The Implications of Emerging Technologies for Farm Programs

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ABSTRACT

Technological innovation is important to the growth and development of the U.S. agricultural economy. Resources freed through adoption of new technologies can be put to other productive uses. Technology that promotes efficiencies in U.S. agriculture is important to consumers and to the competitive position of U.S. farmers in international markets. However, the adoption of new technologies can have structural and distributional implications for the farm sector. Commodity programs which create rigidities in resource adjustment may translate rapid technical advance into mounting Government budget costs.

KEYWORDS: Broilers, commodity programs, corn, cotton, dairy, HFCS, soybeans, sweeteners, technological change, wheat.

INTRODUCTION

Adoption of more efficient ways of doing things in agriculture usually proves profitable to the first farmers who try the new ideas. Once enough farmers have adopted a new technique, prices fall and consumers benefit through the opportunity to consume more at lower cost. And, advancing technology helps the Nation's agricultural economy remain competitive in international trade. In the long run, agricultural resources displaced by technical change can be absorbed into more productive uses elsewhere in a growing economy. However, the blessings of new technology are mixed; while some groups may gain from the increase in efficiency, other groups may lose. For example, in the short run, people displaced by machines may have difficulty finding other jobs. The declining demand for resources replaced by new technology can result in lower returns than would have occurred otherwise, but there may be opportunities for those resources to earn greater returns in other uses.

This article examines four emerging agricultural technologies as examples of the kinds of major changes that farmers may see in coming years. A bovine growth hormone promises to increase milk output; a soybean growth regulator is expected to facilitate double cropping of soybeans with wheat, resulting in increased production of both crops; a bacterial control for wheat fungal disease could well increase yield in wheat grown in the Pacific Northwest; and a table sweetener resulting from the crystallization of high fructose corn syrup (HFCS) will likely

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offer a substitute for other sweeteners. Each of these techniques promises to improve the income of the first innovators to successfully adopt them, to increase the supply of food at lower prices to domestic consumers, and to improve the comparative advantage of U.S. agriculture in international trade.

However, each of these techniques also promises to increase the supplies of some major farm commodities and decrease the demands for others. The result could be lower prices and narrower profit margins for producers of some commodities. Those last to adopt the new ideas would be faced with a cost/price squeeze as the economic impacts work through agriculture. After the new ideas are in general use, even the profit advantage of those first adopters could be narrowed, possibly to less than before the new techniques emerged. Therefore, a major concern of this article is the general effects of technical advance on the output, prices, and income of farmers; and on the redistribution of income that tends to accompany an increase in efficiency. One of the findings is that Government programs such as those that have been in place over the past half-century tend to restrain price and resource adjustments, thus modifying both the beneficial and the adverse effects of the technology. Some aspects of Government programs speed up the adoption of technology, as when yield-increasing practices are adopted on reduced acreages; and other aspects slow the adoption, as when labor retained in agriculture reduces incentives to adopt labor-saving machinery. These effects could add to Government stocks of surplus commodities, and to the costs of agricultural price and income support programs. This suggests that it may be all the more imperative to develop alternative means of accomplishing policy objectives with regard to the well-being of landowners, producers, consumers, and taxpayers.

OUTPUT, PRODUCTIVITY, AND TECHNICAL CHANGE IN FARMING

During the past half-century, total agricultural production increased; the pace varied with changes in factors affecting both the demand for and the supply of farm products. During 1910-35, crop production was about constant and growth in livestock production was the result mostly of gains in dairy. There was an important switch to mechanization from power supplied by horses and mules. Two major forces affected the demand for crop products. Export demand fell steadily from the close of World War I to the late thirties. The cropland harvested for export dropped from a high of 62 million acres in 1918 to a low of 8 million in 1940. With mechanization, the acreage producing feed for workstock fell from a high of 93 million acres in 1915 to 56 million acres in 1935 (and to about zero by the midsixties). The cropland harvested per capita for domestic use was about constant during this period. During 1910-35 no significant improvement in yield levels occurred, although considerable yield variability resulted in year-to-year surpluses and shortfalls. The domestic supplies relative to domestic demand and the reduced demand for exports and for feed for workstock resulted in severe downward pressure on prices received by farmers during the twenties and thirties.

During 1935-50, a remarkable growth in agricultural production occurred. Farm programs imparted increased price stability, more credit was used for the purchase of nontraditional inputs, and information delivered by extension workers and salespeople assisted in accelerating the adoption of technical advance. Annual growth rates in production were 2.5 percent for livestock, 3 percent for feed grains, 4 percent for food grains, and 8 percent for oil crops. Livestock production subsequently slowed to about keep pace with growth in the domestic population, but crop production expanded rapidly through the seventies, spurred by burgeoning export markets, particularly for corn, wheat, and soybean products.

The productivity of agricultural resources also varied during the past half-century. During 1935-50, the multifactor productivity growth rate was 1.9 percent per year. During this period, inputs increased and so did outputs. During 1950-65, output continued to grow even as the aggregate level of inputs decreased, partly in response to supply management programs. Consequently, productivity growth accelerated to 2.4 percent per year. Since 1965, the level of inputs increased again, and the growth in productivity slowed to 1.7 percent per year.

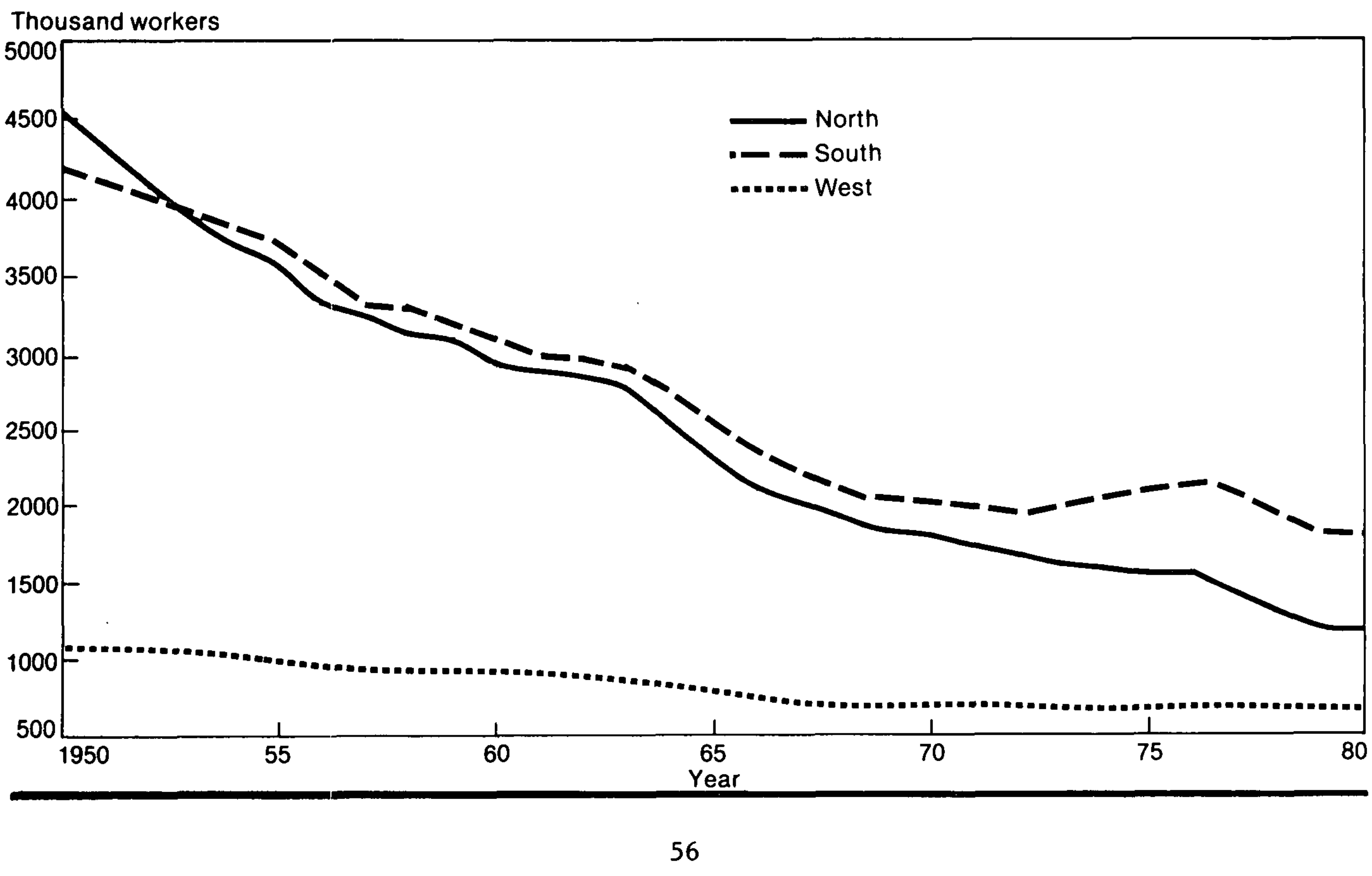
Structural changes in the farm sector have slowed from the rate at which they occurred between the forties and early seventies. General farms have specialized into crop farming and livestock farms, and the commodity mix has shifted to include relatively more crop production. Several important regional shifts in production accompanied this change. Purchased input use followed an uninterrupted 30-year increasing trend. Land removed from production in the sixties returned to production in the seventies and early eighties. Farm labor use has leveled off since 1970 after 25 years of decline (fig. 1). The number of farms and the distribution of farms by size have changed less in the last decade than in the preceding three decades. The population in rural areas increased relative to urban areas during the last decade. As a result, the productivity of land and labor and the multifactor input index have increased less rapidly since 1965 than during 1950 to 1965.

Aggregate Effects on Consumers and Farmers

Growth in the supply of farm products relative to demand reduced the real price of food to the American consumer. Expressed in terms of the minutes of work

Figure 1

Average regional farm employment



required to earn the equivalent take-home pay, the market basket which required 1 hour of work in 1967 and 62 minutes in 1984, required more than 2 hours of work to purchase in 1929. As an example, the purchase of a dozen eggs required only one-third of the wage time in 1984 that it had in 1950 (table 1).

Technological change in agriculture has been embodied in inputs which farmers have purchased from other farmers and manufacturing industries to replace or augment their own limited time and land. As a result, the expenses for nonfarm, intermediate inputs increased from 38 cents per dollar of gross receipts from farming in 1940 and 1950 to 52 cents in 1982. When the landlord, hired worker, tax collector, and banker are paid off, the margin per dollar of receipts remaining for operator living (and land investment) is considerably less than it was a third of a century ago. But, the picture for farm operators is actually more positive than it might seem--the value of farm sales per farm operator has increased. Gross receipts per farm increased from $12,734 (in 1982 dollars) in 1940 to $67,564 in 1982.

The obverse side of increasing productivity is reduced input requirements per unit of output. Agricultural labor is a case in point. Mechanization reduced the number of workers required for a given level of crop production. As technology relieved the limiting labor resource, the retirement of older farmers and migration of younger farm people to nonfarm areas released the other resources (such as land and machinery) necessary for farmers and innovators to expand and intensify their operations. Between 1950 and 1969, farm numbers and farm employment were halved and hours worked decreased 55 percent, with the South and Northwest experiencing a greater portion of the labor adjustment than the rest of the country (fig. 1). Since that time, the labor exodus has slowed considerably outside the South. The effects of technological change were, until the midseventies, reduced farm employment and farm numbers, and increased farm size 1/.

1/ Kislev and Peterson (11) suggest that attractive off-farm employment opportunities were as important as farm technological change in explaining the total decline in farm employment.

Table 1--The price of selected food items in minutes of work 1/

Item	Unit	1930	1950	1970	1980	1984
				Minutes		
Round steak	1 lb.	48.4	43.8	28.8	29.4	24.3
Potatoes	10 lb.	40.9	23.3	20.7	22.1	20.2
Bacon	1 lb.	48.3	29.8	21.0	15.5	15.5
Eggs	1 doz.	50.6	28.3	13.6	8.9	8.6
Bread	1 lb.	9.8	6.7	5.4	5.4	4.5
Butter	1 lb.	52.7	34.1	19.2	20.0	17.6
Milk	1 qt.	16.0	9.6	7.3	5.6	4.7
Coffee	1 lb.	44.9	37.2	20.2	33.3	21.6
Sugar	5 lb.	34.7	22.7	14.4	22.8	15.2
All the above	Total	346.3	235.5	150.6	163.0	132.2

1/ Price of food item relative to manufacturing wage rate after taxes and employee Social Security contributions.

A Synthesis of Effects

Technical change relieves the production constraints imposed by critical resources. The marginal cost of producing the original output is reduced. This permits early adopters to expand output and farm size. The added output puts downward pressure on product prices if demand is not expanding commensurately. This puts noninnovating firms at a disadvantage, increasing the likelihood that they will go out of business. The new technologies frequently require increased purchases of nontraditional inputs, which increases the market exposure of the adopting firms. The credit arrangements to finance the change become an important consideration. They leverage the firm by increasing the fixed cash payments to be made from the variable income stream. If net revenue is not increased enough to offset the higher risks, the new technology may turn out to be a bad investment for the producer. With the declining prices caused by increased product supplies, even technological innovators generally derive no lasting benefits from the technology because their initial profits subsequently fall as the technology spreads. Consumers, however, benefit from the lower prices. Cochrane (6, p. 66) identified this process as part of the "treadmill of agriculture:"

> In summary, the innovators reap the gains of technological advance during the early phases of adoption, but after the improved technology has become industry wide, the gains to innovators and all other farmers are eroded away either through falling product prices or rising land prices or a combination of the two, and in the long run the specific income gains to farmers are wiped out and farmers are back where they started--in a no-profit position. In this sense, technological advance puts farmers on a treadmill.

The price effects described by Cochrane are illustrated by an economic model of change for the agriculture sector 2/. The model separates the effects of technological change and its adoption from changes in product demand and input supply, permitting observation of the effects on individual firms and on prices. The model shows that innovation expands the size and increases the profits of the innovating firm. But as additional firms innovate, net income to the sector declines and the income and production of every other firm declines. The price decreases resulting from widening dissemination of the technology cause both traditional firms and those with the new technology to contract. Innovation is size-expanding; diffusion of technology is size-contracting. A point is reached where the profits of firms with the new technology are less than the original profit was under the traditional technology. At this point, or even sooner, the early adopters will start looking for an even better technology which again will boost their profits. This accelerates the treadmill on which all of the firms are running. Firm exit, changes in market demand and input supplies, and the adoption of an entire cascade of other technological changes alter the structure and performance of the agricultural sector (12).

PROSPECTIVE TECHNOLOGICAL CHANGES

The prospects for the future depend on the technologies that are being developed today and on the economic environment at the time of introduction. Emerging

2/ A nontechnical discussion of the model is in Van Chantfort's Farmline article (26). A more complete discussion of this model is forthcoming in "The Distributional Effects of Technological Change," by Lloyd D. Teigen, to appear in Agricultural Economics Research.

technologies in dairy, soybean, wheat, and sweetener production illustrate the potential consequences of biotechnology for agricultural producers and consumers. In what follows, only the consequences of expanded U.S. supplies will be examined. The effect of a less expensive dollar on farm exports is not examined. The spread of technology is not restrained by national boundaries, and supplies in other countries will also expand. In an open world economy, those supplies generated in other countries will effectively reduce the demand for U.S. exports. This second-order effect of technology on commodity demand is also not examined. It would magnify the price and income effects attributable to the domestic supply effect.

Biotechnology alters life forms. It includes: transfer of genes from one plant to another, from one animal to another, and from animal species to plants, or vice versa; gene manipulation; embryo transfers; and sex determination in semen and eggs. Biotechnology alters the processes internal to the organism, in contrast with technologies which alter elements of its nutrition or environment (such as nutrients, moisture, fertility, pests, and shelter) or improve materials handling by farmers (mechanization).

In the dairy and soybean examples, a hormone is administered to the animal or plant which affects its internal workings without altering its genetic make-up. In the case of wheat, a bacterium which is introduced into the soil enhances the external environment of the plant by producing a substance which controls the fungal disease called take-all. And finally, high-fructose corn syrup, which already competes with natural sugar, may capture an even larger market share if crystallization is made cheaper. While these technologies are at varying stages of research and commercial application, and uncertainties surround health and safety standards, testing, and product registration, it is possible that they could be introduced in the next 3 to 5 years.

Growth Hormones for Dairy Production

Bovine growth hormone (BGH) technology involves the daily supplemental injection of a growth hormone into a lactating dairy cow which increases milk production. The growth hormone is naturally produced by the cow and is one factor regulating milk production. Scientists, however, have been able to identify the gene responsible for its production, isolate it from experimental animals, and splice it onto bacteria. The altered bacteria is reproduced on a large scale by standard fermentation techniques. The resulting growth hormone can then be isolated, purified, and made available for commercial use. This synthesized hormone, when injected into cows daily, has increased production 15 to 40 percent in field trials (10). Field trials also show that only additional grain (and not roughage) is required to sustain the additional milk production. To illustrate the effects of BGH technology, assume that the milk production system at the time of adoption has the following characteristics:

- production cost increases due to the adoption of BGH on dairy farms are estimated to run $0.25 per day per cow for injections plus feed costs of $5.00 per additional hundredweight of milk produced;
- annual milk production per cow before BGH treatment averages 12,300 pounds;
- the price for milk at the farm gate averages $12.10/hundredweight;

- price elasticity of demand at the farm gate equals -.3 (which means that milk prices will decrease about 3.3 percent for every 1-percent increase in milk supply);

- aggregate production gains of 5, 10, and 15 percent are assumed to occur (to account for varying rates of adoption or BGH efficacy).

Changes in costs and returns on a typical dairy farm due to adopting BGH technology are given in table 2. The current revenue for an average-size farm (34 cows) with milk prices of $12.10 per cwt is $50,602.

If the hormone raises production 5 percent, revenue per cow increases about $75, but costs increase more than $100. Thus BGH would not prove commercially viable if only a 5-percent gain in production per cow is realized. With milk at $12.10, BGH is commercially viable when production increases at least 8 percent 3/. At

3/ As market prices adjust (downward) to the increased milk production, the breakeven production increase required to justify the new technology increases. With an annual fixed cost per cow of $76.25 for BGH, feed costs proportional to production increments (and equal to $5 per cwt of milk), and a base level of milk production per cow of 123 cwt per year, the breakeven percentage increase of milk production is 76.25/123 (PM - 5), where PM is the milk price (dollars/cwt) prevailing at that time.

Table 2--Bovine growth hormone: Partial budget for alternative production effects, annual basis

Item	Units	Base	Production increments: 5 percent	10 percent	15 percent
With current prices and policies:					
Milk production per cow	Lb.	12,300.00	615.00	1,230.00	1,845.00
Value at $12.10/cwt	Dol.	1,488.30	74.42	148.83	223.25
Change in costs per cow:					
BGH injections ($.25/day)	Dol.	NA	76.25	76.25	76.25
Added feed ($5/cwt milk)	Dol.	NA	30.75	61.50	92.25
Change in net revenue per cow	Dol.		-32.58	11.08	54.74
Value to a 34-cow farm	Dol.	50,602.00	-1,108.00	377.00	1,863.00
Change in U.S. milk:					
Production	Bil.lb.	NA	7.00	14.00	21.00
Removals	Bil.lb.	NA	7.00	14.00	21.00
Change in dairy program costs	Bil.dol.	NA	1.00	2.10	3.20
Without price supports:					
Price 1/	Dol.	10.50	8.84	7.17	5.50
Net revenue per cow	Dol.	1,291.50	1,034.69	832.35	609.48

NA = Not applicable.
1/ If there were no other changes in production due to lower prices.

this point, all costs involved in BGH are recouped by additional revenue. For every 1-percent increase in production over this breakeven point, about $8.70 in additional profits per cow are generated for the dairy farmer. If on-farm production increases approach the levels realized in field trials, a substantial profit incentive would motivate individual farms to adopt the new technology (12).

The production gains projected to result from use of BGH would increase supply faster than consumption at current prices. Moreover, any production increase would keep prices at support levels and force the Government to acquire additional stocks, especially if future dairy programs continue to use rigid price supports. Costs associated with surplus removal are currently about $15 per hundredweight removed.

By contrast, in an unsupported free market, such industrywide production gains would force some serious adjustment decisions. Under these conditions, prices would decline significantly. A 5-percent industrywide supply increase causes prices to decline to $8.84 per cwt; a 10-percent gain, to $7.17 per cwt; and a 15-percent gain, to $5.50 per cwt (table 2). Price changes of this magnitude are so great that under no circumstances would the adoption of BGH be profitable for the industry as a whole. However, it is probable that before price levels would reach even into the $8.50-$9.00 range, structural adjustments (herd reductions and farmers switching from dairy to other enterprises or other lines of work) would negate some of the supply increases and thus moderate the downward price pressure.

Regional adjustments were examined using ERS analytical models 4/. Production in the Lake States, Southern Plains, and Pacific regions would likely expand, and production in the Southeast and Delta States would decrease. The 15-percent output effect suggests increases in total milk production to the 165-175 billion pound level within 5 to 7 years of commercial introduction. Prices would likely fall as a result of higher production, resting at support levels throughout this period, and prompting the regional adjustments noted. All of the projected production increase (28-35 billion pounds) would go into manufactured dairy products, primarily cheese. These production increases would reduce prices and increase consumption somewhat, but still require massive Government removals (some $3.2 billion if national production is 15 percent higher than the base).

The results in table 2 illustrate the important relationships of all technological advances in agriculture: Adoption of new technology is favorable for individual farmers--assuming prices do not change; the marginal cost of producing the original output is less under the new technology than under the old; nonadopting farmers are placed at a disadvantage relative to adopters; adoption of the technology expands output, reduces prices, and can ultimately reduce producer total revenues (in the absence of price supports); and price changes finally channel almost all of the benefits of the technological change on to consumers (in the absence of price supports). With Government price supports, some of the depressing effects on producer revenue can be controlled, but only at the cost of higher prices to consumers or higher program costs to taxpayers. If incomes per farm fall enough, farms will leave production and the effects of the new technology on the remaining farms will be moderated.

4/ These are the United States Mathematical Programming (USMP) model (9) and Food and the Agricultural Policy Simulation (FAPSIM) model (18). The USMP model is a regional adjustment model and the FAPSIM model is a time-path forecasting model.

Soybean Growth Regulators

Brassinolide was first discovered and isolated by USDA scientists in 1970. It is found in minute amounts in all young plants (200 parts per billion) and is necessary for seedling growth. It was 1980 before processes were found to chemically synthesize the hormone. The synthetic hormone, brassiosteroid, has been under field testing by the Agricultural Research Service for the past few years. In these tests, brassiosteroid is sprayed on seedlings when plants are very young. Seedling growth is accelerated by as much as 10 days without any loss in quantity or quality of yields. In fact, yields may actually increase because early-season losses to insects and diseases are reduced. For example, yields of radishes, lettuce, and green beans were increased by 15-30 percent (14). No process is yet available to cheaply synthesize brassiosteroids, but research may develop one.

If commercial use of brassiosteroids becomes a reality, one of its likely first uses will be on soybeans (15). Soybean yields fall when planting is delayed beyond June 15, which occurs when soybeans follow winter wheat. In west Tennessee, for example, every week's delay after June 15th costs 1 bushel per acre and, after July 1, every week's delay reduces yields as much as 6 bushels. Brassiosteroids could cut growing time of soybeans by 2 to 4 weeks, avoiding these yield reductions. In addition, doublecropping of soybeans and wheat could increase in the South and perhaps move north into Kansas and Missouri. Rotations any further north than this would not likely be affected because moisture is too limited for late-planted soybeans (13, p. 73).

Costs to administer brassiosteroids vary from $15 to $25 per acre. Potential production increases for doublecropped soybeans in most of the Delta States represent present yield losses due to late plantings. Using the West Tennessee rule of thumb, on average, an additional 3 bushels of soybeans per acre could be expected on doublecropped acreage. This would add an additional 20-30 million bushels to the soybean crop.

A larger effect of the soybean growth hormone occurs in the wheat market. Brassiosteroids will allow some fraction of singlecropped soybeans to switch into a doublecropped rotation with wheat. An assumed doubling of the acreage of soybeans doublecropped with winter wheat would add about 7.6 million planted acres in the South. With an average yield of 32 bushels per acre, this would increase wheat production 243 million bushels before price effects are considered. Projected adjustments to introduction of growth regulators on soybeans in the wheat and soybean sectors as prices change are presented in table 3.

As the technology comes on line, production of both soybeans and wheat is projected to increase, prices would decline, and exports, domestic use, and ending stocks would all increase. Net Government program costs for soybeans (primarily intra-year loan activity) would probably not change, despite the added supply and lower price of soybeans. Wheat program costs, though, could be substantial. Average farm prices would likely hover around the loan rate, assuming the current commodity program structure is continued, with further declines prevented by the nonrecourse provisions of CCC loans 5/. Deficiency payments, based on the assumed $4.38 target price, exceed $1.00 per bushel for the added bushels and are increased by the amount of the price change for all

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5/ In the absence of the wheat program, price changes would be larger, demand effects greater, and supply effects smaller than estimated here. The value of farm commodities sold would decrease as a result of the inelasticity of demand.

quantities already in the wheat program. In total, wheat program costs could increase more than $2.00 per bushel for every added bushel of production above the baseline if no program changes accompany the technological change.

The regional effects of the technology were examined using the ERS regional adjustment model (USMP). This analysis suggests that net farm income (gross income after variable expenditures) would increase 2.8 percent in the Southeast, 4.0 percent in the Delta States, and 4.6 percent in the Appalachian region. Net farm income in the Corn Belt and Lake States would decline by 0.5 percent and in the rest of the country, 0.4 percent. Deficiency payments made under the wheat program would tend to somewhat moderate this regional redistribution of income.

Brassiosteriods provide an example of a technology having specific application in one commodity but with greater effect in another. Even if the actual effects on wheat production are smaller than calculated, a substantial impact is possible.

Table 3--Soybean growth regulators: Impact on supply, use, and Government cost

Variable	Changes from the base 1985	1986	1987	1988	1989
			Percent		
Soybean sector:					
Yield	0.2	0.6	1.2	1.4	1.5
Harvested acreage	-.02	-.02	-.3	-.7	-.7
Production	.2	.4	.7	.8	.8
Domestic use	.07	.02	.4	.5	.6
Exports	.1	.3	.7	.9	1.1
Ending stocks	.5	1.3	2.6	3.2	3.5
Season-average soybean price	-.4	-1.2	-2.6	-3.4	-4.0
Soybean program payments:	0	0	0	0	0
Wheat sector:					
Yield	-.1	-.2	-.3	-.3	-.3
Harvested acreage	1.2	3.0	5.9	7.0	7.8
Production	1.1	2.9	5.6	7.0	7.8
Domestic use	.8	1.8	3.1	3.7	3.8
Exports	.7	1.8	3.8	4.8	5.4
Ending stocks	.5	1.9	4.9	8.6	12.9
Season-average wheat price	-1.1	-3.3	-6.9	-8.5	-9.9
Wheat program payments:					
Deficiency payments	4.4	12.8	27.3	35.5	40.4
Storage payments	.7	2.6	6.8	11.9	17.8
Total Government payments 1/	1.1	3.7	8.0	11.2	10.5

1/ Including increased payments in other commodity programs resulting from production adjustments.

More important than the technological assessment is the institutional assessment, comparing the effects of the wheat program with the soybean program. The marginal costs of the soybean program are negligible, while the marginal costs of the wheat program are substantial. The major differences between the two programs are that the soybean program has neither target prices nor deficiency payments, and very few defaults occur under the nonrecourse provision of CCC loans because the soybean loan rate is usually considerably below market-clearing prices.

Microbial Control of Wheat Diseases

Since 1967, Agricultural Research Service scientists have researched various methods for controlling a fungus that causes take-all, a black decaying of the roots and lower stems of wheat and barley. Microbial control, a general term that refers to the use of microorganisms for the control of pests, appears more promising than other chemical, physical, and cultural control measures. Several strains of bacteria called *Pseudomonas fluorescens* were found that attach themselves to wheat roots and produce a substance antagonistic to take-all.

Sometimes called "bacterization," the innoculation of seed with bacteria has been used successfully in many crops. Experiments in California have shown marked increases in the production of wheat, potatoes, sugarbeets, and radishes when seeds were treated with strains of root-colonizing bacteria. For wheat the best strains of *Pseudomonas* applied on seeds at planting significantly reduce take-all damage. Experiments in Washington State conducted during 1979, 1980, and 1982 suggest yield increases of 20 to 30 percent (8). "Bacterization" of wheat seeds could become available for commercial adoption in 5 years and certainly should be available for commercial adoption within 10 years.

A take-all control program would combine appropriate cultural practices with seed innoculation of the antagonistic root-colonizing *Pseudomonas*. A one-time introduction of *Pseudomonas* into a field may be sufficient if wheat is sown on virgin land or if wheat is continuously grown. Fields subject to crop rotation most likely will require innoculated seed to reintroduce the bacteria into the soil each year.

Successful innoculation of wheat seed with the identified antibiotic root-colonizing bacteria strains will likely benefit Pacific Northwest growers first. Other regions also experience take-all, but may require different bacterial strains. Growers in the Northwest could obtain yield increases ranging between 20 and 30 percent (table 4). Economic seed coating methods would increase the price of seed. However, the effect on total production costs per acre would be negligible. Adaptation of the technology to other wheat-producing areas would require observation and isolation of bacterial strains indigenous to the other regional production areas.

A 20-percent yield increase in the Pacific Northwest would increase total U.S. wheat production about 2 percent in the long run. By 1989, production would exceed the baseline by 1.7 percent (table 5). Exports, domestic use, and carryover stocks would be higher than the baseline, and prices would fall. Because Western White Wheat is the variety affected by the technology, its price, stocks, and consumption would be affected to a greater degree than other varieties of winter and spring wheats. Revenue per acre would increase in the Pacific Northwest but fall in other regions. Until the new technology was adapted to other wheat-growing areas, the competitive position of Northwest wheat producers would be improved. Wheat acreage and production and both gross

Table 4--Innoculated wheat seeds: Projected impact on regional production and income

Region	Wheat subsector: Acres	Wheat subsector: Production	Agriculture sector: Gross income	Agriculture sector: Gross income minus variable costs
	Percentage change from base solution			
Pacific	+27	+51	+12	+8
Mountain	+34	+54	+5	+11
Northern Plains	-15	-15	+7	-2
Southern Plains	-26	-26	-16	-4
Other regions	-16	-15	-.3	-.5
U.S. total	-6	+3	+.1	+.3

Table 5--Innoculated wheat seeds: Projected impact on supply, use, and Government cost

Variable	Change from the base: 1985	1986	1987	1988	1989
	Percent				
Wheat sector:					
Yield:					
Pacific Northwest	1.3	6.4	8.2	10.9	12.2
U.S. average	.3	.8	1.3	1.8	2.3
Harvested acreage	0	-.2	-.3	-.5	-.6
Production	.2	.7	1.2	1.6	1.7
Domestic use	.1	.3	.5	.6	.8
Exports	.1	.5	.9	1.1	1.2
Ending stocks	.1	.5	1.1	2.0	2.9
Season-average price	-.3	-.8	-1.6	-1.9	-2.2
Wheat program payments:					
Deficiency payments	1.2	3.7	7.1	9.5	10.3
Storage payments	.2	.7	1.6	2.6	4.0
Total Government payments 1/	.2	.8	1.5	2.0	2.3

1/ Includes increased payments in other commodity programs resulting from production adjustments.

and net agricultural sector income would increase in the Pacific and Mountain regions and decline in others.

Assuming the current configuration of Government programs, program costs would be affected by the increased supply of wheat resulting from the innovation. If it is assumed that there will continue to be a target price set at current levels, it will be higher than the likely market-clearing price and the added production would increase program payments. In addition, the added production would probably put downward pressure on the market-clearing price, increasing the per-bushel deficiency payments made on existing production. Finally, storage payments would increase, just as in the wheat-soybean doublecropping example. Government costs would increase more than $2.00 for every additional bushel of wheat production, given programs like the current ones.

High-Fructose Corn Syrup

High-fructose corn syrup (HFCS) is a product of the enzymatic breakdown of corn starch. Converting corn starch into something sweet is not a novel idea--first attempts date back to 1811 and yielded only glucose corn syrup and dextrose. HFCS was first produced in 1967. In 1972, a new enzyme process made HFCS far less costly than sugar. This new process, involving the use of immobilized glucose isomerase--which "fixes" the enzyme, so that it can be used again and again--made continuous (rather than batch) processing possible. Major capital investments and continued research and development have enhanced efficiencies of HFCS production and use. For example, the current yield of syrup per unit of enzyme is 4-5 times its level in the seventies, reducing the costs of using the enzyme from $1 per 100 pounds of corn syrup to about $0.35 (in late 1982). New plants in the industry require about one-half the labor of comparable plants built in the late sixties. Equally important, product quality has been improved, widening HFCS's use as a sugar substitute.

Prices for HFCS have ranged between 15 and 50 percent less than the domestic price of sugar over the last 5 years, depending on the type of HFCS and capacity utilization in HFCS production. HFCS price levels reflect real differences in production costs, in addition to the marketing strategy of producers. Although allocation of costs among joint products complicates the analysis, HFCS has lower production and processing costs and higher byproduct values than sugar (5). The variable costs of producing HFCS are about 9 to 12 cents per pound. This is about the same as world raw sugar prices of 3 to 6 cents, imported without duties, and processed into refined sugar. The high domestic sugar price, maintained over the years by import quotas, duties, and other support programs for sugar, provided a major incentive for the development and adoption of HFCS.

Growth in production and use has averaged about 25 percent per year since the midseventies. In 1983, about 3.6 million tons (dry basis) of HFCS were produced in the United States. Most HFCS is used in the beverage market where it represents about 75 percent of the total caloric sweetener used. The remainder is used in other food processing industries, such as baking, canning, processed food, and dairy products. Consumption of HFCS in 1983 amounted to over 30 pounds per person in the United States, compared with less than a pound in 1970. Sugar consumption during this same time declined from 102 pounds per capita to about 71 pounds. Table 6 shows how consumption of sweeteners has adjusted to the introduction of HFCS.

The largest share of the adjustment to HFCS has been borne by foreign suppliers of sugar, reflecting a 22-pound-per-capita decrease in consumption of imported sugar between 1970 and 1983 to 23.9 pounds per capita. Domestic sugarbeet production decreased 8 pounds per capita between 1970 and 1983, while per-capita sugarcane production declined 1 pound.

The cost-competitiveness of HFCS with sugar caused major structural changes in the sugar processing industry, reducing overall production capacity, but raising plant size. Between 1970 and 1983, 21 beet factories closed down, but processing capacity per factory rose 19 percent, and total capacity fell 14 percent. The number of cane mills dropped from 75 to 43, but capacity per mill rose 71 percent and industry capacity remained relatively unchanged (1).

HFCS affects corn producers as well, but to a substantially lesser extent. About 250 million bushels of corn go into HFCS production, nearly 3 percent of recent corn crops. Since 1 bushel of corn can be converted to 33 pounds of HFCS, over 300 million bushels of corn could be used for HFCS production by the late eighties based on projected use.

HFCS enjoys several advantages over sugar. The major advantage, of course, is lower cost at sweetness levels equivalent to the use of sugar in food products. Like sugar, HFCS blends well and adds desired bulk. In addition, HFCS provides desired moist-ess for some products and enhances certain flavors, such as citrus. Production advantages include year-round operation of plants producing HFCS and lower operating costs relative to the seasonally operated cane and beet sugar plants. One major impediment for future growth in market penetration, however, is that HFCS is available only in liquid form with a relatively short shelf life. Its use is primarily in beverages. In other uses, HFCS's tendency to attract moisture would probably limit its ultimate penetration of the U.S. sweetener market to less than 45 pounds per capita (compared with 36 pounds in 1984).

If fructose in HFCS could be economically crystallized and kept dry (presently the price of crystalline fructose is several times greater than that of sugar) that product could have another major impact in U.S. sweetener use. Pure crystalline fructose (PCF) presently enjoys a small, stable position in the sweetener market and is considered by most industry observers to be a specialty sweetener. If processes could be found to produce PCF at costs comparable to those of sugar, sugar would be challenged in the table sweetener market. Widespread PCF use could double the use of corn in HFCS/PCF production and displace a substantial portion of the 1.1 million acres of sugarbeets and 0.7 million acres of sugarcane. Future impacts due to cost-effective crystallization technology for HFCS depend on several factors, the most important of which is

Table 6--High fructose corn syrup: Effects on sweetener market

Sweetener	1970-75	1975-80	1980-83
		Pounds per capita	
Total caloric sweeteners	-4.5	+7.0	-0.6
Sugar:	-12.6	-5.4	-12.7
Domestic beet sugar	-1.2	-3.2	-3.8
Domestic cane sugar	-.4	-.3	-.3
Imported cane sugar	-11.0	-1.9	-8.6
Glucose and dextrose	+3.9	-1.6	+.4
High-fructose corn syrup	+4.3	+14.1	+11.6

the effect of noncaloric sweeteners on the total market. Consumer acceptance of the new products is another.

With sugar prices continuing to be supported at a substantial premium over HFCS, about 10 pounds of sugar per capita could be displaced from the market between 1983 and 1986, and possibly more by 1990 if cheap crystalline fructose could be developed. If annual sugar production or import levels were not adjusted, substantial inventories could accumulate. Policy issues would likely arise regarding the share of adjustment borne by domestic versus foreign sugar suppliers and the distribution of the domestic adjustment between cane and beet producers. The price effects could be substantial owing to the inelastic sweetener demand, especially if imports of lower priced foreign sugar were allowed to expand.

IMPLICATIONS FOR COMMODITY PROGRAMS

Technological change will continue to occur in American agriculture. The changes may reduce costs, increase output, enhance the productivity of some resources, or overcome a specific bottleneck in the production process. Ultimately the marginal cost is reduced and output increases for a given level of prices received. The new technology may also shift the demand for productive factors even before product prices adjust, increasing demand for resources complementary with the new technique and decreasing the demand for other resources. In addition, when the change in product supply is large enough to affect the market for that commodity, its price will likely fall and the relative prices of all production inputs will be affected. Purchased inputs might be reduced and the returns to owners of resources used in the production of particular commodities might decline.

If technological change occurs more rapidly than the growth of demand, commodity prices would be expected to fall and producers could experience reduced incomes. If technological change is less rapid, consumer prices rise. A balanced rate of technological change would be rapid enough to match the growth in the market but slow enough to permit the resources displaced by technological change to be absorbed elsewhere in the economy. If the increased production is mostly for export, the benefits will accrue to those who import U.S. farm products in addition to domestic farmers and consumers.

Resources are almost invariably displaced by technological change. Labor was displaced by the cotton picker. Land producing horse feed was freed up when tractors replaced horses and mules. In the future, growth hormones may displace some dairy cows. Wheat production gains in the Northwest from the control of take-all may displace acreage and production in other regions. High-fructose corn syrup now displaces sugar and other sweeteners and may displace more in the future.

Technological change affects the costs and returns of individual farms and alters the geographical distribution of production. Changes in soybean technology affect the income of wheat growers. As adoption of new technology sends larger supplies to market, prices fall--unless Government policy and programs prevent adjustment by the farm sector. Total income to the farm sector may fall but, to the extent that it is shared among fewer farmers, the average income per farmer can rise. The structure of agriculture would change as some traditional farms innovate and others drop out, so that there is a larger proportion of higher technology farms to lower technology farms. Each of these classes of farms is facing lower prices received as the technology spreads and therefore receives lower incomes at each stage of the process. As the proportion of high-tech farms rises, the weighted average income of all farms rises even though the incomes of every farm in each of the two classes are falling. In the long run, income per farm will approach a level below which even the high-tech farms would leave the sector. Ultimately the benefits of technological change are captured by consumers here and abroad in the form of lower food prices.

When Government policy does not permit price and resource adjustments, both the level and the distribution of benefits from technological change are affected. Larger supplies require additional Government removals at greater cost to the taxpayer. Some benefits, which otherwise would accrue to consumers, are passed on to producers and landowners--generally as increased values of farmland and other farm assets. But, there is some loss of economic efficiency. Production asset values adjust to prices higher than indicated by market forces, passing much of the program benefits from the producer on to the asset owner--not always the same person.

Current commodity programs require more flexibility to permit price and resource adjustments to technical change. Milk prices are presently supported by CCC direct purchases of butter, cheese, and nonfat dry milk and, at levels of recent years, adjust only after substantial removals occur. Wheat prices are allowed to adjust in the marketplace above the loan level, but producers receive a deficiency payment to compensate for the difference between the target price and the farm price. With such programs and the present supply/demand balance, every additional unit of output is associated with additional cost to the taxpayer. Without them, the domestic market could not absorb the prospective increase in food production without larger price decreases.

At current production and price levels, every additional hundredweight of milk produced under current programs requires an additional hundredweight of Government removals at a total cost of $15 to the taxpayer, of which the producer receives about $12.10. The variable expenses of producing that hundredweight of milk in 1983 were $9.60 in the region with the highest costs--Appalachia.

Every additional bushel of wheat costs its purchaser about $3.65 and costs the taxpayer an additional $2.00 (of which about $0.75 is that producer's deficiency payment and about $1.25 goes to all other wheat producers as a result of storage payments and the widened level of deficiency payments). Yet, the variable expenses (22) for producing all U.S. wheat in 1983 averaged $1.41, and ranged between $0.98 for hard red winter wheat in the Northern Plains and $1.95 for soft red winter wheat in the Northeast. The variable expenses for white wheat (the major variety in the Pacific Northwest) were $1.16 per bushel.

The margin between price and variable costs 6/ for most commodities provides an adequate return to the producers of the median unit of output (generally those with sales greater than $100,000), but leaves the median producer of that commodity (generally having sales of less than $30,000) with limited net farm income. Price enhancement policies and deficiency payments have little effect

6/ Variable costs are incurred as a result of producing that commodity in that year. Land and machinery ownership costs and the operator's labor and management input are part of the farm overhead and are incurred whether or not a particular commodity is produced. The margin between price and variable costs provides the return to the entire overhead, but cannot be unequivocally allocated to the individual items.

on the incomes of the smallest producers and convey the largest benefits to the largest producers. Government farm policies and price support programs have substantial budget cost at the margin and are quite sensitive to the supplies brought forth by new technologies. Less costly, more flexible means may need to be found to accomplish the objectives of assuring adequate returns and stability in agricultural production, while accomodating the technological change and increased production efficiencies necessary for a competitive position in world markets.

Technological change is difficult, if not impossible, to forecast. It cannot be controlled easily--even if control were deemed socially desirable. Almost two-thirds of all R&D expenditures on agricultural technology are made by the private sector, and research and development continues in other countries regardless of U.S. policies. Technological change affects consumers, producers, asset holders, and taxpayers, and it affects the various regions of the country differently. Government farm policies and programs were originally designed to ease the adjustment by the agricultural sector to structural change, including technological advances. To remain viable, the policies themselves need to take on added flexibility to adapt and adjust to the consequences of changing technology. Flexible commodity policies could insure that the benefits of technological change are shared more broadly among producers, consumers, and taxpayers, enhancing the efficiency and productivity of the food and agricultural system and the U.S. economy.

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