South Dakota State University
Open PRAIRIE: Open Public Research Access Institutional Repository and Information Exchange

Department of Economics Staff Paper Series | Economics

10-1-2001

Selected Economic Implications and Policy Aspects of Agricultural Biotechnology

Evert Van der Sluis
South Dakota State University

Matthew Diersen
South Dakota State University, Matthew.Diersen@SDSTATE.EDU

Thomas Dobbs
South Dakota State University

Selected Economic Implications and Policy Aspects of Agricultural Biotechnology

by

Evert Van der Sluis
Matthew A. Diersen
Thomas L. Dobbs

South Dakota State University
Economics Staff Paper No. 2001-6
October 2001

Papers in this series are reproduced and distributed to encourage discussion of research, extension, teaching, and economic policy issues. Although available to anyone on request, Economics Department Staff Papers are intended primarily for peers and policy makers. Papers are normally critiqued by some colleagues prior to publication in this series. However, they are not subject to formal review requirements of South Dakota State University's Agricultural Experiment Station and Cooperative Extension Service publications.

The authors of this paper have differing philosophical orientations with respect to some issues related to its contents. Therefore, interpretations and recommendations contained herein represent consensus, rather than unanimous viewpoints. The views expressed in this paper are not necessarily endorsed by the SDSU College of Agriculture and Biological Sciences, nor by the Economics Department.

* Associate Professor, Assistant Professor, and Professor, respectively, Department of Economics, South Dakota State University.

Selected Economic Implications and Policy Aspects of Agricultural Biotechnology

by

Evert Van der Sluis, Matthew A. Diersen, and Thomas L. Dobbs

Abstract

The paper provides an overview of the types of economic costs, benefits, and risks involved with agricultural biotechnology at the farm level, at the market level, and for the farm and food system as a whole. Both advantages and disadvantages of agricultural biotechnology are discussed. Among the drivers of the U.S. domestic and international consumer demand for transgenic crop products discussed in the paper are environmental and food safety concerns. A comparison is made between a 'science-based' regulatory framework and a policy based on the precautionary principle. The authors argue that open dialogue is needed for achieving improved public understanding of agricultural biotechnology, and that analyses need to go beyond discussing the scientific merits of biotechnology, to include social scientists, as well as the public at large.

Selected Economic Implications and Policy Aspects of Agricultural Biotechnology

Table of Contents

Selected Economic Implications and Policy Aspects of Agricultural Biotechnology

Background

Biotechnology involves making changes to the cellular and molecular structure of organisms. The application of biotechnology by way of genetic modification and selection to increase agricultural productivity is as old as agriculture itself. What makes modern genetic engineering–as a form of biotechnology–different from traditional means of manipulating the biology of plants and animals is that it enables individuals to move functional genes from one organism to another. In this paper, the term 'biotechnology' refers to the technique used by biological scientists to modify genes within an organism or to transfer specific genes between organisms. Thus, genetic engineering facilitates the development of characteristics that are not possible through traditional breeding techniques. In this paper, the terms "biotechnology," "bioengineering," and "genetic engineering" are used interchangeably, and refer to the use of modern genetic techniques to obtain "genetically modified" or "transgenic" plants and animals.

This paper provides an overview of selected economic issues and policy choices involved with agricultural biotechnology. It is not meant to provide a comprehensive review of all economic issues involved with this new technology. Instead, the paper's focus is on the economic costs, benefits, and risks that are associated with the use of agricultural biotechnology within a farm and food system driven by domestic and international consumer demand. The paper also provides an analysis of how agricultural production, consumer demand, and rural areas are potentially affected by policy choices associated with the use of agricultural biotechnology.

The next section provides an overview of some of the major controversies associated with agricultural biotechnology. This is followed by an analysis of the pros and cons of the use of biotechnology, described in general, as well as from the perspectives of agricultural producers and agricultural markets. This is followed by a description of consumer concerns and international trade issues. A separate section is devoted to the 'precautionary principle.'

The Three Phases of Biotechnology

Genetically engineered crops are generally classified into two, or sometimes three, generations or "waves" (Fernandez-Cornejo, et al.; and Hillier). The current set of genetically engineered products is limited primarily to agronomic input traits that have not provided–and were not intended to give–significant benefits beyond conventional agricultural products to consumers. An example of a trait developed with the use of biotechnology is decreased pest susceptibility, which reduces the need for chemicals that prevent plant diseases and insect infestations. Other production-level traits currently being developed using genetic engineering are the ability of plants to grow under saline conditions, to increase their tolerance to frost, and to improve their ability to resist drought. Further, Federal approval is currently being sought to market genetically engineered Atlantic salmon that grow to market size in half the time as normal Atlantic salmon (Yoon, 2000a).

A second set of products, many of which have already been developed but are awaiting approval for marketing, is characterized by output traits that enhance the products' processing characteristics and that have improved quality characteristics for consumption purposes. This second generation of biotechnology products includes, for example, fats and starches with improved processing and digestibility characteristics. Other examples of second wave products are provided by Coaldrake; and Shoemaker (p. 19).

Fernandez-Cornejo et al. identify a third generation of biotechnology products, with an emphasis on end user quality traits. These products include nutraceuticals or functional foods, which may be produced using crops engineered to contain medicines or food supplements within plants.

Most of the current applications in agricultural biotechnology are still in the first generation of genetically engineered products. Nevertheless, innovations by way of biotechnology already appear to be on their way to becoming one of the most rapidly adopted types of technology in agricultural history.

How Widespread is Biotechnology in Agricultural Production?

Because of the very rapid growth in the use of various applications of agricultural biotechnology in crop production, few reliable estimates of global cropland used for genetically engineered field crops are available. Further, the reliability of existing data on the use of agricultural biotechnology is somewhat questionable for some nations because of the controversial nature and property rights issues involved with agricultural biotechnology. For example, Brazil does not allow the planting of genetically modified soybeans, but its farmers are widely thought to grow such soybeans.

Virtually all studies that list data on the global spread of genetically engineered crops are based on one source, the International Service for the Acquisition of Agri-biotechnology (ISAAA), cited as "James." The ISAAA is a publicly and privately funded organization and has an international network that consists of several centers, one of which is affiliated with Cornell University.

Based on the data collected by James, global cropland planted with bioengineered crops increased from four million acres when the crops became commercially available in 1996, to an estimated 109 million acres in 2000, spread over 12 countries (see Table 1). The United States and Canada account for more than three-fourths of global cropland acres grown with genetically engineered crops. Many of the remaining cropland acres used for transgenic crops are located in Argentina. Other major producers of agricultural products, such as Brazil and China, are also expected to become major participants in growing transgenic crops (Smith). Nations that also grow transgenic crops but are not listed in this table include Romania, Mexico, Bulgaria, Spain, Germany, France, and Uruguay.

Table 2 lists the number of cropland acres devoted to genetically engineered crops. The table shows that in 2000, soybeans accounted for approximately 58 percent of the world's cropland acres used for genetically engineered crops, followed by corn with about 23 percent, cotton with approximately 12 percent, and canola with about seven percent of the global cropland area used for transgenic crops.

Globally, as well as in the United States, the area planted to genetically engineered crops leveled off somewhat between 1999 and 2000. Table 2 shows that cropland areas planted with transgenic soybeans and cotton increased from their 1999 levels, while the planted areas of genetically engineered corn and canola underwent a slight decrease from their 1999 levels.

Agriculture in the Upper Midwest has been in the forefront of biotechnological advances, and some of the most controversial biotechnology products are produced in the region. Tables 3 through 5 list the extent to which transgenic corn, soybean, and upland cotton varieties, respectively, were planted in the United States and in selected states in 2001. Approximately 26 percent of the nation's corn area, 68 percent of the soybean area, and 69 percent of the cotton area was planted with bioengineered crops in 2001. Among 11 Midwestern states, South Dakota ranked first in the percentage of total cropland planted with genetically modified corn, and the state shared its number one position with Kansas in the percentage of total cropland planted with transgenic soybeans in 2001 (U.S. Department of Agriculture).

Globally, the most important genetically engineered trait used in crops is herbicide resistance, which accounted for 69 percent of the total global cropland area planted with transgenic crops in 1999 (see Table 6). In the same year, insect-resistant crops accounted for about 21 percent of the world's cropland area sown with transgenic crops. Crops containing both herbicide-resistant and insect-resistant genes accounted for about seven percent of global cropland area planted with transgenic crops. Finally, virus-resistant transgenic crops comprised close to three percent of the world's cropland acres sown with transgenic crops (James).

Controversies

From its beginnings, the use of biotechnology in agriculture has been controversial. Independent evidence on the benefits and costs of most agricultural biotechnologies is limited, and most of the technology's effects on the environment, food safety, and industry structure remain unknown at this early stage. While some agricultural biotechnology applications have been adopted widely and at a very rapid pace, their number remains very limited, and all technologies were implemented relatively recently. As a result, there has been little opportunity to observe impacts over an extended period of time and over a wide variety of climatic conditions. Also, public funding for research on the potential impacts and risks of agricultural biotechnology has been very limited. Nevertheless, excellent reviews of the currently available evidence on potential benefits, costs, and risks of various biotechnologies have been provided by Ervin, et al.; and Pretty (1999; and 2000), among others.

Benefits

Supporters of the use of biotechnology in agriculture argue that it will improve global and local food security by helping developing nations provide food for their own citizens (McGloughlin). This would be achieved by increasing agricultural output per unit of land and by decreasing production variability. Also, the technology might allow for an increase in agricultural productivity relative to non-land inputs and a decrease in production costs. This could include, for example, an increase in crop yield per unit of fossil fuel energy inputs or per unit of chemical pesticide inputs. Furthermore, proponents argue that applications of agricultural biotechnology are necessary to meet a rapidly expanding global demand for food.

Advocates also argue that biotechnology improves the environment by reducing the need for chemicals in agricultural production. The reduced use of pesticides and herbicides, in turn, would reduce human health hazards associated with the use of these chemicals. Finally, the technology is expected to yield a variety of new or enhanced 'quality' characteristics, such as protein or sugar contents.

Costs

The potential benefits associated with particular biotechnologies may be accompanied with new or additional costs accruing to adopters and others in the farm and food system, but also to other individuals and groups. For example, the use of herbicide tolerant crop varieties involves higher seed costs and may sometimes result in lower per acre yields, relative to using conventional varieties. At the farm level, those costs must be weighed against potentially lower labor, machinery, and chemical pesticide costs in determining the net impact on farm profitability.

Farther up the supply chain, some agribusinesses involved in grain handling are likely to experience increased costs associated with segregating genetically modified grains from those produced using traditional technology if consumer resistance to products containing genetically modified products or processes continues in major foreign markets. Those costs may or may not be offset by premiums that handlers can capture or by charges that they are able to assess.

From an economic perspective, technological change is, in principle, viewed favorably--because it frees up scarce resources for use elsewhere. There are two types of technological change: cost-reducing and quality-enhancing (Caswell, Fuglie, and Klotz). A cost-reducing change lowers input costs, enabling increased input usage and increased crop yields. Cost-reducing changes generally cause an increase in the aggregate supply of a product. Further, a cost-reducing change is likely to have broad appeal, because many producers would be willing to adopt the technology. For example, if the cost of producing corn decreases, farmers have an incentive to increase their production. The resulting increase in the aggregate supply of corn would likely result in lower corn prices.

Biotechnology also may result in quality-enhancing changes to the underlying commodity. By improving product quality, new or improved uses for the commodity become possible. This would cause a shift in the demand for the product, and may lead to higher prices. However, the appeal of quality-enhanced crops may be limited to specific sectors, such as the market for high-oil corn.

A thorough analysis of the impacts of agricultural biotechnology on the farming and food system must include 'technological' (or physical) externalities, as opposed to 'pecuniary' (or price effect) externalities. An example of a technological external cost would be pollen drift from transgenic crops 'contaminating' a neighbor's organic crop. Crops grown with genetically modified seed stock do not qualify for organic certification, and would therefore forego organic price premiums. Consequently, this type of seed stock contamination can have severely adverse economic ramifications for organic farmers, who are unwilling recipients of the impacts of agricultural biotechnology adoption decisions by others.

Risks

A system-wide economic analysis on the impacts of agricultural biotechnology not only includes an investigation of benefits and costs, but also incorporates risks associated with the new technology. Risks in a systems analysis of genetically modified technologies generally are those potential costs that, at best, we can only estimate in rough, probabilistic terms. Often included here are health or food safety and environmental risks (Feldmann, et al.; and Fernandez-Cornejo, et al.). A health concern associated with agricultural biotechnology is that persons with allergies may suffer reactions to genetically modified foods, when allergenic substances are inadvertently transferred from one food product to another. In response to concerns among their citizens about the safety of using biotechnological processes, a number of European countries have banned the importation of many bioengineered products. Thus far, U.S. domestic consumers have been less concerned about the side effects of genetically engineered foods than some of their European, Japanese, and South Korean counterparts.

Among the environmental risks that have been raised is the concern referred to as the 'super weed' problem, caused by genetic drift to wild relatives of the target species that develop into weeds. A second concern is that new genes may move to wild and unrelated plants, which could then become weeds. Third, the use of the technology may harm non-target species, such as butterflies that depend upon the target species' ecosystem. A fourth risk associated with using biotechnology is that new viral pathogens and pathogenic bacteria may be introduced to the environment. A additional environmental fear is that the genetic trait in the target species may decline in efficacy over time. For example, pesticide resistance may develop from increased Bacillus Thuringiensis (Bt) toxins use, necessitating the use of higher dosages of, or more toxic, chemical pesticides later. Finally, bioengineered species may have broad environmental impacts by disrupting the natural evolution of valuable species and decreasing their productivity or by causing a proliferation of new genetically modified species that crowd out others.

Of direct concern to those in production agriculture is that biotechnology is certain to affect the structure of agriculture. Since the introduction of biotechnology in the mid-1990s, its rapid spread in production agriculture already appears to have sped up ongoing structural changes taking place in agriculture. The technology enables agricultural input industries, such as seed companies, to increase their control over plant production, mitigating agricultural producers' ability to reuse seeds, and leading to reduced control among farmers over their production processes. Both cost reducing and quality-enhancing types of technology changes may impact the structure of agriculture. The extent to which biotechnology affects the number and size of farms depends on the 'economies of size' related to adopting the technology. To date, many innovations due to agricultural biotechnology have been scale-neutral (Caswell, Fuglie, and Klotz). That is, they tend to impact only variable costs of production, such as those involved with seed and pesticide purchases. However, if new technologies require large fixed costs to adopt, they may favor larger farms.

Analyzing Costs, Benefits, and Risks

In an attempt to put the benefits, costs, and risks associated with biotechnology in perspective, Young has devised a set of three principles for analyzing new technologies in general. The first principle is the realization that both proponents and opponents of biotechnology strive toward the same goal, which is the responsible use of the new technology. Insufficient attempts have been made among groups and individuals for and against the use of biotechnology–whether in corporate, academic, and government environments–to acknowledge this fundamental factor. Without this realization, progress in a constructive dialogue among groups and individuals with varying views regarding the extent to which biotechnology should be used in the food and fiber sector will be limited.

The second principle is that there are valid concerns about, and potential valid benefits from, the impacts of biotechnology. While biotechnology may become an effective tool to alleviate world hunger, it is generally recognized among scientists that pollen transfer to non-targeted crops will occur. Scientists also recognize that insect resistance to Bt toxins is likely to develop, because target insects are continually exposed to the toxins, creating strong selection pressures for developing resistance to these toxins. Acknowledging both benefits and shortcomings of the technology will improve the transparency of the discussion.

The third principle is that the evaluation of biotechnology and its uses should be based on generally accepted principles that currently exist in the various sciences for conducting comprehensive system-wide analyses.

An additional principle that may be added is that both proponents and opponents of biotechnologies should attempt to avoid sensationalism and exaggaration in discussing advantages and disadvantages of the technology. That is, neither the benefits nor the concerns should be overstated. A case in point is "Golden Rice," which was engineered to contain three new genes that together cause rice to produce beta carotene, a precursor of vitamin A. The genetically engineered rice was intended to prevent vitamin A deficiency, a common cause of childhood blindness in developing countries. However, because beta-carotene must be split by an enzyme to become active, and because both beta-carotene and vitamin A are soluble in fat only–requiring a balanced diet containing a sufficient amount of fats and nutrients–Golden Rice alone does not have the ability to eliminate vitamin A deficiency.

At a more practical level, we can use Bt corn to illustrate the possible distribution of selected benefits, costs, and risks among different stakeholders in society. The entries in the cells of Figure 1 include some of the possible impacts on different groups of people, including people in other countries. Potential benefits of Bt corn include reduced production costs for farmers and increased profits for companies producing and selling the Bt seed. There may also be the environmental benefit of reduced chemical pesticide use, although evidence of reduced pesticide use resulting from the growth in Bt corn area is mixed (Ervin, et al.; and Pretty, 2000). Further, whether any chemical use reductions are lasting will depend in part on how soon resistance to the Bt toxin builds up.

Among the costs associated with the genetically engineered corn are those involved with segregating genetically modified from traditionally produced corn and its products. These costs would be faced by both farmers and agribusinesses if a significant portion of the corn market exhibits demand for products free of genetically modified products. In addition, farmers in countries where genetically modified corn is not widely adopted (countries referred to as the 'Rest of the World,') could face increased competition from lower-cost U.S. imports, if allowed.

Environmentally, the Bt technology probably makes it easier for farmers to continue specializing in the rather narrow corn-soybean rotation. A growing number of people feel that this continued lack of crop biodiversity is unsound from an ecological sustainability standpoint. Further, the StarLink® corn incident suggests that public agencies–meaning US taxpayers–potentially face increased costs in dealing with regulations and consequences associated with agricultural biotechnology. In the StarLink® case, the U.S. Department of Agriculture agreed to spend $20 million to purchase seed from small companies that find their seed supplies 'contaminated' with the Cry9C gene. Finally, the increased concentration occurring in the agricultural input industry as genetically modified technologies take on greater importance could adversely affect rural areas, as could the continued increase in farm size and decrease in farm numbers that tend to accompany technologies which facilitate narrow crop systems.

Among the alleged risks of Bt corn technology are possible health risks. For example, while StarLink® corn has not been shown to pose a health risk, neither was it approved for human consumption; it entered into the human food system in spite of regulations prohibiting that. Similarly, consumers in the 'Rest of the World' countries feel that they also face risks of Bt corn finding its way into their food systems without their knowledge, in spite of various regulations and labeling practices designed to guard against that in much of Europe.

Another risk is that widespread use of Bt crops may result in resistance to the natural Bt spray that is approved for use in organic production, thereby rendering useless or less useful one of the pest control tools used by some organic fruit and vegetable producers. Also, although evidence available thus far is mixed, there is concern that Bt corn may be toxic to some butterflies and beneficial insects (Ervin, et al.).

This illustration of how different groups throughout society may be either beneficially or adversely affected by agricultural biotechnology shows why we should not be surprised by the controversies currently surrounding public policies regarding the application of this new technology in producing food and fiber. The controversies are not simply because of an 'uninformed public' or 'distortions in the media.' At least in the short run, genetically modified technologies will have potential real gainers and losers.

From a research policy perspective, it is not only important that the costs, benefits, and risks of biotechnology are compared, but also that the resulting net gain or loss from implementing agricultural biotechnology be weighed against alternative, appropriate, and locally feasible technologies. Ruttan argues that many developing nations have not yet realized potential yield gains from conventional crop improvement efforts because of a lack of research and development capacity. Improved knowledge in agronomic practices may also contribute to rapid yield increase, as illustrated in a New York Times article, which reported that a mixture of two different rice varieties doubled rice production without additional chemical inputs (Yoon, 2000b). Finally, and perhaps most importantly, no amount of change in technology in agricultural production will relieve world hunger without accompanying political reforms that facilitate group and individual access to food.

Agricultural Producer Considerations

Costs and benefits associated with adopting biotechnology in agriculture are not only important from a policy perspective, but also for individuals interested in applying the new technology. Similar to other participants in the food and fiber system, agricultural producers respond to economic incentives and will produce those products that provide them with the greatest expected returns. In the case of crops, those produced using biotechnology are different from crops produced without this new technology, because the new crops have traits that are dissimilar from those of conventionally produced crops. Hence, crop producers would be prudent to consider currently existing genetically modified crops as products with value-enhanced traits and not treat them as commodities. Producers should also manage the genetically modified crops differently than agricultural commodities.

In considering whether or not to switch from growing conventional to growing genetically modified crops, producers need to understand costs and benefits associated with growing the new crops. This could be achieved by conducting a marginal analysis for a crop, which entails making a comparison between the net revenue per acre from producing and marketing the new crop, and the net revenue of a conventional commodity. The expected gross revenue obtained from growing and marketing the modified crop would include a price premium or discount, multiplied by the yield (accounting for any yield drag). On the cost of production side, technology fees would need to be added and now unnecessary inputs would need to be subtracted. If the net revenue associated with producing the crop that utilizes the new technology would exceed that of a traditionally produced commodity, an incentive to change to producing the genetically modified crop exists.

Marginal analysis provides an initial assessment of whether or not switching to genetically engineered crops is financially worth considering for crop producers, but it may need to be supplemented with other considerations. First, producers do not need to adopt new technologies if they do not want to. Second, blindly adopting the new technology may create previously nonexistent operating problems. Third, some crop traits have changed the underlying commodity sufficiently to cause a change in its crop insurance treatment. This is clearly the case in the presence of any yield drag that affects the crop insurance premium. Fourth, producers who consider contracting their crop must identify alternative markets for obtaining the crop before finalizing their contract, in case of a harvest shortfall and subsequent inability to meet contract obligations. Fifth, a genetically modified crop that does not meet the delivery specifications committed to in futures or cash forward contracts may generate price risk management difficulties for producers. Even if the crop would be acceptable to buyers, its value may not fluctuate consistently with commodity prices, resulting in additional basis risks and reduced hedging effectiveness. Finally, local production and marketing systems may also affect producers' decisions whether to adopt genetically modified crops. For example, if local elevators do not have handling facilities for keeping transgenic crops separate from conventional crops, farmers would need to find alternative distribution channels, resulting in additional costs.

A Market Perspective

Many decision makers in the grain production and marketing system see biotechnology as both a threat and an opportunity. On the one hand, the rapid introduction of new technologies has the potential to disrupt normal planting and merchandising patterns. On the other hand, technological advances are not new or unusual, and the mechanisms for understanding their impacts are available. Different types of technological changes affect prices in different ways. Also, whether a new product represents a valuable segment of the market or a costly segregation within the market also depends on the type of technology introduced. The market has had some time to adapt to biotechnology and has started sending signals to market participants with estimates of market sizes and price premiums or discounts for the various products. These signals will ultimately drive the production system, because planting decisions by farmers, marketing decisions by grain handlers, and the product choice of processors are ultimately driven by profitability criteria.

Segmentation

A market is said to be segmented when a variety of products of a similar type have distinguishing characteristics that give individual products a different value to consumers. Biotechnology is one avenue for segmenting the market for crops that are generally regarded as commodities (corn from Iowa is the same as corn from South Dakota). The objective of adding a value-enhanced trait–that is, a characteristic desired by consumers–is to segment the corn market and make the value-enhanced corn worth more than commodity corn.

For centuries, mother nature has received the credit for improvements in the quality characteristics of plants using traditional plant breeding methods, although producers have traditionally captured the entire premium involved with plant quality enhancement. When crops with value-enhanced traits are developed, developers and producers share the premium, usually through a technology fee. Regardless of the source of the trait, its additional value needs to be communicated to consumers for it to be captured by producers. The distinguishing feature of crops with value-enhanced traits is that the trait is anticipated by agricultural producers and is expected to have additional value. Thus, when a value-enhanced trait is introduced, producers anticipate capturing potential premiums, although the premiums may have to be shared with other participants in the marketing system, because it may cost more to keep the value-enhanced crop segmented than if it were simply a commodity. If, however, producers were to seek to capture the entire premium themselves, they would also be expected to build up the entire supply chain, involving direct marketing of farm products to consumers. The existing marketing system may also handle the trait, for example through a protein premium. Identity preserved crops are another way the marketing system handles such traits, but at a cost.

Segregation

While segmentation is seen as positive, a negative trait may result in the need for segregation. In this case, a trait causes the product to fail to meet either the standard commodity specifications or other regulatory specifications. Such traits impose a cost to the marketing system and cause producers to face a discount for the trait. Because these negative traits tend to surprise the marketing system, they are more costly to deal with than anticipated traits. Hence, discounts for such traits may be disproportionate to premiums observed for quality-enhanced traits.

The marketing system has some experience handling negative traits. For example, in some locations in South Dakota, wheat with a low protein content was discounted in price in recent years. Another example is provided by the presence of vomitoxin in wheat, which led to large price discounts and segregation costs in South Dakota and neighboring states. Further, the distribution problems associated with the StarLink® controversy is but the latest example. The extent of the discounts depends on the relative supply of the crop with the negative trait and the demand for products produced in the segmented market.

Market Structure and Conduct

What is the size of the various markets today? How are the production and marketing systems responding to segmented and segregated markets? A look at the market structure reveals that while the market for crops using traditional production methods is real, it may not be very large. Researchers of the Economic Research Service have offered estimates about the size of the non-biotechnology corn and soybean markets (Lin, Chambers, and Harwood). They suggest that the markets for non-biotechnology corn and soybeans were about one and two percent, respectively, of U.S. corn and soybean production in 1999. They also point out that the market for non-transgenic corn by-products is unknown, but likely depends largely on demand from the European Union.

Lin, et al. also report that 15 percent of farmers are considering ways to handle their own crops in segmented form in an effort to capture premiums and/or avoid discounts. About five percent of the nation's elevators are pre-equipped to adequately handle genetically modified and non-genetically modified crops simultaneously. River elevators may have a comparative advantage, because they tend to be larger and handle grain differently than do country elevators. Imposed segregation of genetically modified crops would have a large cost, estimated at 22 cents per bushel for corn and 54 cents per bushel for soybeans.

The premiums for non-genetically modified corn and soybeans have rarely been large enough to match the cost of segregation. Non-genetically modified corn has typically garnered five to ten cents per bushel in premiums, while non-genetically modified soybeans have received ten to 15 cents per bushel above commodity values (Lin, et al.). Recent data from the U.S. Department of Agriculture show premiums of seven to 12 cents for non-genetically modified corn and 20 to 25 cents for non-genetically modified soybeans. Further information on market size and prices of value-enhanced grains is provided by the U.S. Grains Council.

Consumer Concerns and International Trade

Agricultural commodities produced with the use of biotechnology are at the center of ongoing trade negotiations and discussions with major U.S. trading partners. Import restrictions and labeling requirements of transgenic products are expected to be major agenda items in the next round of World Trade Organization (WTO) negotiations. International trade of genetically engineered products–primarily for use in agriculture–is governed by the "Cartagena Protocol on Biosafety," adopted in Montreal, Canada, on January 29, 2000. This protocol was negotiated under the United Nations Convention on Biological Diversity. A number of nations have regulatory agencies in place to oversee national biotechnology endeavors. However, with the exception of the European Union, there are few other international regulations for genetically engineered products. The Cartagena Protocol is one of the first legally binding international agreements to govern the products of biotechnology, and it is the first to require consent of an importing country prior to trading genetically engineered products. The protocol also allows for an assessment of potential risks to biodiversity and human health in the importing country associated with transferring these products.

The negotiations that led to the protocol evolved from an increased awareness and public concern about environmental and food safety issues, to an escalating trade conflict between the United States and the European Union (EU) involving genetically engineered products. Particular concerns were raised among European nations, but Japan and South Korea also imposed trade restrictions in response to their domestic consumers' concerns about agricultural biotechnology.

In contrast, the majority of U.S. consumers and the U.S. public at large have long held a high degree of confidence in the reliability of their food and fiber system's regulatory processes, in part because of ample and presumably safe food supplies. One of the reasons often cited for EU residents' suspicious attitudes towards genetically engineered food products is that there have been a series of well-publicized cases that jeopardized the safety of the EU food supply. For example, food safety concerns developed in response to the Bovine Spongiform Encephalopathy (BSE) or mad cow disease case that started in the United Kingdom in the 1980s and subsequently spread to mainland Europe. Other food safety concerns were raised elsewhere in Europe after a series of toxins were found to have entered the food chain or water supplies in the late 1990s. Perhaps more important than finding the food contaminants themselves was the fact that in each case, government officials attempted to reassure consumers about the safety of the food supply, only to be proven wrong later. More importantly, most European nations have historically not had central regulatory agencies that would oversee the safety of the food supply, or equivalents to the U.S. Food and Drug Administration. As a consequence, many European nations were left to regulate and impose restrictions on final products, rather than the process in which the product is produced–the approach used in the United States.

The European experience suggests that a major challenge in today's environment in which the development of agricultural biotechnology is taking place in the United States is to maintain public and consumer confidence in the regulatory and research systems. It is likely that U.S. confidence in the regulatory system also would decline if similar events to those in Europe were to occur. While the StarLink® case may have been "an accident waiting to happen," it does indicate system weaknesses that need to be addressed, because the U.S. agricultural system traditionally has not made a distinction between two seemingly identical raw agricultural products that were destined for separate food and feed markets.

Even without further mishaps in the way that agricultural biotechnology is incorporated in the food and fiber system, genetically engineered products have characteristics that have the potential to raise concerns among consumers. Prior to the development of modern biotechnology, Lowrance (p. 87), developed general characteristics of products that tend to increase the perception of danger among consumers. These characteristics were further developed by Senauer, et al. (p. 250). Consumers perceive a general increase in the risks associated with products: (1) whose risks are unknown, (2) that have irreversible consequences (3) which exposed them involuntarily to the risks (4) if there are many alternatives available, and (5) that are not needed by consumers. Each of these five characteristics, as well as others, can be applied to genetically engineered products as they relate to consumers in the European Union, Japan, the United States, and other wealthy nations. Therefore, it is hardly surprising that concerns exist among individuals in some of these nations. Further, dismissing the current controversies about genetic modification technologies in agriculture as being largely due to an uninformed public and distortions in the media, is based on false premises. A technology with such profoundly new and different elements as genetic modification has many unknown consequences. Inevitably, some individuals and groups will benefit from the technology, while others will be negatively impacted. One need only consider the history of the Industrial Revolution for that to be abundantly apparent. Furthermore, different individuals and cultures vary in their 'values,' especially as they weigh the importance of potential benefits of a new technology in relation to that technology's perceived costs and risks.

The 'Precautionary Principle'

Democratic governments differ in the way they decide about which genetically modified products should be approved for commercial application–given the potential benefits, costs, and risks for different segments of society. U.S. policies are based primarily on a so-called 'science-based' approach, in which approval for commercial application is ultimately given if there is no proof of harm. This approach is based on the American philosophy which tends to view science as progress, but contrasts with a somewhat more skeptical view of science in Europe (McCluskey).

Consumer concern about risks associated with the use of biotechnology in food production in Europe has led to a regulatory approach that rests much more heavily on the 'precautionary principle' (Barrett and Flora; and Ervin, et al.). The precautionary principle is based on the premise that "when an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause-and-effect relationships are not yet fully established scientifically" (Barrett and Flora, p. 6). Whereas the U.S. approach tends to place the burden of proof on those who fear potential harm, the precautionary principle places the burden of proof primarily on proponents of biotechnology to demonstrate that there is, in fact, little or no risk of serious harm. Core elements of the precautionary principle include the following:

- A primary goal of society is to protect the environment and public health.
- Proactive measures should be taken toward this goal even in the face of scientific uncertainty.
- The burden of demonstrating the safety of a potentially harmful technology falls on its developers, rather than on the public or government.
- Alternatives must be considered.
- Open, informed, and democratic processes must be used to make decisions about the acceptability of technology, its demonstrated safety, alternatives, research, and policy goals as well as the process to achieve these goals (Barrett and Flora, p. 7).

The European Union emphasizes the precautionary principle in its regulatory approach to biotechnology. This approach has been characterized as "guilty until proven innocent," while the U.S. approach has been called "innocent until proven guilty" (Ervin, et al., p. 37). Of course, there is a wide range of views about how to approach risk both within the United States and within Europe. There are many in the United States who advocate the precautionary principle, while there are sizeable numbers in Europe–particularly within the biological science community–who feel that the precautionary principle is too restrictive. These different approaches emphasize differences in values, both among cultures and among individuals within given cultures and societies. Science can not tell us which 'values' are correct. Consequently, though scientists may have their own, varying, opinions about an appropriate regulatory approach, they are in no position to dictate a philosophy of risk avoidance to the rest of society.

Pretty (1999) has suggested a biotechnology regulatory approach based on six questions. When the answer to any of these questions appears to be 'no,' then there is great need for caution and more research. If the answer appears to be 'yes,' then society is able to proceed with less caution. Pretty's (1999, p. 19) six questions are the following:

- Does the biotechnology process only involve gene transfers within the same or related species?
- Is the biotechnology process fully contained (i.e. does the technology involve no release to the environment of genetically modified organisms)?
- If the transgenic crops are released to the environment, will they affect only the target organisms as predicted?
- Is the likelihood of food toxicity or antibiotic resistance effects in transgenic foods as low or lower than other foodstuffs?
- Is the transgenic product fundamentally for the public good? Will it be distributed through public extension systems?
- Are claims for environmental benefits arising from biotechnology use on the farm supported by practice?

These six questions, based substantially on the 'precautionary principle,' facilitate systematic thinking about the benefits and risks of biotechnologies. The framework helps to clarify that not all biotechnologies are the same. They vary in the types and magnitudes of potential benefits and risks offered. Consequently, policy and regulatory bodies that address these questions will lead to conclusions about research and commercialization of various biotechnology applications that are most appropriate to each application.

Concluding Remarks

There are rational reasons for people's suspicious attitudes towards new technologies. Hence, in democratic societies, public policies dealing with genetic modification technologies must incorporate concerns among citizens at all stages in the demand-supply chain. Such a system-wide perspective allows one to view the multiple impacts and risks for different stakeholders in society. It also facilitates drawing upon the insights of various academic disciplines. Disciplines that are especially valuable for gaining policy insights about biotechnologies in a systems context are ecology, economics, and sociology.

Contrary to a common belief among some non-economists, economics deals with much more than private, monetary benefits and costs. Economics is really about the implications of alternative resource allocation decisions. This includes both direct and indirect effects, as well as the effects that are measurable in monetary terms and those for which monetary measures are not readily available. Examples of effects that are highly relevant to systems oriented economic analyses, but which cannot always be measured monetarily, include many environmental or ecological impacts, as well as various social impacts.

The discussion on the merits and risks of agricultural biotechnology will require involving all participants in the food and fiber system, from agricultural producers to consumers of final products. Justification of biotechnology applications based on purely technical merits is a necessary condition for their successful implementation, but it is not sufficient. An additional requirement is that stakeholder concerns–including those of developing nations, environmental groups, and consumers–are addressed in an open and transparent manner.

Table 1. Global Area of Transgenic Crops, by Country, 1996-2000 (Million Hectares)

country	1996	1997	1998	1999	2000*	2000* (Percent)
United States	1.5	8.1	20.5	28.7	30.3	70.5
Argentina	0.1	1.4	4.3	6.7	8.8	20.5
Canada	0.1	1.3	2.8	4.0	3.0	7.0
China	...	<0.1	<0.1	0.3	0.5	1.2
South Africa	...	<0.1	<0.1	0.1	0.2	0.5
Australia	...	<0.1	0.1	0.1	0.2	0.5
World	1.7	11.0	27.8	39.9	43.0	100.2

* Data for 2000 are based on preliminary estimates
Source: James.

Table 2. Genetically Modified Crops Grown in 2000, by Crop, 1996-2000 (Million Hectares)

country	1996	1997	1998	1999	2000*	2000* (Percent)
Soybeans	...	5.1	14.5	21.6	24.8	57.7
Corn	...	3.2	8.3	11.1	9.9	23.0
Cotton	...	1.4	2.5	3.7	5.2	12.1
Canola	...	1.2	2.4	3.4	3.0	7.0
Other	...	0.1	0.1	0.1	0.1	0.2
Total	1.7	11.0	27.8	39.9	43.0	100.0

* Data for 2000 are based on preliminary estimates
Source: James.

Table 3. Farmer Reported Genetically Modified Corn Varieties, by State and for the United States, in Percent of All Planted Corn Acres, 2001

State	% of Corn Planted
South Dakota	47
Kansas	38
Minnesota	36
Nebraska	34
Iowa	32
Missouri	32
Wisconsin	18
Michigan	17
Illinois	16
Indiana	12
Ohio	11
Other states	20
United States	26

Source: U.S. Department of Agriculture.

Table 4. Farmer Reported Genetically Modified Soybean Varieties, by State and United States, in Percent of All Planted Soybean Acres, 2001

State	% of Soybeans Planted
South Dakota	80
Kansas	80
Indiana	78
Nebraska	76
Iowa	73
Missouri	69
Ohio	64
Illinois	64
Minnesota	63
Mississippi	63
Wisconsin	63
Arkansas	60
Michigan	59
North Dakota	49
All Others	64
United States	68

Source: U.S. Department of Agriculture.

Table 5. Farmer Reported Genetically Modified Upland Cotton Varieties, by State and for the United States, in Percent of All Planted Upland Cotton Acres, 2001

State	Percent of Total Cotton Acreage
Louisiana	91
Mississippi	86
Georgia	85
North Carolina	84
Arkansas	78
Texas	49
California	40
Other states	84
United States	69

Source: U.S. Department of Agriculture.

Table 6. Global Transgenic Crop Traits, by Type, 1999

Trait	Percent of Total Cropland
Herbicide resistance	69
Insect resistance	21
Both herbicide & insect resistance	7
Virus resistance	3

Source: James.

Figure 1. Schematic Overview of Perceptions of Benefits, Costs, and Risks of Bt Corn, by Different Segments of Society

	Benefits	Costs	Risks
U.S. Farmers	Reduced production costs?	Segregation costs.	Access to markets. Loss of Bt spray effectiveness for organic farmers.
Rest of the World Farmers		Competition from lower cost imports.	
U.S. Consumers			Allergic reactions?
Rest of the World Consumers			Introduction to food chain over objections.
Agribusiness	Increased profits for the patent holders.	Higher costs to local elevators.	Liability claims.
Environmentalists	Reduced chemical use in the short run?	Continued lack of crop biodiversity.	Toxic effects on some wildlife species.
U.S. Taxpayers		Increased monitoring costs.	Buyout programs because of poor regulatory decisions.
Rural Communities		Increased concentration of agribusinesses and possibly fewer farms.	

References

Barrett, Katherine, and Gabriela Flora. *Genetic Engineering and the Precautionary Principle: Information for Extension.* Windsor, ND: The Science and Environmental Health Network; and Minneapolis, MN: The Institute for Agricultural and Trade Policy. March, 2000. http://www.npsas.org/GEPrecautionary.html

Caswell, Margriet, Keith O. Fuglie, and Cassandra A. Klotz. Agricultural Biotechnology: An Economic Perspective." Agricultural Economics Report No. 687. Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture, Washington, D.C., May 1994.

Coaldrake, Karen. "Trait Enthusiasm does not Guarantee On-Farm Profits." *AgBioForum* 2, 2 (1999): 99-102. http://www.agbioforum.org/vol2no2/coaldrake.pdf

Ervin, David E, Sandra Batie, Rick Welsh, Chantal L. Carpentier, Jacqueline I. Fern, Nessa J. Richman, and Mary A. Schulz. *Transgenic Crops: An Environmental Assessment.* Arlington, VA: Henry a Wallace Center for Agricultural & Environmental Policy at Winrock International. 2000. http://www.winrock.org/Transgenic.pdf

Feldmann, Matthew P, Michael L Morris, and David Hoesington. 2000. "Genetically Modified Organisms: Why all the controversy?" *Choices* 15 (1) (2000): 8-12.

Fernandez-Cornejo, Jorge, Margriet Caswell, and Cassandra Klotz-Ingram. "Seeds of Change From Genetically Modified Crops." *Choices* (Fourth Quarter 1999): 18-22.

Hillyer, Gregg. "Biotechnology Offers U.S. Farmers Promises and Problems." *AgBioForum* 2, 2 (1999): 99-102. http://www.agbioforum.org/vol2no2/hillyer.pdf

James, Clive. *Global Review of Commercial Transgenic Crops: 2001.* Ithaca, NY: The International Service for the Acquisition of Agri-biotechnology Applications (ISAAA). No. 21 - 2001 preview. http://www.isaaa.org/publications/briefs/Brief_21.htm

Lin, William W., William Chambers, and Joy Harwood. "Biotechnology: U.S. Grain Handlers Look Ahead." *Agricultural Outlook.* Economic Research Service, U.S. Department of Agriculture, Washington, D.C., April 2000. http://www.ers.usda.gov/publications/agoutlook/apr2000/ao270h.pdf

Lowrance, W.W. *Of Acceptable Risk: Science and Determination of Safety.* Los Altos, CA: William Kaufman, 1976.

McCluskey, Jill J. "Read the Warning: This Product May Contain GMOs." *Choices* 15 (2) (2000): 39-42.

McGloughlin, Martina. "Ten Reasons Why Biotechnology will be Important to the Developing World." *AgBioForum* 2, 3&4 (1999): 163-174. http://www.agbioforum.org/vol2no34/mcgloughlin.htm

Pretty, Jules. *The Effects of Genetically-Modified (GM) Crops on the Countryside and Rural Economy.* Report for the Countryside Agency. Colchester, United Kingdom: Centre for Environment and Society, University of Essex, 2000.

Pretty, Jules. "Genetic modification of crops: Partner or pariah for sustainable development?" *The Biochemist* (October 1999): 15-21

Ruttan, Vernon W. "Biotechnology and Agriculture: A Skeptical Perspective." *AgBioForum* 2, 1 (1999): 54-60. http://www.agbioforum.org/vol2no1/ruttan.html

Senauer, Ben, Elaine Asp, and Jean Kinsey. *Food Trends and the Changing Consumer.* St. Paul, MN, 1993.

Shoemaker, Robbin (Ed.). *Economic Issues in Agricultural Biotechnology.* Washington, D.C.: U.S. Department of Agriculture, Economic Research Service, Resource Economic Division, Agriculture Information Bulletin, No. 762, February 2001. http://www.ers.usda.gov/publications/aib762/aib762.pdf

Smith, Craig S. "China Rushes to Adopt Genetically Modified Crops." *New York Times* October 7, 2000. http://www.nytimes.com/2000/10/07/world/07CHIN.html

U.S. Department of Agriculture. *Crop Production–Acreage–Supplement.* National Agricultural Statistics Service, Agricultural Statistics Board, Report No. PCP-BB. June 29, 2001. http://usda.mannlib.cornell.edu/reports/nassr/field/pcp-bba/acrg0601.pdf

U.S. Department of Agriculture–Illinois Marketing News. "Value-Enhanced Grain Survey." Springfield, IL: February 6, 2001. http://www.ams.usda.gov/mnreports/GX_GR118.txt

U.S. Grains Council. *2000/2001 Value-Enhanced Grains Quality Report.* Washington, D.C.: 2001. http://www.vegrains.org/documents/2001veg_report/index.htm

Yoon, Carol Kaesuk. "Altered Salmon Lead the Way to the Dinner Plate, but Rules Lag." *New York Times* May 1, 2000a. http://www.nytimes.com/library/national/science/050100sci-gm-animal.html

Yoon, Carol Kaesuk. "Simple Method Found to Vastly Increase Crop Yields." *New York Times* August 22, 2000b. http://www.nytimes.com/library/national/science/082200sci-gm-rice.html

Young, Nevin. "Comments in response to Assessing Environmental and Evolutionary Impacts." Presentation at a conference on *Governing GMOs: Developing Policy in the Face of Scientific & Public Debate.* University of Minnesota, Minneapolis, MN, February 1, 2001. http://www.jointdegree.org/media/GMOs2001/GMO6h.ram