worthy of preserving, then it may be well to explore new means to preserve such farms without large economic costs in the face of technological change.

A Case for Socio-Economic Impact Statements?

Many social scientists and social activists call for mandatory filing of a *socio-economic impact statement* before a firm or agency undertakes research on technology. While a strong case can be made for more research to anticipate socio-economic impacts, the case for a binding legal structure to impede or halt research on technology is weak at best.

The device undoubtedly would be used like the environmental impact statement to stop or delay resource development projects on the basis of procedure rather than merit as measured by costs and benefits. Social scientists have not been skillful at anticipating benefit-cost ratios from new technology. One example is from a seminar in 1966 at the Delhi School of Economics in India to anticipate the consequences from massive introduction of high-yielding green revolution seeds of dwarf wheat and rice varieties. David Hopper (p. 69) reports:

The seminar participants were government bureaucrats, scholars from agricultural and general universities, a sprinkling of foreign advisors and expatriate technical assistants, and a few political leaders, including, when time permitted, India's minister of agriculture.

Within the first few hours of a three-day meeting, the discussion on a call by many participants for government prohibition of further imports of high-yielding seeds and for government efforts to ban the spread to farmers of the genetic stocks of dwarf materials then available on the research stations of the nation. Despite the protests of the few, the meeting carried a clear consensus for prohibiting the entry and use of the new varieties. Fortunately for the nation's hungry masses, the politicians ignored the consensus.

The second example began six years ago with a lawsuit by California Rural Legal Assistance (CRLA) attorneys. With advice and encouragement from some social scientists, attorneys filed suit against the University of California on behalf of farm workers whose jobs might be eliminated by labor-saving machinery under development at the University of California. Although the lawsuit applied only to labor-saving machinery for agriculture, many in the academic community feared that it would set a dangerous precedent for all applied research. CRLA charged that mechanization research displaced farm workers, eliminated small family farms, diminished the quality of rural life, and harmed consumers (Martin and Olmstead, p. 25). Proponents of publicly supported mechanization research claimed that such research reduced costs of food to consumers, kept the United States competitive with less developed countries in production of commodities, eliminated low-skill jobs often characterized by substantial drudgery and backbreaking labor while retaining food production and processing industries in the United States. Proponents contended that millions of Americans were freed by farm mechanization to work off farms to supply goods and services such as recreation, health, and education highly sought by

Americans. They reasoned that a diversified public institution such as the University of California-Davis can perform a unique role in development of technology such as the tomato harvester. A large diversified research institution can employ an integrated systems approach to technology by simultaneously working on mechanization, variety breeding, and socio-economic research which a private firm cannot do at tolerable cost and risk.

The third example is an effort of the Foundation on Economic Trends and the Humane Society to stop the National Institutes of Health (NIH) from financing research involving the transfer of genes from one mammalian species into another (McDonald, pp. 7ff). The two groups also wanted NIH to withhold financial support from any institution conducting such experiments. The two groups filed a lawsuit against the U.S. Department of Agriculture to halt a study to transfer human growth-hormone genes into pigs and sheep, a study conducted by the U.S. Department of Agriculture and the University of Pennsylvania. The Foundation for Economic Trends persuaded a federal judge to stop some types of genetic-engineering research approved by NIH. The University of California appealed an order by a federal judge stopping all experiments involving releases of genetically engineered organisms.

At issue is the role of society in imposing restraints on the new biotechnology research. Restraint is unavoidable and essential: a scientist cannot be free to unleash intentionally or inadvertently a genetically engineered microorganism that would do great harm. On the other hand, excessive restraint could forego benefits of eliminating genetic disorders, slowing the aging processes, curing cancer and other diseases, and ending hunger for millions of people. To prematurely release technology before it is capable of generating more social benefits than costs is a Type I error. To forego benfits by withholding release of technology with favorable social benefit-cost ratio is a Type II error. Clearly, Type I and II errors must be balanced against each other. To contend as many social activists do that bioengineering research should be stopped until the social, moral, and political issues are resolved is to contend that the moratorium on research be as interminate as the debate itself. Research will go on but tough questions must be faced. One molecular biologist, noting that research is necessary to preserve human life, asked "Whose rights are to be defended, the right of a mouse to its genetic heritage or the rights of human beings to health and happiness?" (see MacDonald, p. 8).

Should We Stop the High-Technology Revolution?

The market generally operates effectively in allocating resources to improve well-being to individuals and society if price signals reflect true social costs (benefits) at the margin. There is no reason to expect social costs (benefits) to markedly differ from private costs (benefits) in microcomputer technology, hence no reason to conclude that free choice will not improve quality of life in rural areas and elsewhere. The issue is much more clouded for the new biotechnology. The best guess is that the market will function reasonably well for applied research and technology and less well for basic research on the new biotechnology.

For the most part, people and firms are adopting high technology because they want to. The choice to adopt is narrowed, however because economic survival requires it for many firms. As long as competitors are adopting high technology, a firm must adopt to compete. The high-technology revolution is worldwide, and there is no stopping it—the potential fruits are too attractive.

High technology is improving economic efficiency in rural and urban areas. But to examine only the change in production or communication costs misses an important aspect of high technology: the personal computer is in no small degree a consumption good which people purchase and enjoy much as they would a boat or a sports car. Given a world population growing nearly 2 percent annually, improved technology of food production is essential to reduce the burden of supplying food and avoiding mass starvation in some parts of the developing world in future decades.

Conclusions

Modern biotechnology, computers, and telecommunications will change the structure of agriculture in profound ways in the future. The pace of technological and structural change along with measures to cushion impacts on losers in the process will be influenced by public policy. Social scientists will provide a major input into that public policy. Simply calling for a halt to research on technology until the social, moral, and political issues are resolved will not do. Social scientists will need to do a better job than they have in the past in appraising the prospective benefits and costs of technology before they can be a constructive part of the inevitable debate over the appropriate public role in guiding technological research and consequent induced farm structural change.

Social scientists are hardly monolithic: Economists have evaluated the net economic consequences of past technological changes in agriculture and proclaimed them mostly beneficial; sociologists and anthropologists more frequently have proclaimed that past and prospective technological changes are not beneficial. Further dialogue could help to reconcile these conflicting perceptions.

The foregoing analysis suggests that the fourth generation technology of the new biotechnology and computers will keep farmers on the technological treadmill. On the whole, the treadmill is not expected to speed up from rates of the 1950s through 1980s. Emerging agricultural technology will move agriculture in the same direction as before—toward more sophisticated and challenging management and marketing, toward larger and fewer commercial farms, toward greater capital intensity, and toward greater separation of management from ownership. Society through public policy could stop the treadmill to make farming more a way of life and less a business. But the public is unlikely to stop the adjustments because benefits of technological progress are viewed as too great to pass up. Furthermore, the nation must compete economically and in other ways with countries pushing technological change. To lag is to lose the competitive struggle in more ways than just the economic. But a case can be made for more human resource investment and other measures to cushion adjustment for those left behind or hurt by technological change.

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Abstract

Prospects for the use of embryos in the control of disease and the transport of genotypes

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SUMMARY: Transfer and low temperature storage of embryos are now proven techniques for a number of mammalian species. These techniques are useful in control of disease and in saving genotypes from infected animals. The place of embryos in the epidemiology of disease depends upon whether the causative organism can gain entry to the oocyte before or at fertilisation and on whether the young embryo can be invaded by organisms in the uterine environment. There is little evidence that important live-stock diseases are transmitted via gametes. The zona pellucida surrounding the embryo is an effective barrier against a number of important disease organisms; in some cases the embryo is susceptible once it has hatched from the zona pellucida. It is important therefore in considering the use of embryos in disease control, to ensure that virus is not attached to the surface of the zona pellucida from where it can infect the recipient and/or the embryo after hatching. Washing procedures have been devised together with the use of enzymes and antisera to remove virus from the surface of embryos. Some viruses enter pores and sperm tracks in the zona and removal of these may present a problem. African swine fever virus has been shown to resist removal by treatment with enzymes. There are no guidelines as to the likely interaction between a certain virus and embryos. Therefore each virus of interest must be tested to determine whether it can be transmitted via washed embryos. Nevertheless there are numerous instances of the use of embryo transfer to eradicate a specific disease or to save valuable genetic material from infected animals without transmitting disease.

Embryo transfer and related technology offers a cheap and humane method of transporting genotypes and it is appropriate that research continue into the reactions between embryos of the major mammalian species and the causative agents of the important animal diseases.
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