IMPLICATIONS OF EVOLVING TECHNOLOGY FOR AMERICAN AGRICULTURE

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Technology has made United States agriculture one of the most productive in the world. In so becoming, agriculture has gone through major technological eras. The mechanical era of 1920-1950 made the transition from horsepower to mechanical power and greatly increased the productive capacity of agriculture. The chemical era of 1950-1980 increased production by reducing the constraint on production caused by pests and disease. American agriculture is now entering a new major technological thrust — the biotechnology and information technology era. The implications of this new era could be more profound than those of either the mechanical or chemical technological eras.

The biotechnology and information technology era has been fostered by substantially expanded private sector investment in agricultural research complemented by increased public sector emphasis on basic research. The output of this new era is in its infancy today but can be expected to have a great impact over the next three decades. Manifestations of this technological era include growth hormones, growth regulators, embryo transplants, gene insertion, computerized farm management decision models, and monitoring and controlling technology.

Biotechnology

Biotechnology is defined as any technique that uses living organisms to make or modify products, to improve plants and animals, or to develop microorganisms for specific uses. It focuses on the use of recombinant DNA and cell fusion which are powerful techniques that allow a large amount of control over biological systems.

A major thrust of biotechnology in animals is the mass production in microorganisms of proteinaceous pharmaceuticals, including a number of hormones, enzymes, amino acids, and feed supplements.

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Previously obtained only from animal and human organs, these biologicals were either unavailable in practical amounts or in short supply and costly. Some of these biologicals can be used for detection, prevention, and treatment of infectious and genetic diseases; some can be used to increase production efficiency.

Another new technique arising from the convergence of gene and embryo manipulations promises to permit genes of new traits to be inserted into the reproductive cells of livestock and poultry, opening a new world of improvement in animal health and productivity. Unlike the genetically engineered hormone, which increases productivity but does not affect future generations, this technique will allow future animals to be permanently endowed with traits of other animals.

Another technique, embryo transfer in cows, involves artificially inseminating a super-ovulated donor animal and removing the resulting embryos nonsurgically for implantation in, and carrying to term by, surrogate mothers. Prior to implantation, embryos can be treated in a number of ways. They can be sexed, split (generally to make twins), or frozen in liquid nitrogen.

Application of biotechnologies in plants could modify crops so that they would make more nutritious protein, resist insects and disease, grow in harsh environments, and provide their own nitrogen fertilizer. While immediate impacts of biotechnology will be greater in animal agriculture, the long-term impacts may be substantially greater for plant argiculture. The potential applications of biotechnology on plant agriculture include microbial innoculums, plant propagation, and genetic modification.

Microbial Innoculums — Rhizobium seed innoculums are widely used to improve nitrogen fixation by certain legumes. Study of the structure and regulation of the genes involved in bacterial nitrogen fixation is leading to the development of more efficient innoculums. Tests are presently being conducted on genetically engineered soil bacteria that produces a naturally occurring insecticide capable of protecting plant roots against soil dwelling insects.

Plant Propagation — Cell culture methods for regeneration of intact plants from single cells have been developed. These methods have been used to provide large numbers of genetically identical, disease-free plants that often exhibit superior growth and uniformity over plants conventionally seed grown.

Genetic Modification — Through the use of genetic engineering techniques, it is possible to introduce deoxyribonucleic acid (DNA) from one plant into another plant, regardless of normal species and sexual barriers. Thus, it will be possible to insert desired traits, such as disease prevention, from one plant to another.

Information Technology

This area is the use of computer and electronic based technologies for the automated collection, manipulation, and processing of information for control and management of agricultural production and marketing. The most significant changes in future livestock production will come from the integration of computers and electronics into a modern livestock production system that will make the farmer a better manager. Examples of information technology for livestock production include:

- Electronic animal identification.
- Reproduction and genetic improvement — Estrus detection, fertility monitoring, pregnancy data collection, etc.
- Disease control and prevention — Animal temperature monitoring, medical history record keeping.
- Controlled environment — Temperature and ventilation monitoring and adjustment.
- Complete record keeping for each animal and collection of timely information for management.

In plant agriculture, information technology will be capable of providing the following:

- Pest detection and identification
- Crop growth and weather record keeping
- Computer retrieval of current and historical information
- Predictive models for analyzing pest-crop environment interactions
- Insect control strategies

Technology's Impact on Yield

The above technologies already have begun making their impact on agriculture. This is particularly the case for animal agriculture — especially for dairy. The Office of Technology Assessment's (OTA) most likely projection is that these technologies will have a highly significant impact on milk production (Table 1). With the use of genetically engineered hormones, embryo transfer, and information technology, milk production per cow has the potential to double between 1982 and 2000. This will have considerable impact on the dairy industry including substantial regional shifts in production and an approximate 30 percent reduction in cow numbers [1].

For crops, the impact will not be nearly so great. The main reason is that biotechnology for plants will not be commercially available to

TABLE 1

IMPACT OF EMERGING TECHNOLOGY ON YIELD BY COMMODITY IN YEAR 2000

	1982	2000	Annual Growth Rate (percent)
Dairy Milk per cow (thousand lbs)	12.3	24.7	3.9
Corn bu/acre	115	139	1.1
Cotton lb/acre	481	554	0.7
Rice bu/acre	105	124	0.9
Soybean bu/acre	30	37	1.2
Wheat bu/acre	36	45	1.3

Source: Office of Technology Assessment

any great degree until the late 1990s. However, crop yields are still expected to increase and with only few exceptions will keep pace with historical annual yield increases out to the year 2000.

Structural Change in Agriculture

Who will use the new technology is as important a consideration as which technology will emerge, because the distribution of technology has a considerable impact both on agricultural production and on the structure of the agricultural sector. The bio- and information technologies discussed earlier will be introduced within a socioeconomic structure that has undergone considerable change in the last 50 years and that promises to continue to change throughout the remainder of this century.

One of the best ways to look at changes in the economic structure of United States agriculture is in terms of value of production as measured by gross sales per year. In this way, farms can be usefully classified into the three categories of gross sales as shown in Table 2.

Small/part-time farms generally do not provide a significant source of income to their operators. Most obtain their primary net income from off-farm sources. However, this segment is highly diverse. This class of farms is operated either by subsistence farmers or by individuals who use the farm as either a tax shelter or source of recreation.

Moderate size commercial farms cover the lower end of the range in which the farm is large enough to be the primary source of income. However, most families with farms in this range also rely on off-farm income.

Large scale commercial farms include a diversity of farms. The great majority of these are family owned and operated. Most of these farms require one or more full-time operators, and many depend on hired

TABLE 2

MOST LIKELY PROJECTION OF NUMBER OF FARMS, BY SALES CLASS

Sales Class	Value of Farm Products Sold	1982		2000	
		Number of Farms	Percent of All Farms	Number of Farms	Percent of All Farms
Small/ Part-time	Less than $100,000	1,936,920	86.6	1,190,000	68.0
Moderate	$100,000–250,000	215,912	9.6	191,400	10.9
Large	Over $250,000	86,468	3.8	368,600	21.1
	Total	2,239,000	100.0	1,750,000	100.0

Source: Compiled from projections by U.S. Department of Agriculture and Office of Technology Assessment

TABLE 3

MOST LIKELY PROJECTION OF FARM CASH RECEIPTS, BY SALES CLASS

Sales Class	1982	2000
	—Percent—	
Small/Part-time	27.4	4.2
Moderate	25.0	10.5
Large Scale	47.6	85.3

Source: Compiled from projections made by U.S. Department of Agriculture and Office of Technology Assessment

labor on a full-time basis. The degree of contracting and vertical integration is much higher in this class.

If present trends continue to the end of this century, the total number of farms will continue to decline from 2.2 million in 1982 to 1.8 million in 2000. However, the distribution of farms will change. Farms will continue to evolve to a bipolar or dual agriculture — a large proportion of small farms, an ever-increasing proportion of large farms, and a declining number of moderate size farms. Small farms will constitute almost 70 percent of all farms in 2000 while the proportion of large farms will increase five times from the number in 1982. This will be due mainly to economies of size and technological advances that will be discussed shortly.

The decline in farm numbers and increase in size will be accompanied by other changes in structural characteristics of United States agriculture. One of the most important is market share accounted for by each class of farm (Table 3). Almost half of all farm products produced in 1982 were marketed by large scale farms with small and moderate size farms evenly dividing the remaining market share. However, if current trends continue, by 2000 the large scale farms will about double their share while the moderate size share will be reduced by one-half and the small farms' market share will almost disappear. In addition, it is expected that: 1) the 50,000 largest farms could market 75 percent of all farm products by year 2000, 2) the 50,000 largest farms could farm 60 percent of total farmland, and 3) off-farm income for moderate size farms will be a necessity for their survival.

Important factors that lead to the above findings include: technology, economies of size, tax laws, price instability, operator's managerial capacity, capital requirements, farm programs, credit availability, and the like. Although all are important, technology advances and economies of size will be dominant factors in continuing to change the structure of agriculture. Economies of size studies recently completed indicate major technical efficiencies for large scale farms in dairy, corn, cotton, wheat, and soybeans [1,2,5]. To speed this process along the bio- and information technology era is expected to have significant impacts on the very same commodities. The combination of economies of size and technology will rapidly move along the concentration of resources in United States agriculture.

Implications for Agricultural Policy

Contemporary farm programs have fostered this trend toward three farm size classes — small/part-time, moderate, and large. Payments to farmers, based on per unit of production, concentrate most of the benefits with the large farms producing most of the output. Economic emergency credit program benefits have been highly skewed toward large farms. Large farms have been in the best position to take advantage of new technologies arising out of the public sector agricultural research system.

Without substantial changes in the nature and objectives of farm policy, the three classes of farms will soon become only two. The moderate size farm will be largely eliminated as a viable force in American agriculture. In addition, the problems of the small subsistence farm will continue to fester as an unaddressed social concern.

If it were decided by Congress that steps should be taken to foster a diverse, decentralized structure of farming in which all sizes of farms had an opportunity to compete and survive, then policy changes would be required. It should be noted that no matter what policy changes are implemented it can still be expected that there will be fewer commercial farms in the year 2000 than there are today. However, government can do much to ease the pain of adjustment. To address the structure issue adequately, separate policies and programs need to be pursued with respect to each of the three farm segments — large farms, moderate farms, and small farms.

Policy for Large Commercial Farms

Recent economic analysis clearly shows that most large scale farmers do not need direct government payments and/or subsidies to compete and survive [6]. However, there is still need for a commercial farm policy.

Two basic policy goals are implied for large scale farmers:

- Farmers need to operate in a relatively stable economic environment in which they have the opportunity to market what they produce.
- Farmers need a base of research whereby they can maintain their competitiveness in the markets in which they operate.

Creating a Stable Environment — To create a stable economic environment in which farmers have an opportunity to market what they produce implies the following farm program initiatives:

- Direct government payments to all farms having more than $250,000 in sales would be eliminated.
- The nonrecourse loan would be converted to a recourse loan. By not accumulating stocks through the nonrecourse loan, the recourse feature would provide a continuing base of support for orderly marketing of farm products.
- Government credit to farms having more than $250,000 in sales would not be available aside from the recourse price support loan.
- Expand foreign development assistance program to include an optimum balance of commodity and economic development aid.
- Provide macroeconomic policy that facilitates growth of export markets and maintains a relatively low real rate of interest. This could be accomplished through reduced deficits combined with more expansionary monetary policies.

Maintaining Technological Competitiveness — Technological competitiveness of American farmers would be assured by a continuing policy that encourages public and private investment in agriculture. The major thrust of research programs as they affect large scale farmers would be as follows:

- Continue trend toward increased public sector emphasis on basic research.
- Continue incentives for private sector to increase the emphasis on applied research.
- De-emphasize direct education by extension to large scale farms. Private consultants would play an increased role in technology transfer to the large scale farm segment.

Policy for Moderate Size Farms

Moderate size farms face major problems of competing and surviving in the bio- and information technology era. Government policy should not be pursued in a manner that allows these farms to fail. However, it should be recognized that only some moderate size farms will survive; farmers of other moderate size farms should be afforded the opportunity to move to other occupational endeavors.

Policy for moderate size farms requires the same stable economic environment and base of support for agricultural research as for large farms. In addition, the following specific policy goals for moderate size farms can be specified:

- The risk to moderate size farmers operating in an open market should be reduced.
- New technologies should be available to moderate size farms with the potential for adoption.
- Opportunities for employment outside of agriculture should be created for those farmers who are unable to compete.

Reducing Moderate Size Farm Risk — The most difficult obstacle to survival of moderate size farms is that of managing risk. Market oriented farm policies greatly increase the amount of price and income risk facing these farms. Three options that reduce risk are discussed. They are not necessarily mutually exclusive.

- Income protection could be provided to moderate size farms by directing income support of present farm programs to these farms.
- Continue nonrecourse loan concept for moderate size farms.
- Increased assistance by public sector could be provided as a means of reducing risk to moderate size farms. Assistance could be in form of educational programs on futures markets and contracting.

Technology Transfer to Moderate Size Farms — Agricultural research is not inherently biased against moderate size farms. Rather these farms may be seriously disadvantaged either by lags in adoption or by lack of access to competitive markets for products produced by new technologies. The following initiatives could assist in curtailing such problems:

- Direct extension technology transfer services to moderate size farms. Primary goal of such programs would be to make technologies available to moderate size farms on same schedule as large farms.
- Intensify extension's evaluation of the increasing number of new products entering the market. This increased effort would play a dual role of providing a check on the efficiency of new products and eliminating the costs associated with individual farmer experimentation with them.
- Develop cooperatives that emphasize technology supply and transfer services to moderate size farms — their main clientele.
- Provide ample credit through the public sector to moderate size farms that have the potential to survive and grow. Emphasis would

be placed on credit required to keep moderate size farms technologically state-of-the-art.

Enhancing Opportunities Outside of Agriculture — Despite the effectiveness of the above initiatives, there will be an accelerated need to move resources out of agriculture into other occupations. In the process of change, rural communities will be adversely affected. There is need for a policy to facilitate adjustment of resources out of agriculture into gainful productive employment elsewhere. Specific initiatives to ease this adjustment include:

- Attract new business activities into rural communities to increase employment opportunities. Emphasis could be placed on attracting those businesses that develop technologies and serve the needs of high technology in rural areas.
- Establish training programs for rural populations in skills required to attract business into rural communities.
- Assist rural communities in developing and modernizing the infrastructure needed to be a socially and economically attractive place to live.

Policy for Small Farms

With few exceptions, small farms having less than $100,000 in sales are not viable economic entities in the mainstream of commercial agriculture — nor can most be made so. They survive because their operators have substantial outside income (part-time farmers); or because they have found themselves a niche in marketing a unique product with special services attached (often direct to consumers); and/or because they are willing to accept a very low return on resources contributed to the farming operation.

For the small farms which either have substantial outside income or have found a niche in the market, government's role would be severely restricted. They are as much able to take care of themselves as large farms.

However, small subsistence farmers with limited resources and often limited revealed abilities, represent a genuine problem for which public concern is warranted — these indeed are the rural people left behind. Commercial farm programs have done and can do little to solve their problems. These impoverished individuals are a social and economic problem for which only social programs can help. The following suggestions are made for dealing with the problems of subsistence farmers:

- Initiate a special study to identify these individuals, their specific status, and needs. Develop social programs to meet those needs.
- To the extent that these individuals are located in the South, direct 1890 land grant university research and extension pro-

grams specifically toward developing farming, credit, and marketing systems designed to maximize the small farms' agricultural production capability. Outside the region served by the 1890s, develop and direct similar programs in the 1862 land grant universities.

Implications for Agricultural Research and Extension Policy

The previous discussion points up the importance of research and extension policy to future agricultural policy. To a great extent the success of agricultural policy will rely on agricultural research and extension. As agriculture enters the biotechnology and information technology era two important issues are raised.

1. What are the consequences of increased private sector involvement?
2. What adjustments are needed in the system to be "state of the art"?

Consequences of Increased Private Sector Involvement

Substantially increased private sector involvement in agricultural research has occurred since the extension of patent rights to plant varieties in 1970 and to other forms of biological discoveries through the United States Supreme Court ruling in 1980. These rights have given rise to increased private sector investment in public universities that would result in profitable, patented discoveries. These policy changes relating to property rights and exclusive licensing rules have called into question the "public goods" nature or the "social contract" under which land grant universities operate, whereby ready and free public access to research results have been provided.

Relationships have developed between private sector research firms and public universities to provide for limited partnerships, or other contractual arrangements, to develop and market innovations arising from private sector investments in public agricultural research. Potential exists for substantial change in distribution of benefits from land grant university discoveries. Questions develop over who controls the university research agenda, the allegiance of scientists to their university employer, the willingness of scientists to discuss research discoveries related to potentially patentable products, and the potential favoritism shown particular companies by the university because of its research ties.

If policymakers want land grant universities to refrain from conferring property rights, it will be necessary for them to provide a level of funding whereby land grant universities can compete with non land grant universities that confer such rights. This basic decision may be one of the most important related public policy decisions since the land grant system was created. Once the system starts competing actively for private sector grants and conferring licensing rights, there will be no turning back [3,4].

Adjustments Needed in the System

The progress of the public agricultural research community in establishing priorities and in adjusting the distribution of its resources among research programs in recognition of potential advances evolving from biotechnology and information technology is considerably more advanced than that of the extension community. Land grant and United States Department of Agriculture (USDA) resources are shifting in the direction of more basic research. As resources are directed to address more basic research issues, there is a potential for gaps developing in the system's traditional function of problem solving and new product testing. This new technological era presents important challenges to the extension community. Extension may have to become more involved in applied research and product testing research to evaluate technologies and products flowing out of the private sector. Without such evaluations, individual farmers can incur exceedingly high costs of experimenting to determine which combinations of products are most profitable to use. Extension staff training and development will be required at both the state specialist and county level for extension to play an effective role in product testing, evaluation, and in technology transfer during the biotechnology and information technology era. Without such training, extension's role in production agriculture will diminish. Technology transfer will occur less efficiently with more structural impacts — larger farms will benefit at the expense of smaller farms.

At current funding levels, the most difficult issue facing extension is whether to limit its role and coverage to those functions for which it has the greatest expertise. Without criteria for limiting the role of extension, extension activities might become so dispersed and out of focus that their effectiveness would be impaired. Regardless of whether the problem is related to agriculture or not, extension may be called upon to solve it. It is not possible for extension to be everything to everybody, particularly in times of limited resources.

As a starting point for defining the role, it must be remembered that the root of extension is research. Similarly, extension is a primary outlet for research, after an appropriate level of product development. Extension is, therefore, delimited by the scientific endeavors of the research components of the agricultural research system, including both the public and private sector components [6].

The major clientele of the experiment station and the extension service are the farmer and rural people. Two major questions must be addressed by extension:

1. Can extension survive without the moderate size farm clientele? and

2. Can extension survive with the primarily urban based clientele it has cultivated over the past few years?

In addition, basic organizational issues need to be addressed by the extension service as it enters the biotechnology and information technology era. The premise upon which extension was developed was that of the research scientists conveying the knowledge of discoveries to the extension specialist who, in turn, supplies information to the county agent who teaches the farmer. Over time, this concept has gradually but persistently broken down as agricultural technology has become more complex, and insufficient resources have been devoted to staff development. Consequently, more emphasis has been placed on direct specialist-to-farmer education. More specialists have been placed in the field to have closer proximity to their clientele, but at the cost of less contact with research scientists. A basic structural reevaluation of extension's function and organization is needed.

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