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THE BIOTECHNOLOGIES: POLICY RAMIFICATIONS FOR AGRICULTURE

by

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Increasing the food supply has long been a concern of society. Malthusian prophets have forecast starvation due to the expansion of the world's population beyond agriculture's capacity to produce. But to date, new technologies, cultural practices, and resources have enabled agriculture to keep pace with the increasing demand for food. However, the rate of increased agricultural productivity has slowed in recent years (Lu, 1983).

Now apparently technological breakthroughs in genetic engineering of plants and animals will allow major, sudden increases in agricultural productivity. To some, genetic engineering and other new biotechnologies are seen as the solution to the world's hunger and health problems; to others, genetic engineering conjures up a myriad of problems--ethical, environmental, economic, and political. The reality probably lies somewhere in between these extremes. Still, when public and private industry scientists and research leaders were asked to evaluate areas of research with the greatest potential impact on agricultural productivity and with a probability of at least 50 percent of being introduced for commercial adoption by the year 2000, they ranked the genetic engineering of plants and animals No. 1 (Lu, 1983, pp. 4, 6).

In this paper, we consider economic and policy ramifications that may accompany developments in genetic engineering. We do not survey the many specific research developments and projects underway in the field of genetic engineering, but illustrate with a few specifics.

"Genetic engineering" as used in this paper is the ability to manipulate the information flow of a biological system that is performed by the genetic structure of an organism. This manipulation is accomplished by regulating or altering the genes. (For a discussion of the methods of genetic engineering, see Board on Agriculture, 1984, and Skelsey, 1984.)

By "revising" or recoding the genetic structure of an organism, the scientist can make plants resistant to various diseases, herbicides, or unfavorable soil conditions; can enhance the photosynthesis process; or can improve the chemical (nutrient or caloric) composition of the plant for human and/or animal consumption. By understanding the genetic workings of the defense mechanisms of plants and animals, scientists will be able to work on those beneficial to agriculture (e.g., encourage stress resistance) and to attack those harmful to agriculture (e.g., break down insect resistance to pesticides) (Skelsey, 1984, pp. 24-25). Genetic engineering also inspires visions of disease prevention and its elimination for animals--and humans. The potential for this new technology appears limited only by the imagination of the scientist. Its application for plants and animals is vast: growth regulation; embryo transplants; gene insertion; disease control; resistance to environmental and biological stress from, for example, saline or drought conditions; nitrogen fixation; and pesticide and herbicide tolerance.

Furthermore, the time framework for such accomplishments may be greatly compressed compared to that for more traditional research programs (Skelsey, 1984). For example, new traits can be developed by splicing genes into a plant or animal and then seeing if the desired traits are carried by the next generation. The time required to obtain the knowledge by selective breeding or cross breeding would be considerably longer--if such results could be obtained at all.

Despite the strong interest and research emphasis on genetic engineering, the field is still in relative infancy. The theories and methods of gene splicing have been developed, but the knowledge about which explicit genes transmit the desired (or undesired) trait is far from complete. Also, the factors that trigger the genes to become active in the information flow is not yet known (Skelsey, 1984, p. 16). And each plant or animal cell contains thousands of individual genes which affect particular physiological processes, but scientists can yet work with only one gene at a time (Arntzen, 1984).

Although the ability to alter the genetic structure via engineering methods is much more difficult or even impossible as the number of genes involved increases (Skelsey, 1984), there are major breakthroughs on the horizon whenever the process being treated is relatively simple. Bachrach (1983, p. 94) notes:

> Transformation that can be effected through single-gene splicings have the greatest prospects for early success. Fortunately, these include the resistance of plants to a wide variety of organisms including fungi, bacteria, viruses, mycoplasmas, nematodes and insects, which consume 25 to 30 percent of American crops.

Some new technologies will be on the market and adopted by farmers by the end of the 1980s according to some observers and researchers (Bachrach, 1983). A California research company has put a herbicide-resistant gene into a tobacco plant which allows the plant to withstand weed spray (The Sacramento Bee, 1985). The company expects to commercialize this finding within two years. Another comapny has developed a bovine growth hormone which, based on tests at Cornell University, will significantly increase milk production in dairy animals. Commercial availability of the growth hormone is expected in the next two or three years. Other scientists have reported the development of a bacteria which lowers the temperature at which frost develops on the leaves of strawberry plants.

The potential for increased agricultural production from this type of research is enormous. Table 1 shows projections from the Office of Technology Assessment that indicate substantial increases in U.S. farm production by the year 2000, principally from technological advances.

Table 1. Projections of Increased Production by Year 2000, Various U.S. Commodites

	1982	2000	Percentage Increase
Milk per cow (1,000 pounds)	12.3	24.7	101
Corn (bushels per acre)	115	139	12
Cotton (pounds per acre)	481	554	15
Rice (bushels per acre)	105	124	18
Soybeans (bushels per acre)	30	37	12
Wheat (bushels per acre)	36	45	25

Source: Phillips, 1985.

While most people support such technological growth, there are many dimensions involved--and many unforeseen outcomes for the future of agriculture. Effects will be felt by individual producers, processors, wholesale and retail marketers, and consumers. The aggregate impact on the structure of agriculture worldwide and on related industries is yet unknown.

From the producer's point of view, the new breakthroughs may mean rapid changes in their systems of operation as adoption of the new technologies is necessitated if a farm is to remain competitive. Generally, reduced costs and/or increased yields will be expected with adoption. But the nature of the product itself may also change as genetic engineering alters protein content or enhances photosynthesis. Such developments will also require an increased emphasis on management practices and planning as new operational techniques and biological knowledge are incorporated into the production system.

Suppliers will face changing demand for inputs they market to the farming sector. The development of resistant plants should increase farmers' demand for pesticides and herbicides. There will be new forms of inputs to market: hormone implants for animals, plant sprays, and new seed stock. New methods of marketing high technology inputs and servicing customers will be required. The question of property rights on marketable biotechnologies is already an issue.

Food processors and marketers will be affected, for changing agricultural products may require changes in handling, safety standards, and processing techniques. For example, the development of a genetic structure to preserve freshness or shelf life of food products would have an important impact on inventory planning. Safety and quality regulations will need to be reexamined continuously to keep pace with scientific developments.

Certainly, consumers should expect lower relative prices and improved quality from the new biotechnologies. (This does not necessarily mean, however, increased per capita food consumption in a quantitative sense.) New products and new forms for old products will call for education about their nutritional attributes.

Given such changes, planning for tomorrow's agriculture is needed. Technological change will put larger farms with younger, better educated managers and a greater ability to obtain financing and handle risk at a distinct advantage (Molnar, Kinnucan, and Hatch, 1985). The comparative advantage that one region or nation has over another in crop production because of weather, soil, and other environmental conditions could change if environmental tolerance is inserted into plants. Then, locational decisions for production and processing could be based mostly on transportation and marketing considerations and the relative abilities to utilize the complex technologies (Molnar, Kinnucan, and Hatch, 1985).

The possible release of the production location constraint is of major significance to California agriculture with its important export markets. The development of a drought-tolerant plant, a salt water-using plant, a nitrogen-fixing plant, or an increased protein-producing plant would greatly aid developing countries in meeting their own food needs--if, in fact, the particular technological development is transferable. (For a discussion of foreign competition in biotechnology, see Phillips, 1985.)

Input markets will see new firms rise and some fall. There has been a fast growth in private sector research companies (as well as quick exit of some) as the search goes on for the innovation that offers the economic "goldmine" (Phillips, 1985). Patentable changes (through the Plant Variety Protection Act) offer monopoly power to the firm with the first breakthrough in the quest for the "billion dollar gene." But monopolies may be broken over night with the next breakthrough. Firms will have to make substantial investment in research and development just to maintain their position in the industry.

Genetic engineering may result in inputs which are substitutes for existing ones (e.g., new seed stock) or complements for items now used (e.g., injections, sprays, implants for animals). New inputs will call for new supply firms, and if a desirable trait is not carried through from one generation to the next (as was the case with hybrid corn), an entirely new supply source will develop in response.

And, of course, it is possible that new food products may be developed which can be produced in an entirely nontraditional agricultural setting. That is, food products may be synthesized in a factory-like setting.

Consider the following illustrations, to gain a more explicit understanding of the ramifications of genetic engineering.

Cornell University researchers have been testing a bovine growth hormone (BGH) developed through genetic engineering techniques. BGH injected into a cow has the potential, based on these experiments, to stimulate her milk production by as much as 25 percent over the lactation period (Kalter et al., 1985). While a somewhat higher energy ration must be fed, no ill effects on either the animal or milk quality have been observed during the relatively short time the experiments have been conducted (Kalter et al., 1984 and 1985). These Cornell researchers expect adoption by up to 85 percent of the nation's dairies within three years of the commercial release of the hormone (Kalter et al., 1984), and this release could occur within two or three years.

But the rapid addition of 25 percent more milk is not entirely attractive in an industry whose excess capacity is already a severe problem--so severe in fact that the government is buying out whole herds. While the price of milk could be expected to drop, consumer demand for milk and milk products is relatively inelastic, meaning that total consumption wouldn't increase as much in percentage terms as the price falls. So the excess capacity in milk production would increase and producers might be forced to drop prices still further. And, of course, the productive base of the dairy industry would sooner or later have to be reduced. Kalter et al., (1985) estimate that if price supports for dairy products were removed and the growth hormone is introduced, the number of dairy farms could fall by 40 percent. With the same assumptions, Phillips (1985) figures that cow numbers could drop by 30 percent.

Molnar, Kinnucan, and Hatch (1985) speculate about the location pattern of milk production after the adoption of BGH. Perhaps the hormone would allow deficit-production regions to become self sufficient, meaning that regions now supplying them would have more surplus.

A major question about increased production resulting from biotechnological developments such as BGH is: What happens to the resources now used in agriculture which become redundant from technological change? For example, if the number of dairy farms is reduced by 40 percent as the Cornell researchers project, what alternative employment do producers have? What other use will be made of the land now used to grow crops to feed the dairy cows? If cow numbers are reduced by 30 percent, what happens to the other industries servicing dairy? Reduced cow numbers will also mean reduced demand for hay and grain, and, therefore, reduced water needs for irrigation. In a state like California where water use is a major policy issue, reduced dairy production could permit reallocation of water supplies for other uses, especially urban areas. At the same time, higher energy feed requirements for remaining dairy animals might require changes in crop rotation patterns to supply these inputs. Clearly, the structural implications of BGH extend beyond the dairy industry.

This one example illustrates some of the major policy questions facing government officials and industry personnel whenever such production breakthroughs occur. When there is already surplus production, what policy instruments are needed for supply control in the face of significant production increases stemming from a relatively low-cost genetically-engineered alteration? Can such policy needs be foreseen to avert the inevitable economic consequences? What policy changes may be needed to facilitate the departure of unneeded resources? Advanced planning on a significant scale is called for to ease the pain of severe adjustments in agriculture that are already occurring.

But not all the ramifications of genetic engineering are economic in nature. In some instances, the biological problems may prove of greater concern than the economic ones. As Molnar, Kinnucan, and Hatch (1985, p. 16) note, the potential "virulence of altered organisms, or the ability of new organisms to gain a selective advantage" is a major fear. In working with such frontiers of science, they comment, "it is not unreasonable to expect that . . . unfortunate mistakes or accidents will occur in the future." But they also voice a concern that overreaction to potential dangers will result in excessive regulation that could stifle advancement.

As an example of an noneconomic concern, consider the case of the California scientists who have isolated the gene from the bacteria which aids in the formation of ice crystals on strawberries. After inserting a new gene by genetic engineering, the bacteria is stripped of its ice-making traits. When the altered bacteria is sprayed on the plant, the temperature at which ice forms on the plant is reduced.

While protection of plants against environmental stress appears at first glance to be beneficial, the development of the bacteria has not been without critics. Lawsuits have delayed its testing. The primary concern here (and in other similar cases) is: "Can the technology be controlled once it is released?" For biological breakthrough may solve the problem at which it is directed, but often little is known about secondary effects. In the case of the frost-free bacteria applied to strawberries, opponents have asked what would happen if the new bacteria strain should dominate the original one and eventually spread to the atmosphere. Then, the frost-forming bacteria would no longer be available to aid the development of precipitation with the result that weather patterns could change dramatically. Proponents of the new bacteria hold that such an occurrence is extremely unlikely.

But the point remains that scientists have little experience or knowledge about how genetically engineered plants and animals interact with and affect the environment. Will the traits such as herbicide resistance in plants be spread by some mechanism to undesirable plants? Although some plants may be made resistant to the herbicides and pesticides, will the residual of such chemicals in the soil cause further pollution problems or preclude traditional crop rotation patterns (see Doyle, 1985)? At this point in time the way that various synthetic organisms will survive, grow, and escape their charted habitat cannot be predicted with much confidence. Acceptable levels of risk need to be established by the innovative scientists, on the one hand, and the public, on the other.

The economic questions accompanying the development of BGH and the biological questions raised about the frost-free bacteria serve to illustrate some of the longer run repercussions that need to be addressed in the planning process while, at the same time, scientists are delving into the genetic nature of plants and animals. By looking ahead, agriculture can possibly avoid the position of being forced into short-run reactions rather than taking anticipatory actions for longer run solutions. In addition, the general public needs to be educated and become involved if the potential benefits of the biotechnological age are to be realized and enjoyed.

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