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Agricultural Biotechnology

An Economic Perspective

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Abstract

The development of agricultural biotechnology offers the opportunity to increase crop production, lower farming costs, improve food quality and safety, and enhance environmental quality. This report describes the economic, scientific, and social factors that will influence the future of biotechnology in agriculture. The supply of biotechnology innovations and products will be affected by public policies and by expectations of producer and consumer demand for the products. The demand for biotechnology by farmers and food processors is derived from the expected profitability of using the technology as an input to production. Ultimately, the use of biotechnology in the farm sector will depend on consumer demand for the biotechnology-derived agricultural product.

Keyword: Biotechnology.

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Summary

The development of agricultural biotechnology offers the opportunity to increase crop production, lower farming costs, improve food quality and safety, and enhance environmental quality. There are public concerns, however, that the negative effects of biotechnology may outweigh the potential benefits. This report describes how social, economic, and policy factors will influence the development, consumer acceptance, producer adoption, and effects of agricultural biotechnology.

Biotechnology techniques can be used to increase a plant's ability to control pests and disease, to tolerate environmental stress, and to enhance food qualities, such as flavor, texture, shelf-life, and nutritional content. Biotechnology can be used for animals to diagnose disease, promote growth, and develop vaccines. Other uses include increasing food processing efficiency and developing more effective diagnostic techniques for testing food safety and environmental quality. Crops could be genetically modified to provide oils, starches, carbohydrates, and proteins tailored for specific uses. For example, carbohydrates or sugars extracted from these new crops could provide a more efficient energy source for bioprocessing to produce products such as ethanol or biodegradable plastics. Also, certain proteins could be genetically incorporated into plants and then harvested as pharmaceuticals.

Initial applications of biotechnology have been in the field of medicine. Biotechnology-derived insulin now makes up most of the therapeutic supply for that drug, and hepatitis-screening techniques have greatly improved the safety of donated blood. The Food and Drug Administration (FDA) recently approved the use of a new genetically engineered drug for multiple sclerosis and an FDA advisory panel has recommended approval of a new drug for the treatment of cystic fibrosis.

Agricultural biotechnology applications, however, have not been developed and introduced as quickly. Nor have they been as well received by the public as some of the human health developments. Some agricultural biotechnology products are ready for commercialization, but are or have been awaiting FDA approval. One example is a vine-ripened tomato with an extended shelf life that would be offered directly to consumers in the marketplace. Another example is a milk production enhancer, bovine somatotropin (bST), which was approved recently by the FDA after several years of deliberation over the effects of bST on human and cow health.

Both private and public sector research and development (R&D) are contributing significantly to the development of agricultural biotechnologies. Stronger legal protection for ownership of biological inventions has increased incentives for biotechnology R&D, especially by the private sector. Public sector research promotes basic scientific knowledge and develops socially beneficial technologies that are not profitable for the private sector, such as some environmental technologies. New funding mechanisms have been developed to encourage private and public research partnerships. Other public policies that influence private sector R&D include regulatory policies, tax policies, and educational policies.

Consumer acceptance of agricultural biotechnology products will be the motivating force in whether agricultural biotechnology innovations will be developed and finally adopted by farmers. Concerns have been raised by many members of the public about the potential effects of biotechnology on food safety, environmental quality, and social change. Food safety concerns about agricultural biotechnology include changes in the allergenicity or nutritional content of food. The development of herbicide-resistant crops could encourage the use of more benign herbicides, but may add to environmental problems if more herbicides are applied.

Social change is induced by the introduction of any new technology, and the individuals that benefit from biotechnology may not be the same as those who bear the costs. For example, the introduction of some agricultural biotechnologies may benefit larger and more efficient farmers, thereby reducing the number of small farms and affecting rural communities. Also, some biotechnology products may be developed to replace imports of agricultural commodities from less developed countries (LDC's). The loss of markets for primary export products would be critical for developing nations. Ethical questions have been raised about animal welfare and the transfer of human and animal genes into plants and animals different from the host species.

Some groups have requested the labeling of some or all foods produced using biotechnology techniques, especially genetic engineering. Labeling should provide facts that enable consumers to make informed purchasing choices. Many have claimed that they have a

“right to know” whether foods have been developed using biotechnology regardless of whether or not there exists a potential health or environmental risk. The FDA regulates food labeling requirements under the Federal Food, Drug, and Cosmetic Act.

Economic assessments of agricultural biotechnology will reveal the type and direction of changes that may be expected and which groups (farmers, consumers, regions, countries) may be affected. A review of 23 studies on the economic effects of agricultural biotechnology prompted two major conclusions. Fist, the economic impact of biotechnology is likely to be incremental rather than dramatic. Second, a significant amount of the economic benefits will be broadly distributed to consumers in increased supplies, lower prices, and higher valued products.

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Introduction

The development and use of new technologies have brought about a continuing increase in agricultural productivity. These technologies can be mechanical, chemical, or biological. Previous "revolutions" in agricultural technology can be traced to the introduction of modem industrial inputs such as the tractor and other mechanized implements, chemical fertilizers and pesticides, hybrid plants, and livestock feed additives. These technologies, for the most part, substituted for land and labor to increase crop and livestock production. These revolutions are not complete, however. The technologies are still being introduced in many parts of the world, so agricultural productivity will continue to increase in these areas. The mechanical, chemical, and biological revolutions represented a fundamental change in agriculture and have had significant social and economic impacts. They represented the incorporation of a new generic technology throughout the economic sector leading to a new "technological paradigm" (OECD, 1989).

The development of biotechnology may be the beginning of a new agricultural revolution. Biotechnology can be broadly defined as the use of living organisms to solve problems or make useful products. This definition includes traditional plant and animal breeding methods, and bioprocessing, such as fermentation. The new biotechnology is the application of cellular and molecular biology to meet human needs, a definition that includes the use of monoclonal antibodies, cell culture, biosensors, and genetic engineering technologies (see box, "Biotechnology Techniques and Applications"). In the following discussion, the term 'biotechnology" will refer to these newer techniques. Biotechnology is a term for a broad generic technology made up of many individual techniques that are potentially valuable for many applications. Blanket statements about biotechnology should be avoided because the term encompasses so many techniques and applications.

There are many potentially beneficial applications of agricultural biotechnology. Biotechnology techniques can be used to increase a plant's ability to control pests and disease, to tolerate environmental stress, and to enhance food qualities, such as flavor, texture, shelf-life, and nutritional content. Biotechnology can be used for animals to diagnose disease, promote growth, and develop vaccines. Other uses include increasing food processing efficiency and developing more effective diagnostic techniques for testing food safety and environmental quality. Crops could be genetically modified to provide oils, starches, carbohydrates, and proteins tailored for specific uses. For example, carbohydrates or sugars extracted from these new crops could provide a more efficient energy source for bioprocessing to produce products such as ethanol or biodegradable plastics. Also, certain proteins could be genetically incorporated into plants and then harvested as pharmaceuticals (Jones and Harlander, 1992). Applications of biotechnology will be pervasive. However, it is the many "small" changes that will result in the new agricultural revolution.

Biotechnology is part of the natural evolution of agricultural biology and could shorten the time for developing improved crops. For example, deciphering the genetic codes for the major agricultural crops would allow researchers to more quickly identify single or multiple genes that regulate specific crop traits. Despite the progress made in recent years, it will be some time before the genetic codes are completely broken for the major agricultural crops. A USDA scientist estimated that "if the genetic codes in a single pollen grain of wheat were typed single-spaced into thousand-page volumes, and the volumes stacked, you would have a tower the height of a 20-story building" (Marsa, 1993). Also, cell culture techniques permit researchers to rapidly determine whether a desired trait has been incorporated into a plant (see box, "Biotechnology Techniques and Applications").

Biotechnology Techniques and Applications

The "new" biotechnology is the application of cellular and molecular biology to meet human needs. Many biotechnology applications are an extension of traditional plant and animal breeding techniques. Biotechnology tools are often complements of traditional methods rather than replacements. The traditional methods are limited, however, to species that are sexually compatible. Biotechnology can expand the range of traits beyond those found in compatible species, but the use of genetic engineering is limited to materials that can be biologically manipulated (OECD. 1989). Current biotechnology techniques are most effective when applied to one gene at a time. However, many of the more important economic traits in plants are controlled by multiple genes (Martin and Baumgardt, 1991).

The term "biotechnology" refers to all parts of an industry that creates, develops, and markets a variety of products using monoclonal antibodies, cell culture, biosensors, and genetic engineering techniques.

Monoclonal antibodies are "identical antibodies that recognize a single, specific antigen (substance that elicits an immune response)" (OTA, 1992), and are produced in batches by fusing tumor cells with the antibody-producing cells. This technique is a diagnostic tool that detects cell proteins and is being used commercially for improved diagnostics and vaccines in human health care. In agriculture, monoclonal antibodies can be used for the diagnosis of plant diseases or the detection of pesticides in foods, and for developing animal vaccines.

Cell culture is used to rapidly propagate cells isolated from living organisms to produce near-identical clones. The new organism is grown in *vitro* (literally "in glass") from a single cell, embryo, or plant part. This technique gives the ability to screen a large number of individual cells for a trait at a relatively small cost.

Biosensors can detect and measure the presence of specific biomolecules. Chemical biosensors consist of an immobilized *enzyme* that binds to the target chemical. Often a color reagent is included to visually indicate the presence of the trace chemical (Fleschar and Nill, 1993). Electronic biosensors are created by fusing organic matter to electrodes to convert chemical reactions to electric currents that can then be monitored.

Genetic engineering is the selective, deliberate alteration in the genetic material of organisms (Fleschar and Nill, 1993). It is the use of genetic engineering to create transgenic organisms that has engendered the most discussion among scientists and members of the public. A transgenic organism is one "whose hereditary DNA has been augmented by the addition of DNA from a source other than parental germplasm using genetic engineering techniques" (OTA, 1992). In current usage, the term "genetic engineering" is synonymous with gene splicing and recombinant DNA (rDNA). The key components of genetic engineering techniques are to isolate the desired gene, to use a delivery system to introduce the gene into the recipient cells, and then to detect the expression of the new genetic information in the recipient cells. The gene transfer systems currently being used are: (1) Ti-plasmids of *Agrobucterium tumefaciens;* (2) plant viruses; and (3) direct DNA systems such as protoplast transformations and microinjection (Copping and Rodgers, 1985).

The introduction of any technology portends change, and the individuals who benefit from technological change, including biotechnology, may not be the same as those who bear the costs. The differences between beneficiaries may be across regions, countries, market sectors, or social groups. Policymakers need to know the tradeoffs that members of the public will face with the introduction of biotechnology-derived agricultural products. Economic analysis offers a framework into which such data as technological characteristics, biological responses, fate and transport of chemicals, human behavior, and environmental benefits can be placed to evaluate the magnitude and distribution of net benefits associated with a new technology. This evaluation is called a technology assessment.

Initial applications of biotechnology have been in the field of medicine. Many new drugs have been developed using biotechnology. For example, biotechnology-derived insulin now makes up most of the therapeutic supply for that drug, and hepatitis-screening techniques have greatly improved the safety of donated blood (Fisher, 1993). The Food and Drug Administration (FDA) recently approved the use of a new genetically engineered drug for multiple sclerosis and an FDA advisory panel has recommended approval of a new drug for the treatment of cystic fibrosis (Southerland, 1993). Recent breakthroughs in gene transfer therapy to correct genetic disorders in humans have received wide publicity and generally favorable reactions from the public. Agricultural applications of biotechnology, however, have not been developed and introduced as quickly. Nor have they been as well received as some of the human health developments.

The first genetically engineered food product to enter the market was recombinant chymosin, which replaces the enzyme rennet in the production of cheese and other processed dairy products. The FDA declared recombinant chymosin as "generally regarded as safe" (GRAS) in March 1990. A milk production enhancer, bovine somatotropin, has been ready for commercialization for several years, but introduction was slowed by FDA delays in setting policy about the review and approval of new types of products (Southerland, 1993). The first biotechnology-derived whole plant product to be offered directly to consumers will probably be a vine-ripened tomato with an extended shelf life. Table 1 presents selected milestones in the development of commercial agricultural biotechnology. Table 2 illustrates the range of applications and the crops that are being developed. The list includes only research that is nearing the commercialization stage (Beck and Ulrich, 1993).

Public concern and distrust have caused biotechnology to be closely watched. Some members of the public have concerns about food safety and environmental quality. Confidence by some segments of the population in government safety regulations and industry responsibility is low, and there is skepticism and

Table 1-Selected milestones in the development of agricultural biotechnology

1866	Mendel postulates a set of rules to explain the inheritance of biological characteristics in living organisms.
1953	Watson and Crick discover the double-helix structure of DNA.
1960	Genetic code deciphered.
1973	First gene (for insulin production) cloned, using rDNA technology.
1976	First new biotechnology firm established to exploit rDNA technology (Genentech in USA).
1980	U.S. Supreme Court rules that microorganisms can be patented under existing law *(Diamond v. Chakrabarty).* Cohen/Bayer patent issued on the technique for the construction of rDNA.
1982	First rDNA animal vaccine approved for sale in Europe (colibacillosis). First rDNA pharmaceutical (insulin) approved for sale in U.S. and UK. First successful transfer of a gene from one animal species to another (a transgenic mouse carrying the gene for growth rate hormone). First transgenic plant produced, using an agrobacterium transformation system.
1983	First successful transfer of a plant gene from one species to another.
1985	U.S. Patent Office extends patent protection to genetically engineered plants *(Ex Parte Hibberd).*
1986	Transgenic pigs produced carrying the gene for human growth hormone (USDA, Beltsville, Maryland).
1987	First U.S. field trials of transgenic plants (tomatoes with a gene for insect resistance). First U.S. field trials of genetically engineered microorganisms (Frostban in California).
1988	U.S. Patent Office extends patent protection to genetically engineered animals. First genetically modified microorganism approved for commercial sale as a biocontrol agent of a plant disease (crown gall of fruit trees in Australia).
1991	Guidelines published for field trials of genetically modified organisms (ABRAC).
1992	FDA announces policy on foods derived from new plant varieties. USDA permission to Calgene, Inc., for Flavr Savr tomato.
1993	USDA-APHIS notification procedure to streamline permitting process. FDA approves supplemental bST for commercialization.
1994	Congressional moratorium on supplemental bST ends. FDA considering policy on voluntary labeling for supplemental bST.

Source: Adapted from Persley, 1990.

distrust of the benefits of technology in general. Concerns about the effects of technology certainly are not new. In 1811, a band of weavers in England tried to destroy the machines that would eliminate their jobs (Watson, 1993). This band was called the "Luddites," a name now synonymous with any opponent of new technologies. The start of the modem environmental movement is often ascribed to the publication of *Silent Spring* (Carson, 1962), which described the potential ecological consequences of chemical use. Public awareness of the mixed nature of technology introduction has increased with each new example of a problem.

Agricultural biotechnology is applied to the production of food, so the technology has the potential to affect everyone. Some people are "intensely technology averse where food is involved" (Beck and Ulrich, 1993). Food consumption is one of the few activities over which people feel they have control (Marsa, 1993). Careful scrutiny of the introduction of agricultural biotechnology was inevitable. Early proponents of biotechnology may have exacerbated the public concerns, however, by arguing in the same breath that "genetic engineering was novel, different, and exciting and that it carried no new risks" (Dixon, 1993).

Table 2-Commercially tangible plant biotechnology research

Application*	Crop
Insect resistance	Apples, cabbage, coffee, corn, cotton, lettuce, mustard, potatoes, rapeseed, rice, tomatoes, wheat
Viral resistance	Alfalfa, bananas, cantaloupe, cucumber, melons, potatoes, squash, tomatoes
Bacterial and fungal resistance	Cantaloupe, cucumber, squash
Herbicide resistance	Canola, cottonseed, soybeans, wheat
Frost resistance	Strawberries, tomatoes
Nitrogen fixation	Soybeans and other legumes
Disease diagnostics	Bananas
Delayed ripening for improved harvesting, transportation, or shelf-life	Broccoli, melon, raspberries, tomatoes
Increased starch or solids content for improved food processing	Potatoes, tomatoes, wheat
Seed control for improved seed harvesting or consumption, or for weed control	Potatoes, grapes, asparagus (respectively)
Oil composition changes for improved processing or health	Canola, soybean, sunflower
Improved flavor	Coffee, lettuce, potatoes, tomatoes
Improved protein content	Soybeans
Crispness retention	Celery. carrots
Healthier crop	Palm
Increased sugar content	Chicory
Increased cancer protective agent	Strawberries
Lower caffeine	coffee
Individual serving size	Lettuce

*These applications are being developed using many different biotechnology techniques including cell culture, classical breeding with screening, cell fusion, antisense, diagnostics, micropropagation, bioreactors, and somoclonal variation.

Source: Adapted from Beck and Ulrich (1993).

This report describes the economic and policy factors that influence the development, transfer, and effects of agricultural biotechnology. Investments in technology development and the demand for biotechnology by farmers and consumers will be determined by expectations of the effects of biotechnology use.

The supply of innovations will be determined by the research investments made by both the private and public sectors. The types of private investments that are made will depend on the expected profitability of biotechnology research. The returns to research investments will depend on the costs of innovation and development and the benefits of the biotechnology product. Public investment in research will depend on social costs and benefits, which may include factors not considered by private firms. The ultimate value of a new biotechnology innovation to society will depend on the extent and rate of technology transfer, and on the impacts of biotechnology adoption on the economy, the environment, and public well-being.

Factors Affecting the Supply of Agricultural Biotechnology

New technologies do not just appear in an industry. Although luck may play a part, most innovations are the result of investments in research and development (R&D). The decision by a private firm or public institution to invest is based on an assessment of the costs and the benefits of that investment. The expected profitability, or net benefits, must be greater for investing in R&D than using the money elsewhere. Investment is a risky venture, however, because there is no guarantee that a research expenditure will result in a profitable innovation. In other words, there is no "production function" for new technologies with which to calculate the number of inventions for a given level of investment.

Modem R&D is often sequential, and all components do not have to be undertaken by the same organization (Scherer, 1980). Basic research is conducted to gain knowledge that will be broadly applicable to other research or technology areas. Basic research is also known as general or "foundations" research. Applied research is directed toward developing a marketable product. Development is the process of testing, modifying, and perfecting to make the technology ready for commercial utilization. The bulk of R&D expenses for private firms is spent on development. Public expenditures are greater for basic research than for either applied research or development.

Both private and public R&D contribute to the supply of technological innovations. Public policies affect the profitability of private R&D investment through mechanisms that include direct public funding of research, intellectual property rights legislation, regulatory policies, financial and tax policies, education policies, and other policies covering the environment and industry.

Private Investment in Biotechnology R&D

Private organizations invest in agricultural biotechnology research in order to increase profits. In general, firms accomplish this by investing in R&D to develop a new technology that will reduce production costs and/or to develop new products that increase the firm's market share or create new markets. There will always be uncertainty about whether the research will result in the desired product. Several factors may influence private investments in R&D, including the appropriability of a technology, public funding of basic and applied research, technological opportunity, and expected demand for the product produced by R&D (Griliches, 1984; Thirtle and Ruttan, 1988). The term "technology" refers to all knowledge resulting from R&D efforts (Govaere, 1991).

A firm's R&D investment is motivated by that firm's ability to capture the returns to innovations resulting from its R&D efforts. Appropriability refers to the ability of a firm to "own" the innovation and exclude others from its free use. If other companies have immediate access to the new technology and are not required to compensate the firm that does the research, there would be little private sector incentive to conduct R&D. A biotechnology research project would not be funded if the company did not expect to recoup its investment costs and earn a profit for its innovations. In general, the higher the appropriability associated with a new technology, the greater the expected payoff and the greater the incentive to develop it.

Firms can apply various mechanisms to enhance the degree of appropriability, including intellectual property rights, such as patents and copyrights; lead time (that is, developing the technology first and capitalizing on the time it takes the competition to imitate); and trade secrecy. The degree to which a firm is able to use these mechanisms depends on a number of factors such as the characteristics of the technology itself, the intellectual property rights available, government regulations, and the market structure of the industry. The legal framework for assigning appropriability is still being developed to encompass the rapid scientific changes from biotechnology research. The following section on public policies includes a detailed discussion of intellectual property rights.

The expected profitability of private R&D will also be influenced by public funding of basic and applied research. Basic research is typically a longrun venture and uncertainty exists as to whether the research will result in a "useful" product. Private firms engage primarily in applied research, which most often yields immediate or near-term commercial applications. Without advances in knowledge generated from basic research, however, applied research would be more expensive and less productive. In addition, the results of basic research are generally not appropriable. Since basic research usually does not lead immediately to a commercial product, private profits to be gained from basic research would be low (or nonexistent), so private firms would not be expected to invest much in basic research.

Publicly funded basic research could increase technological opportunity in an industry. Increased technological opportunity, in turn, may induce firms to invest more in R&D. Technological opportunity refers to the potential for development of new technologies in an area due to advances in basic scientific knowledge or to technological advancements in other, related fields. Research in the basic sciences expands the opportunities for doing applied research on technological innovations. Some new biotechnology developments in agriculture and health resulted from basic research in fields such as molecular biology. For example, the combination of molecular and computer techniques has resulted in the development of "expressed sequence tags" that are used to track down a particular gene. This development allows scientists to characterize the gene's protein and develop products more quickly (Wuethrich, 1993). The range of potential new products that can be economically developed has been expanded by basic research.

Technological opportunity may also be enhanced if the cost of R&D inputs decline. For example, genetic engineering and tissue culture techniques (compared with traditional plant breeding methods) can reduce the time necessary to develop new plant varieties, thus lowering the development costs for new varieties. For many agricultural plants, the development time may be shortened only by a couple of years through the use of biotechnology methods. For trees, however, the use of tissue culture to screen and evaluate traits can reduce the time to develop new varieties from 20-30 years to 2-3 years.

The public sector also funds applied research, but to a lesser degree than the private sector. Publicly supported applied research is mainly for developing technologies that would have high social payoffs but that are unlikely to be developed by the private sector. Public health and defense are two examples of social needs for which the Government assumes a major research responsibility. Public research institutions have tended to avoid applied research in areas that might compete with activities underway in the private sector. Distinct lines between sectors are hard to draw, however. The private sector involved in biotechnology research is made up of many companies, each with its own goal and strategy. The public sector is composed of a diverse group of education, research, and regulatory institutions. Recent changes in university-industry-government relationships are further blurring the distinctions between the appropriate roles for public and private sector research (Day and Frisvold, 1993).

A firm's expected profit from developing a new technology is also influenced by the demand for an innovation or product. Shifts in demand will affect a firm's expected profits, so market forces or policies that result in a demand shift will influence the level of research activity in an industry. Agricultural biotechnology research will not be privately funded if it is expected that the biotechnology-derived product will not be adopted by producers or accepted by consumers.

The international demand for an agricultural innovation or product may influence the choice of agricultural biotechnology R&D projects in the United States. Private research in the United States focusing on Third World staple crop varieties such as cassava and banana/plantain will probably not be greatly increased until international patent laws are improved (that is, developing countries are prevented from the free use of the technology) and the purchasing power of developing countries increases enough to spur the demand for U.S. products (Persley, 1990). Developing countries are concerned that private agricultural research in the United States favors the development of crops that replace raw materials currently purchased from developing countries (Lacy and Busch, 1991).

The private sector has been making substantial investments in biotechnology R&D. In 1988, approximately 500 U.S. firms were investing between $1.5 and $2 billion a year on biotechnology research (Lacy and others, 1988). Despite the difficulty of raising venture capital in a new industry, public investors put nearly $6 billion into 1,000 biotechnology companies between 1991 and 1993 (Fisher, 1993). Only about 50 of these firms were engaged in agricultural biotechnology research with total investments exceeding $200 million annually. However, returns to private R&D investments in agricultural biotechnology have been low thus far. The 1992 sales value of agricultural biotechnology products was about $184 million (Hodgson and Barlow, 1993). Industry estimates of projected sales in 1998 range from $700 million to $1.6 billion (AGROW, 1993).

In fiscal year 1992, 15 agricultural biotechnology firms were surveyed (Spalding, 1993), and they reported $68 million in R&D expenditures. That expenditure represented nearly a 40-percent increase over 1991. The survey results showed that the firms only had sales of $184 million and posted losses of $126 million in 1992. R&D spending increased after an infusion of $107 million in venture capital. Spending will continue to increase as more companies move into the development stage of the process. Eight large chemical and seed companies also interviewed reported R&D expenses of $4.3 billion, but this figure includes research on chemicals and pharmaceuticals as well as on agricultural biotechnology (Spalding, 1993). Biotechnology companies worldwide have raised $20 billion on the public market from 1980 until 1993 (Hodgson and Barlow, 1993).

The biotechnology industry consists of large established multinational companies specializing in oil, chemicals, food, and pharmaceuticals, and a number of smaller, newly established venture capital firms (start-up companies). Of the 400 venture capital biotechnology companies that have been created in the United States since the late 1970's, only 3 percent are currently reporting profits (AGROW, 1993). Start-up biotechnology companies have some advantages over larger commercial R&D units. These firms are usually made up of entrepreneurial scientists at the forefront of molecular biology research. The firms tend to concentrate on a single product, and hence, can react quickly to potential market niches. Some investors believe that the field of biotechnology is undergoing revolutionary, not evolutionary, change and large corporations do not respond well to revolution (Sugawara, 1992). The small companies are at a disadvantage, however, when biotechnology research reaches the stage of commercialization. Smaller companies lack manufacturing capability and marketing networks that are held by the large chemical and seed companies. Many small biotechnology companies have entered into contracts with larger firms. This strategy has led to an industry structure characterized by many small firms tied to relatively few big companies. This industry pattern has been termed "decentralized concentration" (OECD, 1989).

The biotechnology industry has also invested heavily in university research (Lacy and others, 1988). In 1988, an estimated 46 percent of biotechnology firms supported some kind of biotechnology research in universities (OTA, 1988). The emergence of the agricultural biotechnology industry in the late 1970's largely bypassed the Land-Grant Universities because the sources of funding went to schools with the greatest expertise in molecular biology rather than in agriculture (Kenny, 1986). To encourage industry investment in Land-Grant Universities, public funds were channeled through special grants to improve research facilities at some of the agricultural universities. The public investment increased the ability of those institutions to compete for private funds. Several of the larger Land-Grant Universities launched agricultural biotechnology research programs in order to attract private funds. The high level of private funding of university research illustrates the clouding of the distinction between applied and basic research that characterizes biotechnology research. In addition, there has been increasing Federal support to commercialize basic research advances. The Technology Transfer Act of 1986 promotes technology transfer by authorizing Cooperative Research and Development Agreements (CRADA's) between government scientists and private companies to develop and commercialize particular discoveries. These agreements provide private companies with exclusive rights to develop government discoveries for a specified period. Details of a CRADA are proprietary information, however (Day and Frisvold, 1993). There is no transfer of public funds involved. USDA is among the leading Federal departments in setting up CRADA's.

Several universities have set up special offices to facilitate cooperation between companies and university researchers, called Offices of Technology Licensing (OTL). Three goals of an OTL are to "(1) transfer technology for the public good, (2) provide a service to the university faculty, and (3) retain some of the monetary returns from the research" (Parker and Zilberman, 1993). Some OTL's help academic scientists to form start-up companies although the university retains some interest in the venture. Some of these efforts are substantial. The University of California (a Land-Grant institution) has a very active OTL. The Massachusetts Institute of Technology has raised over $70 million in venture capital for start-up companies (Parker and Zilberman, 1993). Agricultural biotechnology research has been only a small part of the activity since most research is for medical applications. The existence of these cooperative mechanisms has increased biotechnology research in general. The closer affiliation between public and private research units has helped to form geographic centers for biotechnology research. The areas of greatest private biotechnology activity are also areas with strong university research units: San Francisco, Boston, New York-New Jersey, San Diego, and Washington-Baltimore (Sugawara, 1992).

Public Policies That Affect R&D Investment

In addition to direct public biotechnology research expenditures, other public policies affect R&D investment by the private sector. These public policies include intellectual property rights legislation, regulatory policy, financial and tax policies, educational policies, and other policies covering the environment and industry practices.

Intellectual Property Rights

Intellectual property rights (that is, patents, trademarks, and copyrights) increase a firm's incentive to invest in R&D by enhancing a firm's ability to capture the profits from the innovation. Under intellectual property rights laws, works of the mind that have commercial applications can be deemed personal property. Intellectual property needs special protection because of the inherent "common good" quality of the asset (Lesser, 1991). New technical knowledge is a common good because it cannot be "used up." Many firms can use an idea repeatedly without wearing it out or diminishing the usefulness of the idea for others. The development of gene manipulation techniques to make new organisms or drugs can be difficult, but once the technique is available, products are often easy to duplicate (Schneider, 1988). Private firms would not be able to earn profits on intellectual property without legal protection of rights. Some ability to exclude others from the use is necessary, however, for any intellectual property right to be enforceable. Both domestic and international intellectual property rights systems will affect the profits that would be expected from investment in agricultural biotechnology research.

U.S. intellectual property rights. Private investment in biotechnology research in the United States has been spurred by recent changes in patent laws and court interpretations. Those who develop living organisms such as new plant varieties now can obtain patent protection for the product of their research. Protection was extended to cover genetically altered animals and parts of plants. Potential profits were increased for a wider range of research by the strengthening of property rights.

The U.S. Patent Act has been in effect since 1790. The goal of patent regulation is to encourage the early dissemination of new knowledge in return for granting a limited monopoly to the inventor. The invention must be shown to be novel, useful, and nonobvious in view of the prior art in order for a utility patent to be granted (Persley, 1990). The term "utility patent" refers to the general patent and is used in this report to distinguish it from the plant patent described below. Ideas cannot be patented — only the embodiment of ideas in physical products or processes (Deardorff, 1990). In the United States, a utility patent is awarded to the first to invent. However, the United States is considering a more straightforward system of first-to-file that is followed by most other countries (Lesser, 1991). If a utility patent is granted, the inventor has the right to exclude others from using the invention for 17 years. The inventor can then profit from the innovation either by exclusively selling the product, licensing others to use the innovation, or selling the patent rights. The granting of utility patents involves a tradeoff between creating extra-normal profits for the inventor for a limited period (monopoly power) and the longrun economic gains from encouraging R&D (Subramanian, 1990). Firms are granted a limited monopoly to exploit their R&D investments. Short-term economic inefficiencies that may result from the monopoly characteristic are thought to be offset by the dynamic economic gains resulting from the introduction of new products and technologies that might not be developed otherwise.

In original utility patent legislation, living organisms were "products of nature" and not patentable (Lechtenberg and Schmid, 1991). The Plant Patent Act of 1930 granted protection rights for developments resulting from asexually propagated plants, but did not grant protection rights for sexually propagated plants, plant parts, genes, or traits (Lechtenberg and Schmid, 1991). In 1970, Congress passed the Plant Variety Protection Act (PVPA), which extended patent-like protection for new, distinct, uniform, and stable varieties of plants that were reproduced sexually. The PVPA, unlike other patent laws, is administered by the USDA rather than the Patent and Trademark Office. The PVPA provides breeders with Plant Variety Protection Certificates (PVPC), which exclude others from selling or reproducing the variety, producing a hybrid from the variety, or importing or exporting the variety (OTA, 1992). However, the PVPA allows researchers to use the protected variety to develop new varieties and also allows farmers, under certain restrictions, to harvest the variety and sell the seed to other farmers. The latter exemption can be costly for the seed company. In the case of *Asgrow Seed Co. v. Kunkle Seed Cu., Inc., et al.,* it was determined that the defendant, a farmer who had sold 1.42 million pounds of a protected variety, could continue selling the protected seed since the sales constituted less than half of his farm sales income (OTA, 1989). The PVPA also empowers the Secretary of Agriculture to require a PVPC holder to license other parties to use the variety, if the Secretary determines that such a license would be in the public interest (OTA, 1992). Even though a royalty would be paid to the holder for the license, this provision diminishes the value of this intellectual property right.

The PVPA was an improvement over existing seed and breed certification schemes, which did not prevent others from using and selling the new variety so long as they did not misrepresent its capabilities (Persley, 1990). The passage of the PVPA has significantly increased the incentive for private sector research in a number of important crops, such as alfalfa, cotton, corn, soybeans, and wheat (OTA, 1992). For example, before the PVPA was passed, the public sector developed most of the new varieties of wheat used in the United States. By 1984, 10 privately developed wheat varieties were being planted on over 500,000 acres (Knudson and Hansen, 1991).

The landmark U.S. Supreme Court case *Diamond v. Chukrabarty* (1980) provided patent protection for genetically engineered microorganisms. Specifically, it was ruled that inventors of new microorganisms, whose. inventions otherwise met the legal requirements for obtaining a utility patent, could not be denied a patent solely because the innovation was alive (OTA, 1992). Intellectual property rights for biotechnology advancements in agriculture were increased when the Patent Office ruled that utility patents could be granted for novel plants *(Ex Parte Hibberd*, 1985). Parts of plants could be patented even if the material was protected under the PVPA. Applications for plant utility patents grew from 73 in 1986 to an estimated 400 in 1988 (Persley, 1990). In general, biotechnology firms prefer utility patent protection because utility patents have fewer exemptions and can be more broadly applied than either Plant Patents or Plant Variety Protection Certificates (Knudson and Hansen, 1991).

In 1988, the Patent and Trademark Office granted the first utility patent issued for “transgenic nonhuman mammals” (Patent No. 4,736,866) to Harvard University for a genetically altered mouse that can be used to detect cancer-causing substances. This decision provided patent protection in the United States for higher life forms. However, despite the potential usefulness of the “Harvard mouse” as a model for human disease, only four transgenic animal patents were granted by 1992. In addition, the European Patent Office has not recognized the Harvard mouse patent.

The assignment of an intellectual property right is an asset to an inventor. Nonetheless, university and Federal researchers have often been denied the right to obtain a utility patent if their research received public funding. In order to provide greater incentives for public institutions to conduct applied research, amendments to the Patent Act in 1980 and 1984 allowed universities and small businesses to patent innovations resulting from federally funded research (OTA, 1992). Universities were required to share patent royalties with the inventor, thereby providing academic researchers with an incentive to stay at the university and to work on more applied biotechnology research. Prior to this change, faculty members could not gain monetarily from an invention without leaving the university. Academic researchers still may face a disincentive to do certain types of research. For example, the utility patent application process poses an incentive problem for researchers in a rapidly developing and highly technical field such as biotechnology if the novelty requirement precludes publication of results prior to patenting. The United States, Canada, and Japan have instituted a grace period that allows scientists to publish their results without forfeiting their rights to patent their innovation. This grace period (1 year for the United States and Canada, 6 months for Japan) is believed to encourage biotechnology research within universities (OECD, 1989; Enayati, 1993).

Patent laws are not the only way that firms can protect their inventions. Trade secrecy contracts prohibit parties from disclosing sensitive information to competitors. However, no protection is available once secrecy is violated. If absolute secrecy is maintained, it may not be possible for a firm to test or market their agricultural product if the regulatory process requires that enough information be given to allow an assessment of efficacy and safety. There is a tradeoff for a company between revealing too little or too much. There are several regulations that affect this tradeoff. For instance, a firm developing a pest-resistant crop would be required to apply for a field-release permit from the Animal and Plant Health Inspection Service (APHIS) of the USDA. The agency would need to know enough about the plant material, biotechnology technique, design of the field trial, and the environment into which the organism would be released to ensure that the genetically modified organism “will not persist in the environment and no offspring can be produced that could persist in the environment” (Federal Register (APHIS), 1993). A firm can claim in a permit application that some scientific data is confidential business information (CBI). The regulatory agency can use that information in its deliberation of health and safety, but may not divulge that information to the public. The Trade Secrets Act of 1982 forbids government employees from disclosing proprietary data unless authorized by law. Even the Freedom of Information Act (FOIA) of 1982 permits regulatory agencies to protect trade secrets and CBI. The purpose of these laws is to protect information that would be of commercial value to a firm’s competitors (OTA, 1992). The focus is on whether disclosure would be harmful to the company. The public benefits of disclosure are not considered.

The ability to enforce a property right is an important component of the value of that right. Recent developments in genetics allow a firm to record the genetic fingerprint of its plant variety or animal whether developed through crossbreeding or biotechnology methods. Genetic fingerprinting gives companies more secure property rights because detection of patent or trade secret violations is easier and the evidence is accepted in court. For example, the Japanese have invested in U.S. genetic fingerprinting research in order to protect the patent on the Blue Rose. The very science of biotechnology is being used to enhance the profitability of research by strengthening intellectual property rights.

International intellectual property rights. Currently, the United States is the world leader in biotechnology research in both scope and magnitude. Biotechnology firms in other countries often draw on research performed in the United States in their quest for new products. Not all countries offer property right protection for biotechnology, however, which can deter technology transfer and product trade. Divergent systems are considered a nontariff trade barrier (Govaere, 1991). Some analysts believe that the United States would gain from greater international protection of intellectual property rights for biotechnology innovations. Greater protection would encourage more private sector research (Barker and Plucknett, 1991).

U.S. firms would not be willing to export their technologies to countries without intellectual property protection. A coordinated intellectual property rights system would increase expected profitability for the technology-exporting country by lowering costs because only one application would have to be pursued rather than several. What might seem a small difference between national laws can be very costly for companies. For example, Japan’s patent system is similar to the U.S. system, but Japan has a more stringent requirement of utility. In Japan, a patent will not be granted unless “an invention *have utility in industry”* (emphasis added)(Enayati, 1993). Biotechnology methods for diagnosing a disease would not qualify for protection in Japan as it would in the United States unless the petitioner could support the claim that the method also had industrial applications.

Harmonization of patent laws and international recognition of intellectual property rights will determine much of the future direction of agricultural biotechnology research, However, many developing countries have little incentive to participate in an agreement that enforces foreign intellectual property rights. Since developing countries have largely been importers of inventions, they may not gain reciprocal benefits from protecting the intellectual property rights of foreigners. Industrialized countries have often used technology to obtain market control abroad (Govaere, 1991). Some developing countries fear that they will be exploited if they grant patent protection. A study by Deardorff (1992) showed that the net benefits of granting patent protection by a developing nation will depend on opposing factors. The monopoly profits earned from innovation will spur inventive activity and technological advance, which might benefit the granting nation in the long run. In the short run, however, the monopoly prices for new technologies will distort consumer choices. The longrun benefits of recognizing intellectual property rights will depend on the role of technological advance on national growth rates and national development. It has been shown that uneven access to technology has led to “technology gaps” between countries and a loss of competitive advantage (Acharya, 1991).

Nations have attempted to harmonize intellectual property rights for some time. The Paris Convention, established in 1883, stipulates that member countries will grant patents to foreign nationals on the same terms as it grants patents to its own citizens (Persley, 1990). Although there are nearly 100 member countries, the Paris Convention does not work well for innovations such as biotechnology. In particular, countries that have a limited capacity to develop new technology but that have a good capacity to adapt or copy technology developed elsewhere have little incentive to adhere to strong patent laws (Evenson and

Putman, 1990). The Patent Co-operation Treaty was established in 1978 and is open to all members of the Paris Convention. This treaty establishes procedures for international patent applications. The European Patent Convention took effect in 1977 and institutes a system of common patent law for most European Community member states. The European Patent Convention forbids the patenting of biological processes, but does allow the patenting of plant and animal varieties that are the products of patented processes (Acharya, 1991). The European Community itself does not have intellectual property rights legislation, however. Despite the lack of internal harmonization, the European Community negotiates the adoption of intellectual property protection by developing countries (Govaere, 1991). Most industrialized nations have signed the International Union for the Protection of New Varieties of Plants (UPOV), which took effect in 1968. UPOV establishes uniform plant protection regulations among member nations and stipulates that members will respect and enforce each other's intellectual property in plant varieties. There are few developing countries as members. Plant breeders' rights protect only a certain variety and allow use of the variety for further breeding and for future cultivation by farmers.

The World Intellectual Property Organization (WIPO) was established in 1970 to assist countries in setting up intellectual property regimes. WIPO conventions lay down general principles and minimum standards of protection, but WIPO does not have any enforcement abilities. The one-country-one-vote system in WIPO places industrialized 'countries in the minority and favors developing and newly industrializing countries (Acharya, 1991).

International trade negotiations include the expansion of such multinational patent agreements. In the latest round of the General Agreement on Tariffs and Trade (GATT), industrialized countries pressed to include discussion of intellectual property rights (Acharya, 1991). The United States has been a strong supporter of intellectual property rights discussions in a multinational framework because bilateral negotiations can be lengthy and incomplete (Deardorff, 1990). Special Section 301 of the 1988 U.S. Trade and Tariff Act threatens to impose trade sanctions on countries that do not extend intellectual property protection. A special negotiating group, the Committee on Trade-Related Aspects of Intellectual Property Protection, Including Trade in Counterfeit Goods (TRIPS), was accepted by the Uruguay Round of the GATT over the objections of developing nations, which preferred WIPO as the forum to negotiate the issues (Acharya, 1991).

Biotechnology holds an important place in the intellectual property protection debate due to the possible link between biotechnology and biological diversity. A diminishing gene pool is not in the interests of the biotechnology industry, and companies argue that biological germplasm is the common heritage of the world. Currently, national intellectual property rights systems protect biotechnology innovations and not the genetic material itself. The TRIPs discussions in the GATT were based on maintaining free access to germplasm (concentrated in developing countries) while strengthening rights to biotechnology innovations (developed primarily by industrialized nations) (Acharya, 1991). The United States favors strong intellectual property protection for biotechnology with which they hold a comparative advantage (Subramanian, 1990, 1991). There are costs and benefits of extending intellectual property protection, and the incidence of these costs and benefits may not be uniform across countries. Some have argued that the poorest of developing countries would bear a disproportionate share of the costs and so should not be required to extend intellectual property protection if the benefits to innovators from expansion of rights in these counties is small (Deardorff, 1990).

Many issues were addressed in the Uruguay Round of the GATT that will affect the development and trade of new technologies. TRIPs will determine the geographic extent of the market for biotechnology-derived products. In a rapidly developing scientific field such as biotechnology, the multinational protection of intellectual property rights is important for establishing a global market for the technology.

Regulatory Policies

The future of private industry funding for biotechnology research will be influenced by the regulations that are in force. Two types of regulatory policies that will directly affect private R&D investment in biotechnology are environmental protection regulation and occupational health and worker safety regulations. Private R&D investment may also be indirectly affected by food safety regulations. These policies affect the profitability of R&D by (1) increasing the cost of developing new technology by extending the time necessary to bring a product to market, and (2) increasing the cost of meeting stricter standards.

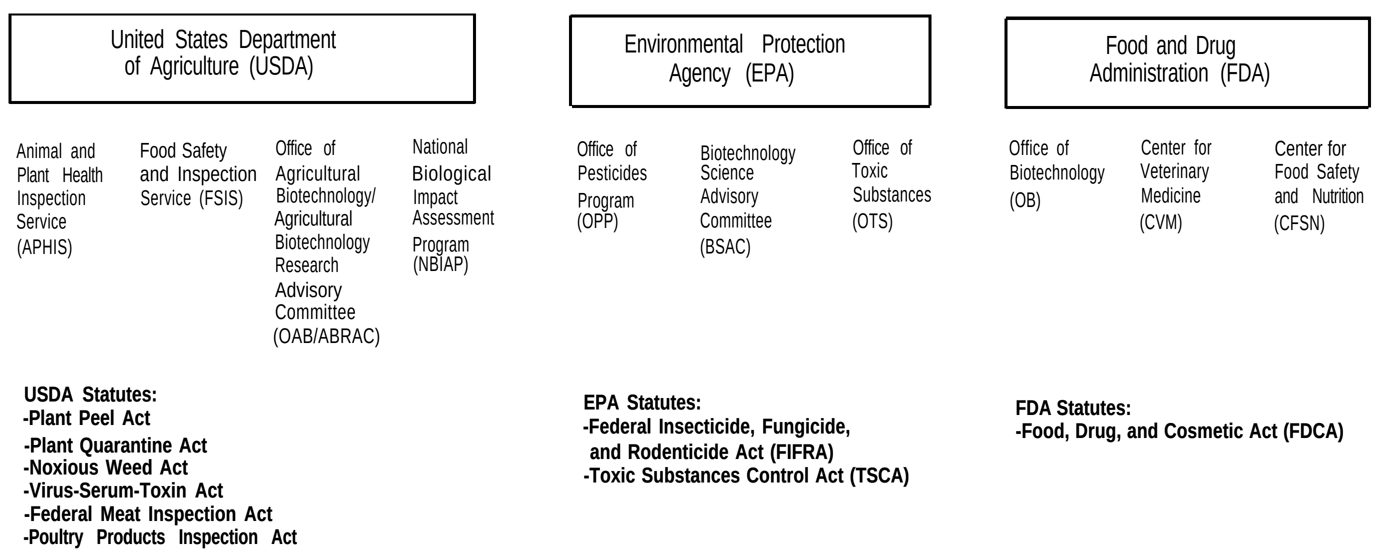
There are public concerns about the safety of biotechnology that affect the regulatory climate. Segments of the public perceive that products of biotechnology research may cause unforeseen harm to human health or the environment. Some people fear that genetically engineered foods will be unsafe. Also, there is fear that genetically engineered organisms released into the environment may mutate and multiply uncontrollably, thereby disturbing the ecological balance. This fear stems from past negative experiences with the introduction of non-indigenous species such as the importation of rabbits to Australia. The regulatory framework is meant to safeguard the environment and public health. The costs of complying with regulations will reduce the private profitability of the R&D investment, but the public will benefit from reduced risk. The balance between the costs and benefits will determine the efficiency of the regulation. Adequate government regulation may be a precondition for the development of the agricultural biotechnology industry because "without controls over quality, effectiveness, and environmental safety, the risk of disaster undermines the confidence of investor and consumer alike" (Masters, 1992).

There have been public and industry concerns about the ability of the Federal Government to ensure food safety and environmental quality because there were seemingly contradictory, overlapping, or missing jurisdictions among agencies with oversight responsibility for biotechnology. These concerns prompted the Federal Government to introduce a "Coordinated Framework" for regulating biotechnology-derived products in June 1986. The Framework assigns authority for regulation to several agencies, but the line of authority for each agency is designed to streamline the regulatory process and to ensure that all aspects of public safety are covered. The stated principle of the Framework is that biotechnology-derived products are not fundamentally different from other products. Therefore, it was determined that biotechnology would be regulated through existing legislation. In addition, only final products and their intended uses would be subject to regulation, not the method of production, that is, regulate the product not the process (ACSH, 1988).

Figure 1 shows the basic framework for the regulation of a biotechnology-derived agricultural product. Under the Coordinated Framework, the U.S. Department of Agriculture (USDA) and Environmental Protection Agency (EPA) have become the predominant agencies for regulating agricultural biotechnology. Within the USDA, two agencies of the Marketing and Inspection Service (M&IS) carry out the USDA's required biotechnology regulation. The first is the Animal and Plant Health Inspection Service (APHIS), which has jurisdiction over plant pests under the Plant Pest Act, animal vaccines under the Virus-Serum-Toxin Act,

Figure 1

Agencies responsible for regulatory policy for biotechnology-derived agricultural products



Source: OTA, 1992

and genetically engineered plants under the Plant Quarantine Act. The second agency is the Food Safety and Inspection Service (FSIS), which has jurisdiction over biotechnology-derived livestock intended for human consumption.

The EPA's authority to regulate aspects of agricultural biotechnology can be traced to two statutes. One is the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), which authorized the EPA to ensure the safety of all pesticides used. The EPA uses FIFRA to require potential users of microbial pesticides, such as pesticides containing altered bacterial strains, to obtain permits prior to application.

The second Federal statute from which the EPA derives its authority to regulate biotechnology is the Toxic Substances Control Act (TSCA). Under TSCA, the EPA may regulate any chemical substance that it considers a possible threat to humans or the environment. By classifying DNA as such a substance, the EPA has required permits to be obtained prior to the manufacture or release of genetically engineered microbes that have industrial or consumer applications (MacKenzie and Vidaver, 1991).

The Food and Drug Administration (FDA) oversees the regulation of food additives as well as animal and human drugs. In May 1992, the agency proposed that food products altered through genetic engineering would not require a special set of Federal regulations to ensure consumer safety. Some biotechnology-derived foods may require FDA oversight and approval if the new traits contained in the food could be considered a food additive. The FDA's oversight role may become more important as a greater number of biotechnologyderived food substances are produced. New categories of food may require more flexible oversight. For example, the development of nutriceuticals will be slowed in the United States by ill-defined regulations. A nutriceutical is a food "used for a specific health benefit, a concept somewhere between nutrition and pharmaceuticals" (L. Miller, 1993). For example, garlic extract could be prescribed by a physician to lower blood cholesterol. These products bridge the gap between foods and drugs and are not wholly covered by current U.S. regulations. If a company developed a biotechnology-derived nutriceutical that had therapeutic properties, the product could be marketed either as a food or a drug. The former would require little government oversight, but no claims could be made about the potential health benefits of the product. To market the product as a drug could take up to 10 years to comply with FDA testing requirements for new drugs (L. Miller, 1993). In Japan and parts of Europe, nutriceuticals are covered by existing regulations and investment in nutriceutical development is strong in these countries. The responsibilities of the Occupation Safety and Health Administration (OSHA) include ensuring worker safety at all work places that utilize biotechnology.

In addition to regulatory requirements, the Federal Government has also produced two sets of guidelines for conducting biotechnology research. In the 1970's, the National Institutes of Health Recombinant DNA Advisory Committee (NIH-RAC) produced the "NIH Guidelines on the Use of Recombinant DNA." These guidelines seek to ensure that the laboratory construction and production of modified organisms pose no significant threats to either laboratory workers or the general public. All researchers receiving Federal funds must follow the guidelines, but voluntary acceptance of the guidelines by privately funded researchers has also been quite high (ACSH, 1988).

The USDA's Agricultural Biotechnology Research Advisory Committee (ABRAC) published a set of voluntary guidelines for the field release of genetically modified organisms. These guidelines are intended to complement the NIH guidelines, and provide guidance to researchers. The ABRAC guidelines endorse the concept of assessing the safety of field experiments based on the intrinsic qualities of the relevant genetically modified organisms and not the process by which they are produced (ABRAC, 1991). ABRAC currently is developing protocols for field trials with transgenic fish and offering guidance to the USDA Food Safety and Inspection Service on the food use of transgenic animals.

The provisions established by the National and Environmental Policy Act (NEPA) of 1969 (42 U.S.C. 4332) also are applicable to biotechnology field research. Under NEPA, any researcher who receives Federal funds or whose research is subject to other Federal regulations may be required to prepare an Environmental Assessment to determine whether the experiment would result in a significant environmental impact. All assessments must be disclosed to the public for comment and then federally approved before field experiments may commence (MacKenzie and Vidaver, 1991). Information classified as confidential business information (CBI) is not disclosed.

The development of a consistent, objective, and streamlined system of regulations in the United States has been slow and it is not complete. Some critics claim that several regulatory agencies "have built huge, expensive, and gratuitous biotechnology regulatory empires preoccupied with negligible-risk activities, and have succeeded in protecting consumers only from enjoying the benefits of the new technology" (H. Miller, 1993). Others recognize that an initially conservative approach may help to build public confidence in the agencies' ability to ensure safety (Masters, 1992). There are unresolved and controversial issues concerning the rights and responsibilities of researchers, however. For example, there is an issue of legal liability for environmental problems caused by the release of genetically modified organisms. There is also a question of whether adherence to Federal regulations and guidelines should reduce the liability of institutions conducting biotechnology research.

Investors in agricultural biotechnology research cannot estimate development costs unless the regulatory framework they face is known. Progress has been made in the United States to provide a clear "road map" through the domestic regulatory system. International harmonization of regulations, however, has been slower. Each government is developing its own set of requirements for research and commercialization of agricultural biotechnology products. The Organization for Economic Cooperation and Development (OECD) has been the moving force in the development of a system based on harmonized principles. A positive step toward harmonization would be if each OECD nation accepted test data from other member countries.

Financial and Tax Policies

Other public policies used to lower the costs of private R&D in biotechnology involve subsidies or tax breaks for biotechnology researchers. For example, Japan and some other nations subsidize private biotechnology research. Such government actions can be considered unfair trade practices and/or boons for consumers and the scientific community.

Tax policies may be used to encourage private firms to invest in the development of innovations. These policies may be designed to reduce the cost of innovation by using accelerated depreciation rates on R&D capital and by allocating tax credits on increases in R&D expenditures. The Economic Recovery Tax Act of 1981 provided a 25-percent tax credit on incremental R&D expenditures and allowed more rapid depreciation of R&D capital. The tax credit expired in 1992 and has not yet been reauthorized. A 1993 proposed bill (Bumpers, D-AR) seeks to provide a capital-gains tax differential for those who make high-risk, long-term venture investments. Start-up companies have indicated that such legislation is necessary to foster the investment of risk capital (Wiggans, 1993). Several States are offering tax incentives to biotechnology research firms to locate in their states.

Education Policies

Education policies are designed to build a more highly trained workforce and to create more knowledgeable consumers. Education is an investment in human capital in that it enhances needed skills. More than for past technologies, the effectiveness and acceptance of biotechnology research will depend on the level of human capital. Training and education contribute to technical advances in agriculture in at least three ways. Fist, training of research scientists is fundamental to continued improvements in molecular biology and other fields. Investments in human capital of this kind provide the basic resource for the development of new technology. Second, a more educated agricultural workforce can better understand, evaluate, adapt, and use new technologies. An educated farming community is necessary for the wide-scale dissemination of technological information. Finally, an educated population of consumers is better prepared to assess claims and counter-claims regarding the qualities of biotechnology-derived products. The first contribution of education and training to advancing agricultural biotechnologies directly affects the supply of these technologies. The second and third roles of education and training affect the demand for biotechnology-derived agricultural inputs and consumer products.

Agricultural scientists have been trained through the Land-Grant University system for more than a century. Until recently, this system was quite successful in providing scientists the knowledge required to continue the progress of agricultural technology. Public funding for education lowers the training costs for private companies, and university research increases the technological opportunities available to firms. The advances in biotechnology have shown that traditional agricultural sciences are only one component, along with molecular biology and other basic science fields, in increasing agricultural biotechnology. There is a concern that the comparative advantage of Land-Grant Universities in agricultural research is waning. New public funding mechanisms have been developed to increase the number of disciplines and types of academic institutions eligible to receive money for agricultural research including agricultural biotechnology. Special grants to improve laboratory facilities were given to public universities and new research partnerships are being encouraged. For instance, USDA fellowships are offered to young molecular biologists to work with traditional agronomists in public research laboratories, and the National Science Foundation has developed university/industry cooperative programs (Parker and Zilberman, 1993).

Other Public Policies

Macroeconomic policies and agricultural sector policies may also influence firms' R&D investments through their impact on firms' expectations about future demand for new products. Publicly supported commodity prices could increase the private incentive to invest in biotechnology research designed to increase the productivity of certain commodities. Environmental regulations such as pesticide-use restrictions could spur research in the development of less harmful practices. These inducements to innovate are sometimes referred to as "demand-pull" because they affect the R&D firm's expectations of future revenues.

Industrial policies also have a direct effect on R&D investment, and hence on the supply of agricultural biotechnologies. The Japanese Ministry of International Trade and Development (MITI) subsidizes applied research in three biotechnology areas (fermentation, large-scale tissue culture, and recombinant DNA) and encourages collaboration in these areas among the 14 largest Japanese biotechnology firms (Barker and Plucknett, 1991). U.S. antitrust laws prohibit this kind of collaboration among the dominant firms in an industry. While collaboration in an industry allows research firms to take advantage of economies of scale and avoid duplicity, it also reduces competition. Competition provides a major incentive for the rapid development and application of new technology and can lead to lower priced products. Therefore, there is a tradeoff between the cost efficiency of R&D and consumer benefits.

Public Funding of Biotechnology Research

The primary rationale for the public sector's investment in agricultural research has been that incentives for private sector research have not been adequate to induce a socially optimal level of research in many areas. The lack of incentive can be caused by a large share of the gains from research being captured by other firms and by consumers rather than by the innovating firm (Ruttan, 1982). Although the gains to the public may be great, profits for the firm are too small to induce investment in the private sector. The firm cannot appropriate enough of the gains from R&D. This is most obvious in the case of basic research. In addition, the public sector undertakes applied research in areas with potentially high social payoffs, but which are less attractive to private investors. Such areas include rural development, defense, food safety, and environmental protection (Ruttan, 1982).

Public funding of agricultural biotechnology research can occur at the Federal, State, and local level. Federal research funds are allocated through formula funding, special research grants, and competitive grants. Formula funding involves block grants to Land-Grant Universities and public research institutions with matching funds from State governments. Special research grants are for specific topics of regional or national interest. The competitive grant program is administered through the National Research Initiative, which awards grants to specific research proposals (Ruttan, 1982). In addition, government agencies can develop cooperative agreements with individual researchers through the university. These agreements can give both parties access to a wider range of research assets such as data, expertise, and reputation (Day and Frisvold, 1993).

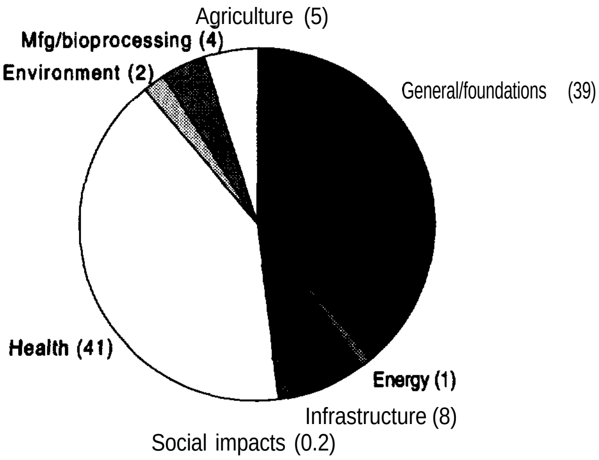
Congressional interest in the commercial development of agricultural biotechnology has resulted in an increase in formula funding and in special research grants for biotechnology. Also, the contribution from State governments to biotechnology research has increased. The ratio of State-to-Federal funding for biotechnology research has grown from nearly one-to-one in 1985 to a two-to-one dominance by the States by 1990 (MacKenzie and others, 1992).

Total Federal investment in all biotechnology research is expected to be more than $4.3 billion dollars in 1994 (FCCSET, 1993). The largest areas of funding will be for health and for general foundations research. Figure 2 shows the proportion of Federal funding spent in each of the major biotechnology research areas. Funding for biotechnology infrastructure is used to construct research facilities, develop instrumentation, enhance career development, and maintain repositories and data bases. It is anticipated that public funding for infrastructure will decline as the biotechnology research field becomes more established, but it may be many years before such a change is apparent. The amount dedicated specifically to agriculture is only 5 percent of the total, or about $234 million. This percentage has been constant over the last few years.

Funding for research on the social impacts of biotechnology is $9.2 million for 1994. This figure represents only 0.2 percent of total Federal expenditure on biotechnology research. Table 3 shows the levels of Federal funding by research area for fiscal

Figure 2

Federal investment in biotechnology research by research area



FY 1994: $4.3 billion

Source: FCCSET, 1993

years 1992 through 1994. Twelve Federal agencies participate in the Federal Biotechnology Research Initiative. The funding commitment of each of the agencies for FY 1994 is shown in table 4. The majority of funding for agricultural research, about 64 percent, is allocated by the USDA even though the USDA portion of total biotechnology funding is only 4.4 percent. The stated purpose for USDA-funded biotechnology research in FY 1994 is to develop "new plant products, safer biological pesticides, healthier animals, new methods to improve the environment, and new fuels" (FCCSET, 1993, p. 72).

Table 5 shows the allocation of funds by area within USDA for FY 1992-94.

The future supply of agricultural biotechnology products will depend on investments in R&D, The amount of public and private investment in agricultural biotechnology research and the range of biotechnology-derived products that are developed will depend on economic factors and public policies. An investment will be made only when the expected profits to be earned from R&D activities are greater than the profits to be earned in an alternative investment. Expectations about farmer adoption and consumer demand for the final product will determine projections of future revenue. The appropriation of the benefits of research, that is, profits, depends on the U.S. and international intellectual property rights laws. Research profits will also be affected by the costs of complying with regulations. The effects on expected profits of many public policies combine to determine the incentives and disincentives to invest in agricultural biotechnology research.

Factors Affecting the Demand for Agricultural Biotechnology

The development of new food production and processing technologies means little to a society until these technologies are put to use by farmers and food processing firms. The demand for biotechnology as an input into agricultural production will depend on the relative benefits and costs of the technology compared with alternative inputs. Input demand is often referred to as "derived demand'* because it directly

Table 3-FY 1992-94 Federal biotechnology research budget by area

Area	FY 1992	FY 1993	FY 1994
		$ Million	
Agriculture	223.8	232.5 (3.9%)	234.2 (0.7%)
Energy	54.0	57.6 (6.6%)	58.1 (0.9%)
Environment	62.6	78.8 (25.9%)	90.2 (14.5%)
Mfg/bioprocessing	128.2	147.8 (15.3%)	160.8 (8.8%)
Health	1,670.2	1,746.4 (4.6%)	1,742.1 (-0.2%)
General/foundations	1,584.3	1,656.1 (4.5%)	1,668.3 (0.7%)
Social impact research	8.8	8.6 (-1.9%)	9.2 (7.0%)
Infrastructure	325.5	340.8 (4.7%)	336.4 (-1.3%)
Total	4,057.5	4,268.7 (5.2%)	4,299.3 (0.7%)

Source: Adapted from FCCSET, 1993.

( ) = Percent change from previous fiscal year

Table 4-Federal Biotechnology Research Initiative for 1994

Agency*	Total	Agriculture	Energy	Environ-ment	Manu-facturing/bioprocessing	Health	General/foundations	Social impact	Infra-structure
					$ Million				
AID	30.9	12.7	0.0	0.2	0.0	18.0	0.0	0.0	0.0
DHHS	3,368.6	29.7	2.3	0.5	26.3	1,572.5	1,523.1	5.0	207.2
DOC	13.9	2.9	0.0	0.6	5.0	1.7	3.0	0.1	0.6
DOD	94.0	0.0	0.0	18.5	19.9	33.4	22.2	0.0	0.0
DOE	244.7	2.1	46.8	22.3	42.7	17.7	74.1	2.2	36.8
DOI	6.4	0.0	0.0	4.8	1.7	0.0	0.0	0.0	0.0
DOJ	1.9	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.6
DVA	72.0	0.0	0.0	0.0	0.0	72.0	0.0	0.0	0.0
EPA	20.3	0.0	0.0	20.3	0.0	0.0	0.0	0.0	0.0
NASA	40.3	4.7	0.0	1.5	2.6	5.2	3.6	0.0	22.7
NSF	215.6	33.1	8.4	19.1	45.1	20.1	41.0	1.7	47.1
USDA	190.6	149.0	0.6	2.5	15.6	1.4	0.0	0.2	21.4
TotalL	4,299.3	234.2	56.1	90.2	160.8	1742.1	1,668.3	9.2	336.4

Data may not add due to rounding.

*AID = Agency for Intl. Development; DHHS = Dept. of Health and Human Services; DHHS is comprised of the Center for Disease Control, the Food and Drug Admin., and the Natl Institutes of Health; DOC = Dept. of Commerce; DOD = Dept. of Defense; DOE = Dept. of Energy; DOI = Dept. of the Interior; DOJ = Dept. of Justice; DVA = Dept. of Veterans' Affairs; EPA = Environmental Protection Agency; NASA = Natl. Aeronautics and Space Admin.; NSF = Natl. Science Foundation; USDA = U.S. Dept. of Agriculture.

Source: FCCSET, 1993.

Table 5-U.S. Department of Agriculture research budget by area*

Area	FY 1992	FY 1993		FY 1994	
		$ Million			
Agriculture	150.35	154.30	(2.6%)	149.02	(-3.4%)
Energy	1.44	1.44	(0.0%)	0.64	(-55.6%)
Environment	2.22	2.57	(15.7%)	2.48	(-3.5%)
Mfg/bioprocessing	14.11	15.56	(10.3%)	15.55	(-0.1%)
Health	1.17	1.17	(0.0%)	1.38	(17.9%)
General/boundations	0.00	0.00	(0.0%)	0.00	(0.0%)
Social impact research	0.20	0.20	(0.0%)	0.20	(0.0%)
Infrastructure	43.81	34.51	(-21.2%)	21.37	(-36.1%)
USDA total	213.30	209.75	(-1.7%)	190.64	(-9.1%)

*Budget figures for FY 1994 do not Include funds traditionally added by Congress for facilities and special research grants.

() = Percent change from previous fiscal year.

Source: Adapted from FCCSET, 1993.

follows from the consumer demand for the final product. This section describes important factors that determine the transfer of new agricultural biotechnologies from laboratories to use in agricultural production systems.

Decisions to adopt new technology are influenced by multiple factors. Agricultural producers seek ways to increase profits by reducing production costs and/or satisfying changes in consumer demand. The profitability of a technology may change over time as prices for inputs and outputs change in response to market forces, government policies, and international events. The compatibility of a new technology with an individual farm depends on the characteristics of the technology and the resource endowments of the farm, including physical and human capital. It is likely that the rate of adoption of new biotechnologies will vary among regions and over time. Many emerging biotechnologies will require that producers learn new skills and undertake investments in human capital (training and education).

The adoption of biotechnology innovations in the agricultural sector will also be influenced by an expanded set of public interests. Some segments of the public are placing greater weight on food quality and safety than in the past. Environmentalists are concerned about the impact of biotechnology on environmental quality. Concerns about the nature of biotechnology and the effects of adoption on rural communities also are being expressed. The demand for biotechnology-derived products will be influenced by all of these concerns and by public confidence in the Government's regulatory framework to address the potential negative effects of the technology.

Government agricultural programs and environmental policies affect technology adoption through their effect on prices and other incentives. The relative profitability of using any technology will change with policy-induced changes in prices and costs. Commodity programs that increase crop prices or change the cost of land relative to other inputs encourage the adoption of production-intensive technologies. Environmental and food safety regulations also affect the choice of technology by restricting the types or amounts of certain inputs that can be used. The effect of these factors on biotechnology can only be determined on a case-by-case basis. For some applications of biotechnology, these factors may encourage adoption, while for other applications the effect may be to discourage adoption.

Producer Demand for Agricultural Biotechnology

Agricultural Production and Demand for Technology

Agricultural producers combine farm-supplied inputs such as land and labor with purchased inputs such as seeds, fertilizers, pesticides, fuel, and machinery to produce crop and livestock commodities. New technology can enhance agricultural productivity by enabling producers to use inputs more efficiently. New technology can also be used to produce new or quality-enhanced commodities that have higher market value. The demand for farm- or industry-supplied inputs, and for the technology to transform them into commodities, is ultimately a function of the market's demand for the agricultural commodities.

Inputs can often be substituted for one another to produce a given level of output. New technology increases the range of substitution between inputs. In order to maximize profits, farmers seek the combination of inputs and technology that can produce a given level of output at the least cost. If the relative prices between inputs change, farmers will be motivated to substitute cheaper inputs for the more expensive ones, Similarly, producer demand for specific types of technology is affected by the relative costs of agricultural inputs. The substitution of mechanical power for labor when wage rates rise is one example of how relative input costs affect input substitution in production. A less obvious example is the use of industrial inputs, such as fertilizers and pesticides, as substitutes for natural resources such as land. The declining cost of chemical inputs relative to the value of land has encouraged farmers to use chemical inputs more intensively (Ruttan, 1982). The discovery of more fertilizer-responsive crop varieties increased the ability of chemical fertilizers to substitute for land, just as the development of the internal combustion engine considerably increased the potential for substituting machinery for labor. The advent of biotechnology enhances the possibilities for substituting biological inputs for chemical inputs and natural resources. Examples of how biotechnology may substitute for these inputs include using pest-resistant varieties in order to reduce applications of chemical pesticides and growing drought-tolerant varieties that require less irrigation.

Inputs are often not perfect substitutes for one another, so yields may be affected when input substitution occurs in response to changes in relative input prices and adoption of new technology. Furthermore, the degree to which available new technologies can expand the range of substitution among agricultural resources may be limited by agro-ecological factors such as soil type, water availability, and climate. The adoption of new technology will be limited to those regions where it performs at least as well as existing technologies. The introduction of new technologies can change regional comparative advantages in production if it is better suited to one region relative to other regions.

The value of a technology to society will depend on its adoption and diffusion. *Adoption* refers to the decisions of individual producers whether or not to use a technology, whereas *diffusion* is the rate and extent of technology adoption over time. Within a region, the pattern of adoption among farms may be uneven. The cost of adopting new technology may differ between farms that have different endowments of resources such as land and capital, including human capital.

Technology Adoption and Human Capital

The term "human capital" refers to the skills and abilities embodied in the decision maker. These abilities can be innate or learned. Differences in human capital among producers with farms having similar natural resource endowments, such as soil type, will result in differences in profitability. Therefore, the introduction of a new technology will not have an identical impact on profits for all producers. When new technologies are first made available to producers, there is a period of adaptation in which early adopters learn how to apply and manage the new technology efficiently in their farming systems. Early adopters of new technology tend to be producers who are good managers; who are not averse to taking risks; who are well educated, experienced, and financially sound; who have good connections with farm input suppliers and agricultural extension agents; and who have had positive experiences with adopting new technologies in the past (Rogers, 1982). These farmer-innovators play an important role in the process of transferring new technology from laboratories to farms. They help screen and adapt new technology and farming methods to local environments, so other producers often benefit from their efforts. After a period of trial and adaptation by early adopters, technologies that are found to be profitable spread rapidly to other farms in areas where they are well suited. Some producers may be very slow to adopt or may never adopt a new technology because the technology is not profitable or is too difficult to use. Other factors not directly related to profitability, such as social concerns, ethical values, and religious beliefs, may also cause some farmers not to adopt new technology.

The growing complexity of many new agricultural technologies implies that human capital and managerial requirements for farmers who wish to adopt these technologies could increase in the future. The timely adoption and efficient application of new technology will depend in part on a farmer's knowledge of new analytical methods and on access to low-cost information (Sundquist and Molnar, 1991). Some emerging biotechnologies are likely to require investments in information technology, such as computers and expert systems, in order to be adopted effectively (OTA, 1992). The adoption of biotechnology-derived agricultural inputs may be slowed if farmers lack expertise with the appropriate methods. Agricultural applications of biotechnology that do not diverge too much from existing production practices are likely to have a higher rate of acceptance than technologies that require new skills.

Both the public and private sectors assist farmers with the adoption and management of new technology. Public investment in building human capital occurs through the funding of education. In addition, the USDA Extension Service and Soil Conservation Service provide technical information and advice to farmers about new agricultural practices and resource management. Private sector farm implement dealers, seed and chemical company representatives, and farm management consultants are also an important source of information about new technology for farmers. Public and private information sources tend to complement one another. While agribusiness salespersons actively promote new production inputs, farmers often rely on agricultural extension agents and other farmers as objective sources of information concerning the performance of new technology. Public extension services also provide farmers with information about technologies and practices with a high social value, such as natural resource conservation methods, which would not be promoted by the private sector.

The importance of human capital for agricultural production efficiency and technology transfer is well documented. Jamison and Lau (1982) reviewed more than 30 studies on the effect of farmer education on agricultural productivity. Birkhaeuser, Evenson, and Feder (1989) reviewed studies that assessed the economic impact of agricultural extension services. Almost all of the studies reviewed in these papers found that human capital, either in the form of general skills or technical knowledge, had economic value because it enabled farmers to become more efficient and productive. The diffusion of an agricultural biotechnology will depend on the extent of human capital needed to incorporate the technology profitably in the production system.

Rate of Diffusion of Biotechnology

The rate of diffusion of a new technology is often directly correlated with the profitability of adoption. Other factors being equal, the greater the yield increase or cost reduction from adoption, the more rapidly the use of the new technology is likely to spread. In a seminal study of the diffusion of hybrid corn in the United States in the 1930's-1950's. Griliches (1957) found that diffusion of the new varieties occurred most rapidly in States where hybrid varieties offered the greatest yield advantage over open-pollinated varieties. On the other hand, technologies that offer only marginal improvements to existing methods or are difficult or costly to use tend to diffuse slowly. Artificial insemination techniques for livestock, for example, have been available since the 1940's. Only about 70 percent of livestock producers had adopted the techniques by 1985, however. A significant number of farmers remained unconvinced by the claims of profitability compared with alternative reproduction methods (Yonkers, 1992).

The rate of diffusion of agricultural biotechnologies will depend largely on their profitability over alternatives. The relative profits will depend upon the characteristics of a particular application of biotechnology. Profitability will also depend on consumer demand and public attitudes toward biotechnology. Even for technologies that may offer a strong yield or cost-reducing advantage over existing techniques, adoption may be slowed by uncertainty over consumer acceptance of the biotechnology-derived product. Demand for agricultural biotechnology will be determined by prices, consumer preferences, and public attitudes.

Consumer Demand for Agricultural Biotechnology

Consumer Demand for Food

One of the major forces motivating technical change in agriculture is the increased demand for food resulting from worldwide population and income growth. Without new agricultural technologies to improve productivity, increases in demand would lead to higher production costs and higher food prices. Technological innovations in agriculture have enabled U.S. producers to expand food production and, at the same time, reduce unit costs of production. In high-income countries like the United States, per capita food consumption is relatively insensitive to changes in income and prices. Technological change that results in a dramatic increase in production efficiency could lead to price decreases and could reduce producer profits in high-income countries.

Although the quantity of food consumed per capita in industrialized countries has remained fairly constant, the demand for higher quality agricultural products has grown. Consumers are willing to pay higher prices for foods that offer enhanced qualities, such as improved nutrition, safety, flavor, and appearance. Consumers are becoming more quality-conscious as the level of available information about quality attributes increases. Consumer demand for particular quality attributes may stimulate research on these quality improvements (that is, demand-pull technological change).

In addition to quality characteristics, consumer demand for a particular food product is influenced by the price of the product, the price of substitutes, and the consumer's income. The demand for most products increases as its price falls, but the degree to which the quantity purchased responds to price changes varies considerably among goods. Consumer demand for many food items, especially staple foods, is fairly insensitive to price changes. For these products, large variations in price would result in only a small change in the quantity purchased. This type of demand is called *price-inelastic* demand. For commodities with inelastic demand, increases in production can significantly lower market prices. Other commodities are more *price-elastic.* Increases in production of these commodities can result in an increase in per capita consumption, but market prices are affected relatively less than for products with inelastic demand. Commodities that have close substitutes in consumption tend to be price-elastic. If a product becomes less expensive compared with its substitutes, consumers may have an incentive to switch consumption from the substitutes to this product.

The effects of biotechnology on agricultural productivity and profitability will depend, in large part, on the demand characteristics of the agricultural product to which biotechnology is applied. The degree of price elasticity will determine the relative benefits of technology-induced supply and price changes on producers and consumers.

Public Attitudes Toward Biotechnology

Many early proponents of biotechnology were victims of "technological super optimism" (OECD, 1989) and were surprised by the strength of the concerns about biotechnology expressed by some segments of the public (Hayenga, 1988). Some members of the scientific and science policy community tended to dismiss public concerns about biotechnology as being the product of scientific illiteracy (Lacy, Busch, and Lacy, 1991). They were slow to realize that many of these concerns involve uncertainty surrounding new technology introductions in general and the degree of "acceptable risks"; increasing public demand for environmental quality and food safety; a lack of public confidence in the regulatory system; differences in basic values; opinions about the treatment of animals; and legitimate conflicts of interests over who may gain and lose from technological change.

Public knowledge of biotechnology and its many applications (for example, medical, agricultural, and environmental) are becoming more frequently discussed in the media. Some surveys have been conducted to determine public awareness of biotechnology. It is unclear from the survey results whether public awareness of biotechnology has changed much over the last several years. A 1985 survey (Berrier, 1987) reported that 49 percent of respondents indicated that they had some knowledge of biotechnology. A national survey conducted in 1986 by the Office of Technology Assessment (OTA, 1987) found that 35 percent of respondents indicated they had heard or read a lot about genetic engineering. Another 24 percent indicated they were aware of genetic engineering but that they had only read or heard very little about the topic. In another survey conducted in 1987 (Russell and others, 1987), 61 percent of those interviewed had heard of biotechnology. However, a survey conducted by Hoban and Kendall (1992) in North Carolina reported that only about 47 percent of the respondents had heard some or a lot about biotechnology and its applications. In Europe, a study on public attitudes revealed that the level of awareness of biotechnology applications ranged from 38 percent to 69 percent depending on the country (CUBE, 1991). It is likely that as the public gains more familiarity with biotechnology and its many applications, attitudes will change either positively or negatively about agricultural biotechnology. Many new applications of biotechnology in the health and environmental markets, such as human vaccines and Rest-resistant crops, could have a positive influence on public attitudes for biotechnology in general.

One source of public concern expressed about biotechnology reflects discomfort with the unknown elements surrounding the introduction of any new technology and the level of "acceptable risk." Unanticipated negative experiences with the introduction of past technologies have influenced public perceptions about new technologies (Lacy, Busch, and Lacy, 1991). Public perceptions vary about what levels and types of risk are acceptable. Value-laden words such as "safety," "hazard," and "risk" are often used without an understanding of the precise meaning of these words (Hotchkiss, 1990). "Safety" is not a scientifically useful term because there is no way to quantify safety (Hotchkiss, 1990). A "hazard" is anything that has the capacity to do harm, no matter how small. "Risk," on the other hand, is the statistical probability that harm will result and can be determined by considering the exposure to a hazard. Studies have shown that the public "tends to underestimate familiar risks and to overestimate risks that are unfamiliar, hard to understand, invisible, involuntary, and/or potentially catastrophic" (H. Miller, 1993). In the food safety debate, it has been expressed that uncertainty in data, conclusions, or methods entails risk to members of the public (Thompson, 1990). Safety regulations could be established to ensure public safety by using either the definition of "risk" or "hazard." The definition used would have implications for public confidence. There is a lack of confidence among some members of the public in the effectiveness of current laws and regulations to adequately protect public safety. The Hoban and Kendall (1992) survey reported that 47 percent of the respondents lacked confidence in the Government's ability to effectively "protect citizens from most environmental risk."

Ethical questions have also been raised concerning the transfer of human and animal genes into plants and animals different from the host species (transgenics). The Hoban and Kendall (1992) survey respondents indicated that the use of biotechnology for modifying plants was more acceptable than for modifying animals. Most respondents indicated that transferring genes from plant to plant would be acceptable (66 percent), but they felt it would be unacceptable to transfer genes from animals to other animals (61 percent), animals to plants (75 percent), viruses to plants (80 percent), or humans to animals (90 percent). Animal rights advocates argue that genetic modification of animals is "'radically different from and less acceptable" than genetically modified plants (Fox, 1992). Many believe that the use of biotechnology techniques could be considered "messing with nature." The survey found that about 90 percent of the respondents agreed or strongly agreed that "the balance of nature is very delicate and easily upset by human activities" (Hoban and Kendall, 1992). Vegetarians and those following certain religious practices may not want to consume vegetables or fruits containing certain animal genes.

Animal welfare concerns have also been expressed. Many potential benefits could be gained from transgenic research. Transgenic animals created with a genetic predisposition for certain diseases are serving as models for discovering cures for some human illnesses. Although better information about human disease would result, animal suffering might be involved. Biotechnologies that increase milk or meat production could lead to health stress in an animal and an increased use of antibiotics. Some are concerned that biotechnologies may also lead to a more "industrialized" agriculture where animals are treated more like machines than as living creatures. On the other hand, animal welfare could be increased by the use of biotechnology techniques, such as the development of diagnostic tests and vaccines to detect and cure animal diseases.

Technological change, by definition, will affect the status quo. Different groups may not share equally in the benefits, costs, and risks associated with the introduction of a new technology. Net benefits may vary across regions, countries, economic sectors, or social groups. Some segments of the population may experience dislocations and welfare losses. For example, the adoption of the tomato harvester displaced farmworkers who depended on tomato-harvesting jobs. The development of large tractors made the operation of large farms more cost-effective than small farms, thus contributing to the trend toward larger agricultural production units. Some agricultural

Consumer Demand for bST-Supplemented Milk

Bovine somatotropin (bST) is a naturally occurring protein that stimulates milk production in dairy cows. The hormone works by converting nutrients from fat production to milk production (McClelland and others, 1991). In the 1930s, it was discovered that injecting cows with bST could greatly increase milk production per cow. However, bST could not be economically produced until the development of biotechnology techniques. Early estimates of productivity increases were very high (up to 40 percent). Later estimates, based on realistic farm conditions, predicted a 10-20 percent increase during the latter part of lactation which would be an overall increase of only 6-12 percent per year per cow (Kuchler and McClelland, 1989; OTA, 1991). The commercial application of supplemental bST in the United States was recently approved by the Food and Drug Administration (FDA) after several years of deliberation about bST safety and efficacy.

Considerable uncertainty exists in the marketplace concerning consumer acceptance of milk produced from cows treated with biotechnology-derived bST. Smith and Warland (1992) summarized several consumer surveys that were conducted over the preceding 6 years on bST. Aggregating the survey results, they estimated that about 60 percent of respondents would not change milk consumption, 30 percent would change consumption slightly, and 10 percent would stop altogether if producers supplemented milk production with bST. A more recent consumer survey estimated that the use of supplemental bST could decrease milk consumption in New York by 6 percent with a 27-percent consumer awareness, and by 16 percent when all respondents were provided with information about bST (Kaiser and others, 1992).

Consumer and public concerns regarding the use of supplemental bST for increasing milk production primarily center around perceived health effects and the potential impacts to the structure of the dairy industry. Although the FDA has determined that milk from bST-supplemented cows is safe for human consumption (Juskevich and Guyer, 1990), some consumers are still wary. In addition, many members of the public are concerned about encouraging milk surpluses which could cause a further movement toward fewer and larger dairies. They are concerned that increased government expenditures may be required to mitigate negative impacts to dairy producers. Like most biotechnology applications, bST may not necessarily favor large operators over small ones. Regional factors and level of human capital, such as management ability, will be the important determinants of cost efficiency.

Food marketers believe that public concerns about food safety effects and social change associated with supplemental bST could reduce the demand for all milk products. To assure concerned consumers, some retailers of dairy products may request that milk cooperatives guarantee that they will only supply milk from cows not treated with supplemental bST. In California, some milk cooperatives may require signed affidavits from milk producers to certify that the delivered milk was not produced with supplemental bST. Milk cooperatives in other States are also proposing certification procedures. A 1992 survey of California dairy producers indicates that only about 7-9 percent of producers would adopt bST immediately and that 34-38 percent would adopt overall (Butler, 1993). The survey results and potential retailer action suggest that a limited number of producers may actually adopt bST in California.

biotechnologies may be similar to other technologies in that they could further restructure agriculture into fewer and larger farms, thereby reducing the number of small farms and affecting rural communities. However, the intensity of the effect of biotechnology adoption on farm structure will depend on scale factors (see "Economic Effects of Agricultural Biotechnology," p. 31).

The commercial success and societal benefits of agricultural biotechnology will be influenced by the technology's ability to meet consumer demand for cheaper, higher quality, and safer foods; a healthy environment; and socially acceptable technologies. Public approval or disapproval of food products is expressed in the marketplace. If a significant number of consumers remain reluctant to purchase these products, adoption by producers of biotechnologies could be significantly slowed.

Several surveys have been conducted to determine public attitudes toward specific agricultural biotechnology products. Most surveys have focused on the use of supplemental bST in milk production (see box, "Consumer Demand for bST-Supplemented Milk"). One problem with such surveys, however, is the lack of relevant information given to respondents (Smith and Warland, 1992). Responses easily can be biased by the use of value-laden language. Terms such as "genetic engineering" and "hormone" may carry negative connotations for some individuals, regardless of the precise nature of the specific technology under consideration. In a consumer's willingness-to-pay experiment, Buhr (1993a) found that consumer attitudes were more favorable toward leaner pork produced using porcine somatotropin (pST) after the participants were provided with information regarding product attributes and scientific evaluations ensuring the safety of the product. The knowledge base of an individual and the source of the knowledge or information will help form public attitudes toward agricultural biotechnology and its products.

Public concerns about food safety, environmental quality, regulatory oversight, animal welfare, and social change have led some interest groups to demand special labeling of foods that are produced using biotechnology (see "Labeling Foods Derived From Biotechnology," p. 25). Public opinions have a significant impact on consumer demand for agricultural biotechnology products.

The public's willingness to buy foods produced using biotechnology was examined in the Hoban and Kendall (1992) survey. About 59 percent of the respondents indicated they would be willing to buy biotechnology-derived foods that were 10 percent cheaper than the same foods produced without the use of biotechnology. About 43 percent of the respondents were willing to pay more for biotechnology-derived foods compared with other foods if those foods were of higher quality. These responses indicate that there are trade-offs between the perceived risks from consuming genetically modified foods and the lower prices and/or higher quality of these foods.

The heterogeneous nature of consumer preferences can lead to uncertainty about consumer demand for new agricultural products derived from biotechnology. Uncertainty about consumer demand means that producer profits from adoption are also uncertain, and this may affect a producer's decision to adopt a particular technology. Many producers may take a "wait and see" attitude to evaluate consumer reaction to new products on the market. If consumer acceptance of these products grows, more farms and firms will adopt biotechnology-derived inputs.

Public Policies and Regulations

Agricultural and Environmental Policies

The objectives of agricultural and environmental policies primarily are to support farm incomes and conserve natural resources while maintaining, for consumers, adequate agricultural supplies at reasonable and stable prices (Langley and Baumes, 1989). As discussed above, an agricultural producer's choice of technology depends on the relative prices and productive capacity of substitute inputs, and on the market demand for the commodity produced. Agricultural and environmental policies can have substantial effects on profitability through policy-induced impacts on the prices of farm inputs and outputs, and on the value of natural resources.

Technological change in agriculture can create disparities in farm incomes by changing the relative comparative advantage of agricultural producers. Agricultural policies attempt to adjust the disparities between farm incomes by shifting the social cost burden from farmers to taxpayers. Common agricultural policies include commodity programs, input subsidies, and Federal credit programs. Commodity programs target specific commodities to be managed with supply control or price support policies. These policies attempt to enhance farm incomes by restricting output and keeping prices above a minimum level. Input subsidies and Federal credit programs can reduce an agricultural producer's risk of investing in new technology inputs. The choice of agricultural policies may influence the potential adoption of certain types of agricultural biotechnology inputs. For example, agricultural biotechnologies that increase output (that is, reduce the costs per unit of production), such as the use of supplemental bST in a supply-controlled dairy industry, would tend to increase government expenditures to maintain price supports. The impact of biotechnology introduction will depend on the degree of government involvement in the product market.

Agricultural practices can have damaging effects on environmental quality and the supply of natural resources. The social costs of these effects are not reflected in input costs and output prices. The environmental or health damage caused by chemical runoff from a farm is not included in the private cost of chemical use. The effect of an individual's use of water from an aquifer on the future availability of water to others is not included in the private cost of water use. The social cost is equal to the private cost plus the cost of the external effect. Environmental policies and regulations attempt to incorporate social costs in two ways: (1) by increasing the cost of environmentally damaging or natural resource-intensive inputs relative to more benign inputs, or (2) by increasing the price of commodities that are produced using environmentally damaging practices or scarce natural resources, thereby lowering demand for the commodity. These policies would effectively decrease the profitability of using environmentally harmful agricultural inputs by increasing production costs and decreasing demand. Environmental policies could include cost-sharing, or input and output taxes. With cost-sharing, the Government helps to cover the costs of investing in agricultural inputs that limit natural resource use and damage to the environment. Cost-sharing creates an incentive for the voluntary adoption of the targeted input, technology, or practice. Input and output taxes would affect the demand for the agricultural input or commodity that is harmful to the environment. The choice of pollution-reducing or resource-conserving policy would directly affect farm profits. The underlying assumption behind cost-sharing is that farm income would be maintained and environmental improvement costs would be borne by taxpayers. Taxes, on the other hand, transfer costs to the farmer, which may reduce crop supply and raise consumer prices.

Some emerging agricultural biotechnologies may provide farmers with new alternatives and opportunities for maintaining productivity while adhering to environmental regulations implemented to reduce environmental costs. The effect of environmental policies and regulations on the adoption of agricultural biotechnology will depend on the characteristics of the particular technology under consideration. Environmental policies and regulations limiting the use of environmentally damaging agricultural inputs could encourage producer demand for some biotechnology-derived inputs. For example, a regulation that established minimum pesticide residue levels found on food would affect the choice of chemicals used in production. In this case, there may be a producer incentive to adopt seeds genetically modified for pest resistance in order to replace or limit the need for chemical inputs. There also may be environmental benefits associated with the use of pest-resistant crops. The pesticidal properties in the residues of genetically modified crops left on the field would probably biodegrade and not contribute to loadings of potentially harmful constituents to leach into ground water supplies.

International Trade and Agricultural Biotechnology

The farmer's decision of whether to use biotechnology-derived inputs will be strongly influenced by the size of the market for the product. Product demand is a major determinant of the price a biotechnology adopter expects to receive. U.S. consumer demand was discussed above, but the domestic market is not the only outlet for biotechnology products. One of the major sources of growth in demand for U.S. agricultural products over the past two decades has been in overseas markets. In 1991, 22 percent of all U.S. agricultural production was exported, and agricultural exports accounted for 10 percent of all U.S. commercial exports (USDA, 1992). A strong export market helps support higher prices for farm commodities, which in turn encourage farmers to invest more in new technology and productive capacity.

The future demand for U.S. agricultural exports will depend critically on international trade agreements. The successful conclusion to the Uruguay Round of the GATT may open international markets for U.S. products by increasing agricultural exports. However, nontariff barriers and public concerns in other countries may restrict foreign markets for U.S. biotechnology products. For example, the European Community has placed a temporary moratorium on the use of supplemental bST in dairy production. Moratoria could limit access of producers to markets in other countries that have stronger restrictions on the use of certain commodities or production inputs. The result could be a decline in trade and a reluctance of U.S. farmers to adopt the new technology.

Regulatory standards for food safety and environmental quality often differ between countries. When standards vary significantly, it is costly for firms in one country to tailor products to meet the different standards in another country. Standards also can be used as a form of nontariff barrier to trade that protect domestic producers from foreign competition. Harmonizing regulatory standards for product quality and safety, such as acceptable levels of pesticide residues or additives in foods, was addressed in the Uruguay Round of GATT. Harmonization is the process of making regulations compatible, not necessarily identical, across countries.

Differing environmental standards between countries also can be costly for some industries. Where environmental standards are strict, producers may have higher costs than their competitors operating in regions with lower regulatory standards. The sale of biotechnology-derived seeds would depend on the environmental laws existing in the purchasing country that pertain to growing biotechnology-derived plants. Harmonization of environmental regulations could increase the international market for biotechnology-derived food products.

Another major factor affecting the demand for U.S. agricultural exports is the rate of economic growth in less developed countries (LDC's). Since the 1970's, the major source of growth in the demand for U.S. agricultural exports has come from LDC's (Vocke, 1988). Economic growth has led to large increases in the demand for food in these countries since a large share of per capita income goes to food purchases in developing countries. The performance of these economies in the future will play a major role in determining the demand for U.S. agricultural exports.

Biotechnology products may be developed in the United States to replace imports of agricultural commodities from LDC's (Lacy and Busch, 1991). The loss of markets for primary export products would be critical for developing nations. The reduced trade in raw materials provided by LDC's is a continuation of an ongoing trend to replace products like jute and rubber with synthetic products (OECD, 1989). Already, the production of enzyme-based sweeteners has affected the demand for sugar exports from developing countries. Future biotechnology developments threaten to decrease trade in some agricultural products. In addition, biotechnology-derived feedstocks such as sucrose, methanol, and lignocellulose may replace commodity chemicals currently produced from petroleum. The basic contradiction is that developing countries have the need and potential markets for biotechnology products, but do not have enough purchasing power to make trade profitable for many technologies (OECD, 1989). On the other hand, some LDC's, particularly the faster growing Asian economies, are investing in biotechnology by welcoming foreign biotechnology investors. Foreign investors have an incentive to invest because some of the host countries have few regulations that restrict field testing or product sales. Countries with less strict regulatory environments may be able to quickly move products throughout the development stage and then compete in agricultural markets with more developed countries.

Labeling Foods Derived From Biotechnology

Consumer demand for a food product depends on the perceived characteristics of the food. Some consumers believe that the derivation of foods from "genetically engineered' plants or animals is a negative characteristic. The purchasing behavior of consumers will result from perceived tradeoffs between the positive and negative aspects of consuming biotechnology-derived foods. Public concerns about environmental and food safety, animal welfare, and social change have prompted consumers to request labeling on biotechnology-derived foods.

Product appearance, price, familiarity, and labels help to provide information about food products to consumers. Labels can facilitate an informed choice by providing information about the characteristics of the food product. Labels could also provide producers some protection from costly lawsuits. The form and type of the information provided, and the costs incurred by providing labels, influence consumer demand for the final product and producer demand for the new technology inputs.

Consumers may reject biotechnology-derived products if they feel that they are being denied the information needed to control their own food choices (Thompson, 1993). Several types of labels could be used, including trademarks or other logos, or merely information provided at the point of distribution. A warning label, on the other hand, may have a more negative impact on consumer demand than a basic label indicating food ingredients. Also, the higher producer costs of providing labels could be transferred to consumers in the form of higher product price. A reduction in consumer demand and an increase in producer costs could inhibit producer adoption of a new technology.

In the United States, some consumer groups and other members of the public have requested the labeling of some or all foods produced using biotechnology techniques, specifically genetic engineering. Many have claimed that they have a "right to know" whether foods have been developed using biotechnology regardless of whether or not there exists a potential health or environmental risk. The FDA regulates food labeling requirements under the Federal Food, Drug, and Cosmetic Act (FDCA). FDA policy is to regulate the food product and not the process by which it was produced when considering market approval and labeling. The FDA currently is reviewing labeling policy. As proposed, the FDA would not require the labeling of food products derived from biotechnology unless those products differed substantially from existing products (for example, nutritional changes), or if consumers need to be warned about the safety (for example, increased allergenicity). Labels may also be required to inform a consumer about special preparations or uses of the food product. Finally, labeling may be required if consumers consider disclosure as important or the lack of a label as misleading (that is, "material information"). In 1993, the FDA published a request for comments on the labeling proposal for biotechnology products (Federal Register, 1993). The agency will use the public response to define the scope of any labeling requirement, particularly with respect to what would be considered material information. Currently, many proponents of biotechnology argue that having a generic label identifying a product as having been produced using biotechnology methods gives no material information. For instance, the consumer would not be informed as to whether food safety had been improved or compromised, or whether the product required different chemicals to produce. The terms "biotechnology" and "genetic engineering" encompass many techniques and applications, so what would constitute material information would differ for each product.

Labeling requirements for biotechnology-derived foods could have significant economic consequences for consumers, the food industry, and government expenditures. The magnitude of the effects of labeling will depend on which type of labeling regime is instituted. Three general types of labeling are discussed below:

Voluntary labeling would maintain existing FDA regulations for food labeling, as discussed above, where labeling would be requited if the food contains a potentially harmful substance or differs substantially from existing foods. Otherwise, producers would be free to label products as either produced with or without using genetically engineered plants, animals, or microorganisms. Producers who voluntarily label food products may be required by the FDA to verify that labels are not misleading or false. Voluntary labeling may allow producers to take advantage of higher prices from niche markets if there is only a subset of consumers who feel strongly about the use of biotechnology to develop food products. This option is the least costly to implement for the Government, but would provide the least assurance to consumers that adequate disclosure was being supplied about whether or not foods were produced using genetic engineering. The producers providing the labeled food and the consumers purchasing the labeled food would share the additional costs of supplying the labels.

Regulated voluntary labeling would allow food producers who choose not to use "genetically engineered" plants, animals, or microorganisms in food production to label their products as such. The difference from the "voluntary" option above is that the FDA would require a certification procedure (either by a government body or by an industry association) that would verify that labels were not misleading or false. This procedure would be similar

Labeling Biotechnology-Derived Foods In the United Kingdom

The Food Advisory Committee (FAC) in the United Kingdom is also reviewing labeling regulations for genetically modified food products. Like the FDA, the FAC proposed regulating the product and not the process. Both already require labeling on the basis of food safety. According to the FAC proposal, there would be a greater chance that biotechnology-derived food products would require labeling if the source of a transferred gene was from an animal or human rather than if the gene came from a plant source. The difference reflects public concern over genetic modifications that are derived from animal or human genes. In addition, the FAC maintains that vegetarians and those practicing certain religions may choose not to purchase food products containing animal genes, so they have a legitimate right to know. Labels may also be required for some processed foods that still contain ingredients that have been genetically modified. However, labels would not be required if the primary purpose is to educate the consumer, or if there is opposition based solely on principle. Finally, the FAC warned against a blanket label covering all genetically modified foods since this would not provide enough information to address the specific concerns of consumers. The FAC recommendations will now be considered by the Government of the United Kingdom.

to state-level certification and labeling regulations found in organic food markets. This option is more costly to implement for the Government than the "voluntary" option, but would provide more assurance to consumers that adequate disclosure was being supplied about whether or not foods were produced using genetic engineering. The Government could collect certification fees from producers to cover implementation costs as is done in the marketing of organic foods or allow industry to set its own standards. Again, consumers and food producers providing the labels would share the labeling costs. However, the burden would fall primarily on producers that do not adopt the new technology and on consumers who prefer not to purchase biotechnology-derived products since they would be the target of labeling.

Mandatory labeling would require all food producers to provide labels on foods derived from genetically engineered (or biotechnology-derived) plants, animals, or microorganisms. This form of labeling would be the most costly for the Government to implement, but would provide consumers with the most assurance that adequate disclosure was being supplied about whether or not foods were produced using genetic engineering. Consumers and producers of these labeled foods would share the increased production costs. The burden would fall mostly on producers that use the new technology and on consumers of those products.

Mandatory and regulated voluntary labeling could be costly to implement for both the food industry and the Government. Labeling costs to the food industry would be embodied in printing, inventory loss, required administrative and marketing changes, and analytical testing (OTA, 1992). The high costs could discourage producers from adopting agricultural biotechnologies that require labeling. Increased government outlays would be required to cover the enforcement and monitoring costs of labels. The taxpaying public would bear this cost. Monitoring throughout the stages of the marketing chain would be extremely difficult. Processing grains of wheat into bread typically involves purchasing wheat from many sources and consists of many processing levels. It would be nearly impossible to verify which portion of the wheat was grown from a genetically engineered seed variety. The expression of the transferred genetic trait may never appear in the harvested crop. For example, genetic modification of a corn plant to resist insects may not affect the ear of corn itself. No generic means exists today to identify whether a food constituent has been genetically engineered, and it is unlikely that a cost-effective method can be developed in many cases (OTA, 1992). Without this level of detection, genetically modified food products would have to be segregated throughout the marketing chain if labeling were required. This requirement for segregation has implications for marketing relationships. For instance, food processors may require their agricultural suppliers to confirm they use varieties not genetically modified. There would be more vertical linkages and control from the farm to the market.

Consumers value labels, but an analysis of a consumer's willingness to pay for labels for future food products derived from biotechnology is complex. It is difficult to predict the knowledge and perceptions of consumers about genetically modified foods at the time of purchase, and to predict the level, type, and costs of information about genetically modified foods that would be provided on labels. The type of label will also affect the consumers' value of the information. A generic label indicating that a biotechnology process was used at some time during production gives virtually no substantive information except to the subset of consumers who object to the use of biotechnology methods on moral grounds. A consumer with a particular food sensitivity would value information about a change in allergenicity. Information about improvements in nutritional characteristics would be of value to other consumers.

Because consumers do not have experience with genetic engineering in agriculture, their views may change over time (negatively or positively) as they become more familiar with foods produced using these technologies. The uncertainty about consumers' preferences implies that labeling regulations instituted before the introduction of biotechnology-derived foods may need to be modified as perceptions change. There are important tradeoffs to be considered in the decision to require labels for biotechnology-derived products. Those who gain may not be the same individuals as those who pay the costs. An ineffectual labeling scheme that does not instill public confidence or a scheme that is unnecessarily restrictive could inhibit the adoption of biotechnology.

Review of Empirical Studies on Adoption and Diffusion of Agricultural Biotechnology

The extent and rate of adoption are important factors in estimating the potential market for agricultural biotechnology products and in assessing the effects of technical change. Several empirical studies have attempted to estimate the adoption and diffusion of agricultural biotechnology applications in U.S. agriculture. A study on *adoption* examines whether an individual farmer will decide to use the new technology. A study on *diffusion* investigates the change in aggregate adoption of a new technology over time. From a biotechnology investor's perspective, if only a small percentage of potential users will ever adopt a new technology, the high costs of R&D may never be recouped. Also, if the rate of adoption is expected to be very slow (only a few adopt at a time), there may not be a sufficient incentive to do research. Therefore, an investor's decision would be based, at least partially, on estimates of technology adoption and diffusion. From a public policy maker's point of view, forecasts of technology diffusion could be informative since the effects of biotechnology adoption may have a significant impact on farm structure, environmental quality, human nutrition, or animal health.

Most of the empirical studies on the adoption and diffusion of biotechnology-derived agricultural products have focused on supplemental animal growth hormones in the livestock industry since this biotechnology application is close to commercialization and information about these technologies exists. Three basic approaches are used to estimate the adoption and diffusion of agricultural biotechnology (table 6). The first approach is to survey agricultural producers to ascertain whether they plan to adopt a new technology, and to what extent they plan to adopt. The second is the expected profits approach, which uses information on the technical characteristics of the technology, farm conditions, and the economic and policy environment farmers face in order to determine the number and type of farms that are likely to find the new technology profitable. The third approach is to forecast technology diffusion by using data on historical market trends to extrapolate the expected future market with the use of the new technology. Each of these approaches is used to predict the extent and rate of biotechnology adoption.

Producer Survey Approach

The producer survey approach uses questionnaires to elicit responses from producers on whether they plan to adopt the new technology. The survey instrument may include several sections. The producer's initial level of awareness about the new technology is obtained, and then details about the new technology are usually provided. The producers are then asked whether or not they would adopt these technologies, and to what extent they would adopt over time. The producer surveys reviewed for this report were conducted mostly on the use of bovine somatotropin (bST) as a supplement for dairy cows to boost milk production. One questionnaire (Kalter and others, 1985) resembled a decision calculus format. This interviewing procedure is designed to elicit subjective responses by rephrasing the same questions several times to include more or assorted information about the new technology.

To analyze whether socioeconomic factors influence a producer's decision to adopt, information is collected on producer characteristics such as education, age, and management style. Also, farm characteristics such as yields, costs, and physical attributes of the farm are collected.

A number of inherent problems exist with producer surveys conducted prior to the commercial availability of a new technology. The producer survey results reported in table 6 predict that the percentage of early or immediate bST adopters and eventual bST adopters could range anywhere from 8 percent to 41 percent, and 33.7 percent to 92 percent, respectively. The wide ranges could be attributed in part to differences in regional characteristics, such as weather, soil types, and production systems (McClelland and others, 1991). Other causes for the varying estimates, however, could include survey bias, underlying assumptions about the characteristics of the technology, and changing opinions. Most of the surveys provided the respondents with hypothetical facts about bST because information is limited about the costs and production responses associated with bST use. Responses can be influenced by the information provided in the survey and the way questions are asked. For example, answers to questions would depend on who was asked and what the respondents thought about how the survey results would be used. The year the survey was conducted will also strongly affect a producer's decision to adopt bST because as more information becomes available, new opinions are formed about the product. Dairy cooperatives, producer associations, neighbors, cooperative extension agents, and the media continuously help form these opinions.

An annual California survey concerning the use of supplemental bST in the dairy industry was initiated in 1987 (Zepeda, 1990). During the interview process, producers were not given any information about bST if they indicated they were not aware of the technology. The results showed that during the first 4 years of the survey, producers became more aware of bST and were less likely to adopt this technology (Butler, 1993; Klotz and others, 1994). These results are consistent with theories of producer adoption. In recent years, there has been an increase in negative consumer and producer reaction to bST use due to more media coverage about the safety of bST and the

Table 6-Studies on adoption and diffusion of bST and pST

Paper (publication year)	Technology	Region	Approach	Adoption and Diffusion Rates
Buhr (1993a)	pST	Iowa	Producer survey	2% immediate 24% in 1 year
		Large farms		33% immediate 69% in 1 year
Butler (1993)	bST	Cslifomla	Producer survey	
			1987	50.8-70.6% total[1]
			1988	57.7-73.0% total
			1989	47.6-55.2% total
			1990	33.7-42.6% total
Butler & Carter (1986)	bST		Profit function	
		California	bST price = $.50/day	24%. of cows[2]
		Wisconsin	bST price = $.50/day	6% of cows
Fallert & others (1987)	bST	Regional & national	Profit function	10-12% in 1 year[3] 45-70% after 7 years
Kalter & others (1985)	bST	New York State	Producer survey	27% immediate 66% in 1 year 85% after 5 years
Kinnucan & others (Feb. 1990)	bST	Southeastern dairy States	Producer survey	41% immediate 77% in 1 year 92% after 5 years
Klotz & others (1994)	bST	California	Diffusion model/ Producer survey	53-63% total[4] See Butler (1993)
Lesser & others (1986)	bST	New York State	Diffusion model/ Producer survey	51.2-84.7% of cows[5] See Kalter & others (1985)
Marion & Wills (1990)	bST	Wisconsin	Profit function	
			bST price = $.40/cow/day:	56-92% of cows[6]
			bST price = $.65/cow/day:	1-55% of cows
Nowak & Barnes (1988)	bST	Wisconsin	Producer survey	13% early 69% total 31% nonusers
OTA (1991)	bST	Regional	Historical trends	13-17% in 1 year[7] 25-46% after 5 years 31-67% after 10 years
Saha & others (forthcoming)	bST	Texas	Diffusion model/ Producer survey	34% of cows See Schwartz & others (1993)
Schwartz & others (1993)	bST	Texas	Producer survey	14% immediate[8] 36% waiters 45% nonusers
Sporteder & Liu (1992)	bST	Regional & national	Historical trends	7.7% of cows in 1 year[9] 74.5% of cows in 10 years
Zepeda (1990)	bST	California	Producer survey	8% immediate[10] 34% waiters 29% nonusers

Note: Unless indicated otherwise, the results reported are the number of producers (farms) that indicated they would use bST. Also, diffusion models are used to estimate adoption over time and maximum adoption.

[1]The lower number in the range Includes Immediate adopters and those who would wait to adopt bST. The higher number includes those participants who had not heard of bST. [2]Adoptlon rate predictions are based on a 15-percent increase in milk production and a 50-cent profit from using bST. [3]The range of adoption rates were calculated for 1990-96, and the percent adoption depends on price support scenario and various other assumptions about bST costs and milk price. [4]The lower model estimate does not include producers who had not heard of bST. The upper estimate incorporates a portion of producers who had not heard of bST, but were predicted to adopt bST. [5]Diffusion rates depend on survey response and the method of treating cows with bST (that is, injection or transplant). [6]The lower estimate is based on a 9-percent increase in milk production, a milk price of $10.50 per hundredweight, and higher costs. The upper estimate Is based on a 12-percent increase in milk production, a milk price of $11.00 per hundredweight, and lower costs. [7]The range of adoption rates are for regions. The adoption estimates included the Pacific, Lake States, Northeast, Appalachia, Southeast, Southern Plains, and Corn Belt regions. [8]The repotted survey results do not include 5 percent of producers who did not know if they would adopt bST. [9]The national results are reported. [10]The results reported did not include 20 percent who were not aware of bST and another 9 percent who did not know if they would use bST. Of those who were aware of bST, 11 percent would be immediate adopters, 46 percent waiters, and 41 percent nonusers.

potential negative impact on smaller dairies from bST adoption. Therefore, surveys conducted in earlier years may have overestimated the extent and rate of bST adoption.

Expected Profits Approach

The expected profits approach uses information on the technical characteristics of the technology, farm conditions, and the economic and policy environment that farmers face in order to determine the number and type of farms that are likely to find the new technology profitable. This approach requires assumptions about the effects of biotechnology adoption on input requirements, resource use, yields, costs, and the expected commodity price. First, historical data and technical information are gathered from experts. Then, this information is used to identify the type of production systems and regions that would be able to profitably adopt the new technology. To obtain estimates about the performance of new technology in different production systems, these studies typically elicit the judgments of a panel of experts familiar with the technology. The Delphi method is a technique that is used to collect this type of information (Farrell and Funk, 1985; Tauer, 1990). This technique involves interviewing a large number of experts using an iterative procedure to develop a consensus on the plausible impact of the new technology on agricultural production. This procedure has not yet been employed in assessing the adoption of agricultural biotechnology. Many of the economic studies on agricultural biotechnology have referred to published materials covering the physical characteristics of the new technology and/or to communications with scientists.

The expected profit approach assumes that those producers who find a new technology more profitable to adopt than continuing the use of current production technologies will do so. The net gain in profits obtained from using a new technology must be greater than zero for a producer to adopt it, but how much greater than zero depends on the risk averseness of the producer. Therefore, adoption predictions using this approach could be biased upward if risk premiums are not considered. There are other potential problems with adoption predictions from the expected profit approach. To calculate the expected profit, many assumptions must be made about bST price, future milk prices, consumer demand, projected yields, and government policies. A change in these assumptions can significantly alter the adoption forecasts. The more flexible the model to incorporate changes in assumptions, the more useful the adoption and diffusion model. In addition, producer surveys have demonstrated that there are other factors besides accounting profits that affect the adoption of a new technology. Farmer attitudes and abilities are also important.

Historical Trends Approach

Historical trends are used to forecast technology adoption and diffusion by using data on historical market and production trends to extrapolate the expected use of the new technology. The historical trends approach has several limitations. In any adoption and diffusion analysis, it is important to be aware of past trends, but the analyst must also be aware of the characteristics of the new technology and how similar those characteristics are to the ones reflected in the historical analysis. The less the new technology resembles traditional practices, the less relevant historical trends will be for predictive purposes. The uniqueness of some aspects of biotechnology would limit the usefulness of the historical trends approach for predicting adoption.

Two studies (Sporleder and Liu, 1992; OTA, 1991) estimated adoption and diffusion rates for bST using historical data of the milk market. Sporleder and Liu used data from 1975-89 to predict the number of dairy cows that would be on supplemental bST between the years 1994 and 2003. The OTA study incorporated the historical rates of change for dairy industry inputs to estimate the percentage of herds that would be supplemented with bST. This study assumed low, medium, and high rates of adoption to show the sensitivity of results to assumptions about the factors affecting adoption. The scenarios based on different assumptions showed how adoption and diffusion rates may change as a result of changing socioeconomic and technological conditions.

Summary of Empirical Studies on Adoption and Diffusion of *Agricultural Biotechnology*

The empirical studies of agricultural biotechnology presented in this report dealt only with one type of biotechnology application, animal growth hormones. Analyses of other products might have very different results due to differences in the fundamental characteristics between technologies. For instance, the development of an effective, safe, and inexpensive diagnostic tool might be adopted quickly by the majority of potential users. The empirical approaches for predicting this pattern would be the same as those described above even though the technologies are different.

There was a wide range in the forecasts of adoption and diffusion rates estimated by the studies. Estimates of adoption of bST after the first year of commercialization ranged from 6 percent to 77 percent of either total farms or cows. The estimates from individual studies were fairly evenly dispersed within this range. No study predicted complete adoption by the entire dairy sector, even after 10 years of availability. Estimates of the extent of final adoption ranged from 1 percent to 92 percent based on different assumptions, with most studies falling between 30 and 75 percent. There were no significant differences in ranges of estimates for different regions of the country.

The wide range of forecasts is due primarily to uncertainty about several important variables: the acceptability of the biotechnology-derived product among producers, dairy processing firms, and consumers; the level of production efficiency that can be achieved when the technology is applied under actual farm conditions; and possible changes or adjustments in government dairy policy.

The decision by farmers and food processors to adopt a biotechnology product will be influenced by many factors. A new technology will be used if profits from adoption will be sufficiently larger than profits that would be earned without adoption. Profitability will differ between potential adopters due to differences in farm and farmer characteristics. External factors also affect the relative profits of the new technology. Public policies and regulations often change relative costs for inputs or the revenues that can be earned by farming. Ultimately, however, it is the consumer demand for the products of biotechnology that will determine the derived demand for the technology as an input into production.

Economic Effects of Agricultural Biotechnology

The introduction of any new agricultural technology will have implications for markets, producers, and consumers. In previous sections of this report, the determinants of demand for new technology were discussed. In this section, the many elements that determine the economic effects resulting from the creation, adoption, and diffusion of agricultural biotechnology are examined.

The economic effects of biotechnologies on the market for agricultural products will depend on how the technology affects costs of production, product quality, or both. Technologies that reduce costs of production are likely to lower food costs. Technologies that enhance product quality can increase the demand for agricultural products.

The introduction of biotechnology may affect the structure of the agricultural sector. The development of any new technology can contribute to the trend toward fewer and larger farms. Excess capacity exists when resources can be used more efficiently to produce a product with a relatively inelastic demand. Increased farm efficiency may lead to excess capacity and resources leaving the agricultural sector. New technology can also favor large farms through economies of scale. Other structural issues facing agriculture are increased vertical integration between producers and processors and increased concentration among input suppliers. These trends are due to several economic and technological forces, and can be only partly attributed to developments in biotechnology.

The application of emerging biotechnologies also has implications for environmental quality and food safety. Some agricultural production practices can contribute to the depletion of natural resources and environmental quality. Some of these environmental impacts include soil erosion due to tillage practices, water depletion, the effects of chemical fertilizers and pesticides on water quality, the use of scarce petroleum supplies for fertilizer production, and the impact on biodiversity and ecological balance. Some of these agricultural production and processing practices may also affect food safety by leaving unacceptable levels of pesticide residues on food. Agricultural biotechnologies may contribute to environmental damage or increase food safety risks in some cases, and benefit the environment or food safety in others.

The impacts of biotechnology adoption include the effects on product and input markets, farm structure, environmental quality, and food safety. A review of empirical studies is presented that examines the economic effects of adopting some agricultural biotechnologies. The review serves as an example of some of the questions addressed in an *ex ante* economic assessment of new agricultural technologies.

Implications for Product Markets

Cost-Reducing vs. Quality-Enhancing Technological Change

Two basic types of technological change exist: cost-reducing and quality-enhancing. Cost-reducing technological change reduces a producer's unit production costs by increasing yields or reducing input costs. Quality-enhancing technological change results in improvements in the attributes of the food product. Each type of technological change will have a different impact on existing market conditions. Changes in market prices and quantities result in changes in the distribution and magnitude of social costs and benefits. Therefore, the type of technology adopted by producers will have implications for assessing the economic impacts of agricultural biotechnology.

Cost-reducing technologies could increase profits by allowing a producer to produce a given amount of a crop at lower cost. Sometimes a distinction is made between cost-reducing and quantity-increasing new technologies; cost-reducing technologies may reduce production costs without increasing yields, and therefore market prices would not be reduced since cost savings would be kept by the farmer in terms of higher profit margins. This argument overlooks the fact that farmers currently producing the commodity may shift more of their resources to that commodity. Furthermore, other farmers not currently producing the commodity may shift into that commodity. These shifts would increase total output and put downward pressure on market prices similar to those that occur when a quantity-increasing technology is introduced (Tauer, 1988; Reilly, 1988).

Some examples of potential cost-reducing (quantity-increasing) agricultural biotechnology products include plants developed to resist pests, disease, and herbicides; plants that fix nitrogen; plants with the ability to tolerate adverse environmental conditions, such as drought and frost; transgenic animals and somatotropins produced to increase lean muscle tissue and milk production; and improved feedstock to increase fermentation efficiency in food-processing. These products are being developed to increase yields or reduce the use of more costly inputs.

Quality-enhanced food products have the potential to increase producer profits through increased demand for the improved food. Quality-enhanced foods can he sold at a higher price if consumers value the quality change. The higher prices may be an incentive to agricultural producers to adopt these technologies even if production costs remain unchanged or increase. Agricultural biotechnology could be used to improve food quality traits such as flavor, texture, shelf life, or nutritional content. Biotechnology techniques could also be used to develop foods with decreased amounts of toxins and allergens.

Many biotechnologies that are being developed may be both cost-reducing and quality-enhancing, like the somatotropins used to increase feed efficiency and lean muscle tissue as well as to reduce the percentage of fat in animals. Presented below is a discussion of how cost-reducing and quality-enhancing technologies could affect the supply and demand of a product. The discussion addresses changes in longrun market values for producer and consumer groups. Impacts on individual consumers or producers are not addressed. Although some of the new agricultural biotechnologies could be both cost-reducing and quality-enhancing, the discussion is simplified by considering the market impacts of each type of technology separately.

The productive capacity of a market sector depends on existing resources and technology. Given this productive capacity, a producer will supply different quantities of a product for each market price (that is, a supply function). Given certain product attributes, consumers will demand different quantities of that product at differing market prices. Consumer demand theory suggests that increases in market price of a product, everything else being equal, will decrease product demand. Market equilibrium exists at a particular price at which the quantity of a product supplied by producers equals the quantity demanded by consumers.

Cost-reducing technological change allows a producer to offer a greater or equal quantity of commodities at lower prices. The change in supply may not occur instantaneously. The magnitude and speed of the supply change will depend on the rate of adoption and diffusion of the technology. The adoption of the new cost-reducing technology results in a movement to a new market equilibrium price and quantity. As a group, consumers will benefit from having more of the commodity at a lower price. Producer benefits are uncertain, however. Producer benefits would increase if the new level of profits earned from selling more at a lower price is greater than the initial net benefits. For most cases of technology introduction, it can be assumed that consumers do not care which process was used to create the cheaper commodity (that is, the demand, or perception of quality, was unchanged).

Changes in consumer and producer benefits depend on the extent to which changes in price affect demand. If demand is fairly price-inelastic, then supply increases would result in little or no change in the final quantity demanded, but the price of the commodity would fall sharply. Demand for many staple crops has this characteristic. For products with a *price-inelastic* demand, consumer benefits would increase greatly from the biotechnology-induced drop in price, and total producer benefits would fall. On the other hand, if demand is *price-elastic,* then the increase in supply would result in a small drop in price, but a large increase in the quantity demanded. Products such as champagne and lobster may have this property. Consumer benefits would be less and producer benefits would be greater than in the *price-inelastic* case.

Determining the distributional consequences of quality-enhancing technological change can be more complex than in the cost-reducing case. A technology that improves the quality of a food relative to a similar existing food could segment the market into two markets: a high-quality and a low-quality market. In this case, the two products would be considered substitutes and the relative prices of each would determine final consumer demand in each market. Also, each of the two markets may operate under two different production technologies, which would have implications for producers' ability to supply each product. A new quality-enhanced food product would command a higher price than the lower quality food. The rate of the demand change to the higher quality product would depend on changing consumer preferences for the new product at a higher price. As demand moves away from the low-quality product to the high-quality product, the price of the low-quality product will begin to decrease. As the price of the low-quality product decreases, demand will increase for those products. A similar process will take place for the higher quality product as well. These iterations continue until each market adjusts to new equilibrium prices and quantities. Consumers of both the high-quality and low-quality commodities benefit from lower prices and increased variety as a result of quality-enhancing technological change. Producer benefits are uncertain, however. Some producers may actually become worse off due to lower profits.

The Effect of Public Policies

Public agricultural and environmental policies can have major impacts on market equilibrium prices and quantities. These impacts change the benefits and costs to producers, to consumers, and to taxpayers who fund government expenditures. Although other agricultural policies exist, the following examples offer a simplistic description of some of the problems to consider when assessing the potential impacts of biotechnology on agricultural producers, consumers, and government expenditures.

Commodity programs, such as price supports and supply controls, can cause market distortions. Price supports that establish minimum prices above equilibrium levels tend to encourage increases in commodity production above the demand for that commodity at the supported price. Supply controls limit production to below equilibrium quantities, which effectively increases price. Demand for the controlled commodity decreases in both cases and results in higher market prices due to the artificial market controls. Consumer benefits are reduced as a result. Government expenditures are generally required to purchase excess supply, or in some cases to subsidize prices, to maintain the increases in agricultural producers' benefits. Cost-reducing (that is, output-increasing) agricultural biotechnologies that affect commodities under commodity programs, such as the use of supplemental bST in the dairy industry, could further contribute to market distortions created by commodity programs. Studies focusing on the potential economic impacts from the use of supplemental bST in the dairy industry are reviewed at the end of this report. Several of the studies examined the impacts to the dairy industry of bST use under different agricultural policies. The impact of the introduction of quality-enhancing agricultural biotechnologies, on the other hand, would probably be less sensitive to the choice of commodity programs.

Environmental policies attempt to correct an existing market distortion created by environmentally harmful agricultural practices (Tietenberg, 1988). Agricultural prices currently do not reflect the true social costs of damage to the environment from soil erosion or degradation of water quality. Two types of public policy can be used to take account of both private costs and damages (external costs). Production costs can be increased for those producers employing the harmful practices. Alternatively, the producer can be compensated for adopting a pollution-reducing technology. The costs of the former type of policy would be borne primarily by the farmers and consumers. The latter policy would be paid for by the taxpayer. The degree to which producers, consumers, and the Government share the social cost burden depends on the environmental policy employed.

Implications for Market Structure

The Number and Size of Farms

The widespread adoption of many emerging biotechnologies could increase production and, given an inelastic demand for most farm commodities, could reduce farm-level and retail prices for the affected commodities. Part of the gains from higher agricultural productivity is transferred to consumers and to other sectors of the economy through these quantity and price changes. The distribution of gains from new technology among producers is likely to be uneven. Early adopters of new technology realize increased profits, at least in the short run. As more farmers adopt, the increase in aggregate supply causes agricultural prices to fall. Farmers who have not adopted the new technology could experience a reduction in farm income. Farmers who have adopted the new technology may also see their profits fall but are more likely than nonadopters to stay in business because the new technology also lowers their production costs. Nonadopters risk being driven out of business. The cycle of technological advance, supply increase, price decrease, and structural readjustment is known as the "technology treadmill" (Cochrane, 1958).

Concerns have also been raised as to whether biotechnology may favor large farms over small farms. The relationship between new agricultural technology and farm size may determine the structure of rural communities, and who wins and loses from technological change.

A technology is said to be "scale-neutral" if small, medium, and large farms can use the technology efficiently, that is, if the cost of producing a unit of output is the same for all farm sizes. Many chemical and biological technologies (for example, chemical fertilizers and new crop varieties) are scale-neutral because they can be used efficiently on small and large farms. However, some kinds of technology may be particularly well suited for large farms. For example, large-scale machinery may not be economical to use on limited acreage. The relative advantages of size is called "economies of scale." Large farms can make better use of this kind of technology and reduce their unit production costs below those of small farms. This advantage makes large units more competitive and may eventually force small farms out of the market.

Another source of size bias may occur in the technology adoption process. The adoption of new technology by farms involves a period of discovering, acquiring, and adapting a new technology to particular farm conditions. The information costs associated with adoption can be considered a fixed cost that must be paid by every producer regardless of the size of farm. If these costs are high, then an "information bias" may exist in which large farms find it easier to adopt new technology since they can spread the fixed costs of adoption over a larger level of production (Kinnucan and others, 1990b; Perrin and Winkelmann, 1976).

The case of supplemental bovine somatotropin (bST) provides a good example of the debate over the effects of adoption on the size and distribution of U.S. dairies. While there is a historical trend in the dairy industry toward fewer and larger dairy herds, there is a concern that the introduction of bST could accelerate this trend. There may also be significant regional effects. Some maintain that bST is scale-neutral and would not necessarily favor larger dairy farms over small and medium-sized farms. However, this scale neutrality argument considers only the technical efficiency of bST, and does not account for other factors such as management ability, capital ownership, and production capabilities that may vary with farm size. Several studies have shown that bST could affect the size, number, and distribution of dairy farms (OTA, 1991; Marion and Wills, 1990; Fallert and others, 1987; Kalter and others, 1985; Kinnucan and others, 1990a/b; Larson and Kuchler, 1990; and Tauer, 1992). McClelland and others (1991) argue that environmental or regional characteristics may be the most important determinants of who would adopt bST. Kinnucan and others (1990b) demonstrated that an "information bias" may exist in that the cost of human capital per unit of production is a strong determinant of bST adoption. With or without the use of bST, Tauer (1992) claims that there will probably be a shift toward more and larger dairy producers in the Southwest and fewer Northern dairy farms. The magnitude of these impacts will depend on factors including adoption and diffusion rates, government support programs, the supply and price of milk, and consumer demand for bST-supplemented milk.

Vertical Integration Between Producers and Processors

The introduction of many new technologies, including biotechnologies, is leading to greater vertical integration and coordination in the agricultural sector. Vertical integration and coordination are arrangements between agricultural producers and processors that ate designed to achieve improved alignment and control across segments of the production and marketing system (King, 1992). Both supply and demand factors underlie the trend toward vertical integration. On the demand side, a more consumer-oriented agribusiness sector is responding to increasingly diverse consumers who are more aware of what they are consuming and who are demanding certain product attributes. Advances in information technology mean that retailers are able to track tastes and preferences on product attributes with greater accuracy (Barry and others, 1992). Biotechnology may increase vertical integration in both crop and livestock sectors (Harlander, BeMiller, and Steenson, 1991). Biotechnology will enable firms to develop new crop varieties with specific nutritional, functional, and processing characteristics (OTA, 1992). Labeling requirements for biotechnology-derived products may also lead to more vertical integration in the market because processors will need to control and monitor the production system.

Vertical integration may involve direct acquisition or the use of formal contracts between producers and marketing firms. An increased use of contractual arrangements between farmers and processing firms has both advantages and disadvantages for farmers and consumers. For producers, contracts are likely to offer premiums over average market prices for agricultural commodities, greater access to new technology and inputs, and new sources of capital. However, contracts may also erode a tradition of farmer independence in production decisions and management. For processors, integration ensures predictable supply and consistent quality. While vertical integration could reduce competition in the agricultural sector, it could also improve marketing efficiency and lower the cost of processing food (Harlander, BeMiller, and Steenson, 1991; Barry and others, 1992).

Concentration of Input Suppliers

Increased concentration in the seed and chemical industries supplying agricultural inputs may be due in part to advances in biotechnology (Sundquist and Molnar, 1991; Kloppenburg, 1988). Over the past decade, many chemical and pharmaceutical corporations have acquired seed companies to obtain more control over the development and marketing of new seed varieties. Many of the major seed companies in the United States are owned by multinational petrochemical and pharmaceutical corporations (Kloppenburg, 1988).

The market structure for farm inputs could affect the direction of biotechnology developments (Hueth and Just, 1987). The petrochemical and pharmaceutical companies are the major developers and manufacturers of agricultural fertilizers, herbicides, and pesticides. New seed varieties developed by these firms may be designed to take advantage of these linkages (that is, to be highly responsive to agricultural chemicals). For example, several companies are currently developing herbicide-resistant corn varieties. Adoption of these varieties could increase the use of specific herbicides, but it is unclear whether this will encourage an increase in total herbicide use or the substitution among existing herbicides, some of which may be more environmentally benign (Krimsky and Wrubel, 1993). Some observers have suggested that concentration among agricultural chemical and seed suppliers may cause some socially desirable technologies not to be developed (Hueth and Just, 1987). For example, biotechnology can be used to develop pest-resistant varieties, biological pest controls, and varieties with enhanced biological nitrogen fixation. These technologies may not be developed by the private sector because they could potentially reduce the demand for agricultural chemicals and fertilizers. Krimsky and Wrubel (1993) found that private sector chemical firms were investing in pest and virus resistance applications for which current chemical controls are not available or ineffective. However, they found that none of the companies interviewed indicated that their research efforts on pest resistance were aimed at replacing existing chemical control methods. About 60 percent of the APHIS field-testing permits issued to large chemical companies between 1987 and 1991 were for testing pest- and virus-resistant plants. Another 30 percent of their permits were issued for herbicide-resistant crops. Of total permits, 45 percent were issued to large chemical companies, 21 percent to biotechnology companies, 20 percent to public institutions, and the rest to food and seed companies (Ollinger and Pope, 1994).

Implications for Environmental Quality and Food Safety

Some agricultural production practices can contribute to the depletion of natural resources and environmental quality. Some of these environmental impacts include soil erosion due to tillage practices; water depletion; effects of chemical fertilizers and pesticides on water quality; the use of scarce petroleum supplies for fertilizer production; and changed biodiversity and ecological balance. Some of these agricultural production and processing practices may also affect food safety by leaving unacceptable levels of pesticide residues on food. Agricultural biotechnologies may contribute to environmental damage or increase food safety risks in some cases, and benefit the environment or food safety in others.

Concern about risks associated with the release of genetically modified organisms (GMO's) into the environment is due to the fact that these organisms have the potential to reproduce, grow, migrate, and mutate. Public concern results partially from past experiences when the introduction of a new species from one ecosystem into another led to considerable change or damage, Some members of the public believe that a risk exists that genetically modified plants and animals may compete with indigenous populations and disrupt an ecosystem. The release of any particular GMO may have only a small chance of becoming a problem, but the problem could have long-term consequences that may be irreversible (Lacy, Busch, and Lacy, 1991).

Public and private biotechnology research groups recognize the seriousness of potential environmental effects. Public confidence in the regulatory process may increase due to a series of conservative rulings and the development of experimental guidelines on field testing by an independent panel of experts (ABRAC, 1991). Any firm that plans to field-test a plant developed with biotechnology must apply for a permit to the USDA's Animal and Plant Health Inspection Service (APHIS). An environmental assessment is made and public comment is encouraged throughout the process. The permitting process has been streamlined recently by the APHIS notification procedure for certain crop/technique combinations (Federal Register, 1993). Ollinger and Pope (1994) describe the history of field-testing genetically modified organisms with respect to the types of products and the characteristics of the organizations involved.

Concerns also have been raised about whether the development of agricultural biotechnology products is compatible with efforts to move toward a low-input agricultural production system. One goal of low-input agriculture is to reduce the amount of potentially harmful agricultural inputs, such as pesticides, herbicides, and nitrogen fertilizers, that could contaminate ecosystems and food and water supplies. Another goal is to conserve scarce resources, such as soil and water. In addition, a goal of low-input production is to reduce animal waste and feed use through more efficient meat production. Meeting these goals would improve environmental quality and food safety.

Agricultural biotechnology could help or hinder the development of low-input agricultural production systems. The development of pest-resistant plant varieties could reduce the need for chemical pesticides, placating strong public concern about the health risks of pesticides in food. A recent study by the National Academy of Sciences (NAS) determined that pesticides may pose a greater health risk to children than to adults (NAS, 1993). Nevertheless, NAS emphasized that reducing the intake of fresh fruits and vegetables in daily diets could be more harmful. The increased risk from small amounts of chemical residues is probably outweighed by increased nutritional benefits from eating these foods.

Agricultural biotechnologies under development that could promote low-input agricultural systems include: (1) biological nitrogen fixation (BNF) technologies that would allow plants to more efficiently absorb nitrogen from the soil or air, thereby decreasing the use of nitrogen fertilizers that could leach into water supplies; (2) drought-resistant crops that could reduce irrigation drainage flows by reducing crop water requirements; (3) increased feed efficiency of meat production, which reduces animal stocks, feed use, and waste; and (4) better and more user-friendly diagnostic tests to assess environmental quality and food safety on the farm so producers could adapt practices to limit damage to the environment and risks to human health.

There is a concern, however, that some biotechnologies, such as herbicide-resistant crops (HRC's), may actually encourage the continued use of chemicals in agriculture. HRC's are crops developed to survive the application of certain herbicides used to control weeds. Proponents of HRC's argue that the herbicides that these crops would resist would be less harmful than herbicides currently being used. Opponents claim that the development of HRC technologies is not appropriate since these technologies would not altogether reduce an agricultural producer's dependence on chemicals. The biotechnology-induced changes in volume and toxicity of herbicide applications are not yet known, but a recent study has concluded that herbicide-resistant crops "have the potential to reduce pollution and mitigate the environmental impact of pesticides in agricultural production" (Hoyle, 1993).

Risks to human health from consuming genetically modified plants and animals would primarily be from changes in the concentration of allergens, toxins, and nutritional content in those foods. Risks arising from intended genetic changes may be identifiable. A hypothetical example would be the transfer of a flavor gene from a nut into another food. Since nuts may contain allergens that affect certain people, it would be important to ascertain whether the properties of the allergen had been transferred along with the target flavor gene. Genetic alterations either from applying biotechnology or from traditional breeding methods could pose an unforeseen risk that would be more difficult to detect. For example, the "Lenape" potato bred with traditional methods was found to contain twice the level of glycoalkaloids (which are naturally occurring toxins) as standard potatoes (Doyle and Marth, 1991). Scientists have argued that biotechnology methods would be less likely to result in unplanned changes than traditional breeding methods.

In addition, the use of biotechnology could offer cheaper and more efficient diagnostic techniques to test for pathogens, toxins, or allergens in foods. Unfortunately, little is known about the mechanisms and pathways of allergenic effects of many food components. The FDA is the Federal agency charged with oversight in these matters.

Environmental quality and food safety can be considered externalities. Externalities occur when the social benefits and costs of a particular activity, like agricultural production, are not borne by the source of that activity (Tietenberg, 1988). As a result, the true social costs and benefits of these technologies may not be incorporated into market prices for agricultural commodities. The potential economic value of the different agricultural biotechnology applications on environmental quality and food safety is difficult to measure and the results of different estimation methods can be questionable. Several nonmarket methods are used to determine the unobservable costs or benefits of an environmental change. Nonmarket valuation techniques include contingent valuation, travel cost, hedonic pricing, and damage function methods (Bentkover, Covello, and Mumpower, 1986). Some of these nonmarket valuation methods, as well as market valuations, are also used to determine the value of food safety (Smallwood and Blaylock, 1991).

The *contingent valuation* method applies a survey technique to "elicit how people respond to hypothetical changes in environmental resources" (Smith, 1993). This method can be employed in food safety valuations as well. Respondents are asked what they are willing to pay for different levels of environmental quality (Smith, 1993) or food safety (van Ravenswaay, 1992; Smallwood and Blaylock, 1991). However, contingent valuation methods have some shortcomings. The hypothetical nature of the surveys presents situations that are not familiar to respondents, who may have difficulty assigning appropriate market values to environmental goods. Also, respondents may offer biased answers in hopes of achieving a particular outcome that benefits them (Tietenberg, 1988).

Travel cost methods are used to estimate the economic value of environmental resources by observing costs incurred by a visitor to a recreation site. These costs include the actual costs of traveling as well as the opportunity costs of time (Smith, 1993). Determining individual travel costs to a national park, for example, can be used to estimate the willingness-to-pay for that environmental resource. The validity of the economic valuation estimates would depend on travel costs being solely associated with the environmental resource in question and on the valuation of time lost that could have been allocated to some other activity such as working.

Hedonic pricing methods attempt to decompose observable market values of a product into its constituent parts (Tietenberg, 1988). For instance, decisions involving house purchases may include a list of valued characteristics, such as size, color, location to schools, and environmental quality. If the value of each part can he determined, then the economic value of environmental quality can be estimated. This method depends on the researcher's determining a list of valued characteristics, which may not be homogenous among individual purchases.

The purpose of *damage functions* is to establish a link "'between exposure to pollutants and health responses" (Smith, 1993). This method often requires subjective assumptions, which include the valuation of human life and losses from reduced activity caused by health problems. The damage function method is also used for valuing food safety risks (Roberts and Foegeding, 1991).

To date, there has not been a detailed use of these methods to determine the risks, and benefits or costs, of environmental and food safety impacts of different agricultural biotechnologies. One reason is that agricultural biotechnology products currently on the market, such as animal disease diagnostic kits (OTA, 1992) and biotechnology-derived rennet used in making cheese, may not have produced environmental or food safety externalities. Also, these methods of valuing potential environmental or food safety consequences associated with agricultural biotechnology may not yield viable results since consumers are not familiar with biotechnology-derived products and may not be able to give informed answers to hypothetical questions.

Review of Empirical Studies on the Economic Effects of Adopting Agricultural Biotechnologies

Technology Assessment: An Overview

Studies of the effects of technology adoption are referred to as "technology assessments." The goal of technology assessment is to investigate the economic, social, policy, environmental, aesthetic, and moral consequences of the introduction of a new technology (Ruttan, 1982). Technology assessments can be *ex ante*, before the new technology is adopted, or *ex post*, after adoption has occurred. The economic assessments of agricultural biotechnology have all been *ex ante*. In the Federal Government, assessment of agricultural technology has been a regular responsibility of the Office of Technology Assessment (OTA) and the U.S. Department of Agriculture (USDA) since the 1970's.

A USDA workshop provided the following definition for technology assessment:

"Technology assessment is the formal, systematic, interdisciplinary examination of an existing, newly emerging or prospective technology with the objective of identifying and estimating first and second order costs and consequences, over time, in terms of the economic, social, demographic, environmental, legal, political, institutional and other possible impacts of the technology, including those consequences which may not have been anticipated, intended or desired by the inventors, and of specifying the full range of alternative courses of action for managing, modifying, or monitoring the effects of the technology." (Back, 1977, p. 152)

Table 7 illustrates the wide range of issues that could be included within a technology assessment of a biotechnology product. These issues are divided into six major goals for technology assessment: (1) to describe the technology and assess the potential for adoption and use; (2) to identify and quantify economic impacts; (3) to identify and measure distributional consequences; (4) to assess health and safety impacts; (5) to evaluate environmental impacts of technology use and technology byproducts; and (6) to assess a broad range of social, legal, political, moral, and aesthetic issues. Researchers have had difficulty, however, evaluating social, aesthetic, and moral issues arising from technological change (Ruttan, 1982). One approach has been to develop "synthetic" indicators to summarize changes in important sectors (OECD, 1989). There is also a concern among proponents of biotechnology that any change in economic or social structure will be used as grounds to inhibit technology development. A balanced assessment, however, could be used to gauge the positive and negative effects of technology adoption and to devise ways to minimize or mitigate the negative effects.

The following is a review of several technology assessments of specific applications of emerging agricultural biotechnologies. These studies focus primarily on the economic impacts and distributional consequences of adopting agricultural biotechnologies. Some studies comment on environmental implications as well. These studies employ a variety of methodological approaches and make different assumptions about adoption, diffusion, and consumer demand. None of the studies assessed the less quantifiable quality-of-life issues.

Animal Biotechnology Assessments

The technology assessments of animal biotechnology focus on technologies that would (1) increase the production of animal products by promoting growth and increasing nutrient intake efficiency, or (2) enhance the quality of the animal product (for example, leaner meat).

Biotechnologies that could enable farmers to produce leaner meat more efficiently include porcine and bovine somatotropin (pST and bST), beta agonists, and transgenics. Somatotropins are naturally occurring hormonal proteins that regulate growth in animals. These proteins can now be produced in larger quantities using biotechnology. Bovine somatotropin can be used to increase milk production in dairy cows as well as to produce leaner beef. Beta agonists are compounds similar to adrenaline that can convert nutrients into muscle growth rather than fat production. Transgenic technologies (the transfer of genetic information from one organism to another) can be used to enhance the nutrient intake efficiency in animals, and thus the quantity and quality of meat. Transgenics, like biotechnology-derived vaccines, can also be used to produce animals with increased disease resistance, which could increase meat and milk yields. The aforementioned biotechnologies are not limited to cattle and hogs. Other livestock, such as sheep, chickens, and fish, could also be improved using these technologies. The following animal biotechnology assessments are grouped by major technology category. No studies have explicitly assessed the introduction of transgenic technologies.

Porcine somatotropin (pST). pST is a naturally occurring hormone that can now be produced in larger quantities using biotechnology techniques. Experimental results show that when injected with supplemental pST, pigs experience an increase in average daily weight gain, feed efficiency, and the conversion of fat to lean meat. pST is an example of a biotechnology-derived product that can reduce the production costs while offering consumers leaner meat. Hayenga and others (1988) examined the effects of pST on pork supply, market prices, farm profits for adopters and nonadopters, livestock feed demand, and changes in hog waste. This study also examined the economic effects of supplemental pST use on the demand for pork substitutes such as chicken and beef. In a more recent study, Buhr (1993a) also examined market and welfare effects of pST, paying explicit attention to consumer attitudes toward biotechnology. Both studies indicated that early adopters of pST would receive higher profits, but that profits would eventually fall as adoption became more widespread. Greater adoption would increase production and reduce prices of pork. Buhr estimated that hog prices could fall by 0-5 percent for adopters and by 10-15 percent for nonadopters. Higher prices received by adopters would be due to higher quality (leaner) hogs. Hayenga and others (1988) also found that the demand for feed corn would decline while the market for soybean meal would not be significantly affected.

Lemieux and Wohlgenant (1989) estimated the potential social welfare benefits from pST and the distribution of benefits among pork producers and

Table 7-Goals and issues for technology assessment

Describe Technology and Assess Potential for Adoption and Use

- Description of the new technology
  - --technical feasibility
  - --likelihood of availability
  - --resource and managerial requirements
  - --costs of the technology
- Identification and descriptions of alternative technologies
- Implications of the socioeconomic environment, industry structure, and public policies on the development and use of new technologies

Identify and Quantify Economic Impacts

- Effects on commodity production and input productivity
- Implications for input demand and prices, such as water, land, labor, chemicals, energy, and capital
- Effects on commodity demand and price
  - --quality-enhancing vs. cost-reducing technical change
  - --identification of new markets
- Effects on prices, demand, and supply of competing commodities
- Implications for public policies and government expenditures
  - -- commodity program payments
  - -- regulatory costs
- Implications for farm industry structure
  - --market concentration
  - --vertical integration
  - --market competitiveness
- Sensitivity of technology productivity to economic shocks such as major changes in supply, demand, and prices

Identify and Measure Distributional Consequences

- Identification of the welfare implications for groups likely to be affected by the new technology, such as consumers, producers, industry and minority groups, and gender
  - -- changes in regional and national comparative advantage, and commodity trade flows
  - -- changes in income and employment
  - -- implications for generational equity

Assess Health and Safety Impacts

- Effects on human nutrition
- Effects on food safety

Evaluate Environmental Impacts of Technology Use and Technology Byproducts

- Soil erosion and soil pollution
- Water quality and quantity
- Air pollution and global warming
- Biodiversity
- Endangered species and wildlife habitats
- Vulnerability of technology productivity to shocks from natural forces such as major changes in weather, pests, and disease

Assess Broad Range of Social, Political, Legal, Moral, and Aesthetic Issues

- Legal issues such as patenting laws; compensation schemes; and marketing, safety, and environmental regulations
- Determining benefits and costs to different groups by valuing human life and comparing present versus future benefits and costs
- Implications for international relations and trade agreements
- Implications for rural communities
  - --rural migration
  - --stability of rural economy
- Animal welfare concerns
- Cultural and religious implications
- Worker alienation

consumers. They estimated that pST would increase the value of pork production by $1-2 billion per year, or by 10-20 percent, once the technology was fully disseminated. Consumers would receive the largest share of these benefits in the form of increased supply, higher quality, and lower retail prices of pork products.

Bovine somatotropin (bST). Most of the socioeconomic impact assessments of agricultural biotechnology have been conducted on bST due to the implications for the structure of the dairy industry and to consumer concerns about the safety of milk produced using bST. Adoption of bST could significantly alter the cost of government dairy programs. Government programs to support the incomes of dairy farmers have included price supports through purchases of surplus production, and a herd-buyout program to control supply (OTA, 1991).

Kalter and others (1985) examined the effects of bST adoption on milk supply and prices, feed demand, milk price, and farm income for different types of New York dairy farms. Results showed that returns per cow supplemented with bST were greater on larger farms than on smaller farms. A survey of dairy farmers indicated that adoption would be extensive and rapid. The authors concluded that "unprecedented implications for farm management practices, milk markets and prices, and farm structure will follow."

USDA researchers conducted a comprehensive analysis to forecast changes to the dairy industry between 1990 and 1996 with and without supplemental bST use (Fallert and others, 1987; Blayney and Fallert, 1990). The national and regional implications for dairy production, the structure of the dairy industry, and government program costs were evaluated under different policy scenarios. The study predicted that major structural adjustments could occur in the dairy industry either with or without the use of supplemental bST because of other productivity-enhancing changes in dairy technology. The availability of bST could slightly accelerate these structural adjustments.

The Office of Technology Assessment also conducted a comprehensive analysis of technological change in the dairy industry, putting special emphasis on the effects of supplemental bST adoption (OTA, 1991). National, regional, and farm-level impacts were assessed under alternative dairy policy options as established in the 1990 farm bill, and under alternative demand and supply scenarios. The OTA study found that farmers in all regions would have a strong economic incentive to adopt bST, and that adoption of bST would increase the potential of a farm to survive. The OTA study also concluded that bST would be more rapidly adopted in the Pacific region, and that the Pacific region would increase its market share of national milk production, largely at the expense of Corn Belt States.

Other studies have come to other conclusions concerning the regional effects of bST. Sellschopp and Kalter (1989) determined that changes in government policy could have a major effect on regional comparative advantage in milk production. Without any changes in the current level of price supports, they concurred that bST would favor Pacific States. However, Corn Belt and Northeastern States would gain in market share if government dairy price supports were reduced. Fallert and Hallberg (1992) found that regional market shares would not be affected greatly but that the share of the Nation's milk produced in the Northeast and Upper Midwest would increase while the share of the Pacific and Southern States would decrease somewhat.

Policy implications of bST introduction were further explored by Kaiser and Tauer (1989) and Tauer and Kaiser (1991). Their models suggested that modifications to current dairy policy could diminish some of the negative impacts of bST adoption on the dairy industry. Combining dairy-herd buyouts with gradual reductions in price supports could ease structural adjustments in the dairy industry while keeping government expenditures from increasing beyond acceptable levels.

Other studies have evaluated the implications of bST on local or regional economies. Marion and Wills (1990) estimated the potential economic impacts of bST on the Wisconsin dairy industry. They predicted that the effects of bST on the dairy industry would be less severe than previously forecast since adoption could be less extensive than indicated by earlier studies. Marion and Wills estimated that if bST were used on one-quarter of U.S. dairy herds, then the milk price would decline about 50 cents per hundredweight. In this scenario, the dairies that did not adopt the technology would lose up to $100 million per year in net income. Zepeda and others (1991) examined the potential economic impacts of bST adoption in California. They forecasted milk production and prices between 1991 and 1994 with and without bST. Their results indicated that bST use under existing dairy policy would increase milk production by 2-6 percent and would reduce milk prices.

Several studies have assessed the implications of bST adoption on international trade in dairy products (Blayney and Fallert, 1989; OTA, 1991; von Witzke and Hanf, 1992). The United States may be in the best position among the industrialized countries to benefit from bST adoption (Blayney and Fallert, 1989). It is not known, however, to what extent international buyers would be willing to purchase dairy products containing milk from bST-treated animals (Blayney and Fallert, 1989). Harmonization of food-quality standards could be an important factor in facilitating international trade.

Growth-promotant technologies. Buhr (1993b) analyzed the economic impacts of growth-promotant technologies (beta agonists and/or somatotropins) in beef and pork production on the livestock, meat, and feed grain markets. A dynamic model was developed to predict how market changes could affect prices, production, and profitability over a E-year period following initial adoption. In the short run, adopters would reap higher profits than nonadopters. In the long run, prices would decrease due to increased production, and this would reduce profits. Buhr noted that the accrued and distributional benefits of the growth promotant technologies would also depend on factors not thoroughly examined in the study such as the development of "niche" markets for animals not treated with growth promotants.

Two other studies (Kalter and Milligan, 1986; Kuchler and McClelland, 1989) assessed the economic impacts of growth-promotant technologies in the dairy, beef, pork, and poultry markets. These studies assessed the impacts on market prices and quantities, feed demand, land use, and international trade patterns. They also estimated how producer profits and consumer welfare would be affected. With increased feed efficiency, the demand for livestock feeds and the acreage planted to corn would decline. Both studies concluded that consumers would receive the major share of productivity gains through lower prices and higher supplies.

Plant Biotechnology Assessments

Biotechnology research is being conducted to increase a plant's resistance to herbicides, pests, and diseases, a plant's ability to tolerate environmental stress, and to enhance the food quality of plants. Economic assessments of plant biotechnology have focused on technologies that would affect the yield capability of crops, such as biological nitrogen fixation, herbicide and disease tolerance, and frost resistance. The consumer and producer net benefits due to quality changes in plants derived from biotechnology were not assessed in any of the studies reviewed for this report.

Biological nitrogen fixation (BNF). Advances in biological nitrogen fixation technologies could make plants more efficient in absorbing nitrogen from the atmosphere and/or soil. At least four general types of BNF technologies are being studied (Hill and others, 1986). *Autosufficient technologies* would genetically engineer a plant to be able to extract nitrogen from the atmosphere. *Symbiotic technologies* would create plants in which bacteria would produce nitrogen-absorbing nodules that attach themselves to the plant's roots. *Leaky legumes* are leguminous plants, such as soybeans, clover, or alfalfa, which are genetically engineered to produce an excess of nitrogen that would be available to another crop through rotational planting or interplanting. *BNF factory technologies* would consist of large onfarm vats or lagoons containing microorganisms that produce a liquid form of nitrogen. These technologies could reduce the need for synthetic nitrogen fertilizers derived from fossil fuels. They may also improve environmental quality by reducing the level of nitrates in ground and surface water. Although BNF technologies were predicted to be available for use in 10-25 years (Sundquist and others, 1982; Hill and others, 1986), many of these technologies are still not close to commercial development. Since there is considerable uncertainty about how specific production relationships would be affected by BNF technologies, the economic assessment studies rely heavily on expert judgments and sensitivity analysis. Quantitative assessments of impacts are very sensitive to the particular set of assumptions employed.

Hill and others (1986) developed a model to determine the production and prices of corn and soybeans in the year 2000 under different BNF technology applications in corn production. In addition, a qualitative assessment evaluated the impacts of the adoption of BNF technology to identify the various economic participants that would be affected by the new BNF technologies. The results showed that the BNF technologies would generally cause an increase in corn production and a decrease in soybean acreage. A decrease in farm prices of corn would benefit consumers. The nitrogen fertilizer industry would be negatively affected, and there would also be an increase in grain exports and a decrease in nitrogen fertilizer and petroleum imports.

Halbrendt and Blase (1989) analyzed the state-level impacts of the adoption of BNF technology in corn production. The nitrogen fertilizer industry would be negatively affected by a drop in demand for synthetic nitrogen. Agricultural producers that rely on large amounts of nitrogen fertilizer would benefit the most from BNF technology and corn acreage could increase slightly. In the long run, food and fiber prices could decrease given the competitive nature of the agricultural industry, thereby benefiting consumers.

Tauer (1989) estimated that if nitrogen fertilizer needs were completely eliminated by BNF technology, then total economic benefits to producers and consumers would be nearly $4 billion annually. Three-fourths of the benefits would go to consumers in the form of lower prices and increased quantities of food. The welfare measurements do not include the value to society from decreased nitrate contamination of ground water.

Herbicide-resistant crops. Herbicides are used extensively in crop production to control weeds. The use of certain herbicides is limited since some agricultural crops may not survive the application of these herbicides. With genetic engineering techniques, herbicide-resistant crops (HRC's) can be developed to survive the application of specific herbicides. The development of HRC's could reduce crop loss from weeds, thereby increasing yields and reducing costs to agricultural producers. Nevertheless, opponents contend that HRC's would reinforce the use of chemicals in agriculture.

Tauer and Love (1989) considered the potential economic effects of transgenic corn developed to resist certain herbicides. Early adopters would gain from higher yields and higher profits but as the technology became more widely diffused, increased production would reduce market prices and consumers would eventually capture most of the benefits. They estimated total benefits to producers and consumers from HRC's to be $1.9 - $3.8 billion annually after the technology was fully adopted. There were also regional implications. Regions that suffer the most from weed losses could gain the most from improved weed control technology. They found that aggregate corn production could increase 2-4 percent and lower corn prices by about 30 cents per bushel if the HRC technology costs $13 per acre. There could be regional shifts in corn production since resources may be shifted to soybean production when corn prices fall. Overall, they conclude that increases in corn yields and acreage, and total changes in net income from adopting HRC's, would be relatively small.

The environmental impact of HRC's has been controversial because some herbicides have undesirable environmental qualities. However, since herbicide use is so pervasive in U.S. agriculture, the development of HRC's is unlikely to significantly increase treated acreage (Krimsky and Wrubel, 1993). Rather, it is more likely to affect substitution among herbicide products. Tauer and Love (1989) noted that the development of HRC's could lead to the substitution of more environmentally harmful chemicals by more benign herbicides. However, "at this point there is no formalized mechanism that would prevent a company from developing crops resistant to environmentally undesirable herbicides if those herbicides had not been withdrawn from the market voluntarily or by EPA order" (Krimsky and Wrubel, 1993: p. 19).

Virus-resistant crops. At present, there are no chemical pesticides that directly control viruses. Viruses are controlled either by developing resistant varieties or by using avoidance measures such as quarantine programs.

Love and Tauer (1987, 1988) estimated that about 5 percent of the U.S. potato and tomato crop is lost annually to viruses. Developing virus-resistant transgenic varieties could increase the value of the potato and tomato crops by 2.6-5 percent. Production costs would be lower and retail prices would fall by 9-24 percent. Consumers would capture most of the benefits from improved virus resistance through more abundant and cheaper food products.

Frost-resistant crops. When sprayed on crops, "ice-minus" bacteria lower the temperature at which frost begins to form and help to protect fruit and orchards from frost damage. Existing alternative technologies include selecting frost-tolerant varieties and practices such as planting site selection, orchard heating, and sprinkler irrigation.

Love and Lesser (1989) evaluated the potential economic impact of using genetically modified bacteria to reduce frost damage to the New York State fruit industry. The authors used historical weather data to estimate potential losses from frost damage and estimate the cost and effectiveness of existing frost protection technologies. They concluded that ice-minus bacteria are unlikely to be economically competitive with currently available technology.

Conclusion

The advent of biotechnology is likely to make a significant contribution to furthering the growth in agricultural productivity. However, the rate and direction of development and use of biotechnology will depend on a multitude of factors, including government policies, consumer demand, and serendipitous advances in science and technology.

Government policies provided a major impetus in making the United States the current world leader in biotechnology. Public support of basic research in microbiology, genetics, and molecular engineering has resulted in scientific advances that have opened up new possibilities for technological applications of biotechnology. New incentives have been created at publicly supported universities and research laboratories to increase their involvement in the development and commercialization of new technology. Furthermore, stronger legal protection of intellectual property rights has increased the incentives for private sector investments in biotechnology applications. Whether the United States maintains its lead in biotechnology will depend on the future direction of these policies, including how international intellectual property rights for biotechnology evolve.

These and other government polices also influence the type of biotechnology innovations that are developed. Biotechnology has created new opportunities for resource substitution that could reduce chemical use in agriculture and thereby enhance environmental quality and food safety. However, the extent to which developments in biotechnology will follow this path is uncertain. The evolution of government regulations concerning food safety and environmental protection will have a significant influence on the type of biotechnology innovations that are developed by the private sector. The expected demand for biotechnology-derived products will be a crucial determinant of the potential profitability of research. If consumer acceptance differs over product types (for example, negative attitudes for transgenic applications), research priorities would be affected.

The adoption of biotechnology innovations in the agricultural sector will be influenced by an expanded set of consumer interests. Today's consumers are placing greater weight on food quality, food safety, and environmental quality than in the past. Furthermore, concerns about the nature of biotechnology and the effects of adoption on rural communities are being expressed. To allay these concerns, consumers may need to be provided with additional information about how food is produced and processed. The information could be provided by government, industry, or consumer groups. Product labeling is one proposed way of conveying the desired information. Public confidence in the regulatory framework may increase over time as more experience is gained with biotechnology.

Some studies were reviewed that forecast the rate of adoption (diffusion) of specific livestock biotechnologies (growth promotants) among U.S. farms. Most studies analyzed the adoption of bST by the dairy sector. Study forecasts of the extent of adoption and diffusion were wide-ranging. No study predicted complete adoption by the entire dairy sector, even after 10 years of availability. Most of the estimates of the upper limit to adoption, as either a percentage of farms or of dairy cows, ranged from 30 to 75 percent. There were no significant differences in estimates of adoption rates for different regions of the country. The wide range of forecasts in the empirical studies is due primarily to uncertainty about several important variables. The largest source of uncertainty concerns the demand for the biotechnology-derived product by producers, dairy processing firms, and ultimately consumers. Another source of uncertainty is the level of production efficiency that can be achieved when the technology is applied under actual farm conditions. Possible changes in government policy are also sources of uncertainty that will affect the forecasts of demand for biotechnology.

This report reviewed 23 studies of the economic impacts of several biotechnologies on U.S. agriculture. The majority of the studies focused on animal growth hormones. All of these studies focused on economic impacts and on the distributional consequences resulting from the adoption of biotechnology. Two major conclusions can be drawn from this review. First, it appears that the economic impact of biotechnology is likely to be incremental rather than dramatic. Second, although private sector firms that develop and apply biotechnology innovations will seek to capture these new income streams, a significant amount of the economic benefits will he broadly distributed to consumers in the form of increased supplies, lower prices, and higher valued products.

Less can be said from these studies about the environmental impacts of new biotechnologies. The extent to which emerging biotechnologies will affect environmental quality will be strongly influenced by regulatory policy and other institutional forces. Furthermore, there is considerable uncertainty concerning how specific biotechnologies will affect the number and size of farms and regional comparative advantage in the production of various commodities. Other factors, such as how government agricultural programs adjust to increased commodity supply resulting from technology adoption, will have a significant impact on the direction of regional impacts. Continued improvements in agricultural productivity will reinforce present trends toward fewer and larger farms. In the future, successful farms will be those with more highly skilled labor, and with economical access to new technologies and information.

Any prediction of the social, environmental, and economic impacts of biotechnology development will depend on the accuracy of the underlying assumptions that are made for the analysis. The interaction between the physical characteristics of the biotechnology application and productivity for an adopter will be relatively easy to estimate. The more uncertain components are legal, institutional, and social. The profits that result from biotechnology development will depend on intellectual property rights, regulations, and consumer acceptance of the biotechnology-derived product. The uncertainty of consumer reactions is the largest impediment to assessing the future potential of biotechnology in U.S. agriculture.

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