

Agricultural Biotechnology: Farm-Level, Market, and Policy Considerations

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This study provides an overview of the 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 U.S. domestic and international consumer demand for transgenic crop products discussed 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.

Key Words: acceptance, agricultural biotechnology, benefits, costs, public dialogue, risks

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 not new. However, modern genetic engineering—as a form of biotechnology—is different from traditional means of manipulating the biology of plants and animals, because it allows for the movement of functional genes from one organism to another.

Genetic engineering or modification facilitates the development of characteristics not possible through traditional breeding techniques. In this study, the term “biotechnology” refers to a collection of techniques used by biological scientists to modify genes within an organism or to transfer specific genes between organisms. Also, 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.

The purpose of this analysis is to examine tradeoffs involved with agricultural biotechnology at the farm level and from a public policy perspective. A discussion

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is provided of economic costs, benefits, and risks associated with the use of agricultural biotechnology within farm and food systems driven by domestic and international consumer demand. Also presented is 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 gives 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. Next, consumer concerns and international trade issues are considered. A separate section is devoted to the “precautionary principle,” which places the burden of proof primarily on proponents of biotechnology to demonstrate there is little or no risk of serious harm to public health and the environment. Finally, research policy perspectives are discussed.

The Diffusion of Biotechnology in Agricultural Production

Because of the 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 reporting data on the global spread of genetically engineered crops are based on one source, the International Service for the Acquisition of Agri-biotechnology Applications (ISAAA) (refer to James, 2001). The ISAAA is a publicly and privately funded organization and has an international network consisting of several centers, one of which is affiliated with Cornell University.

Based on the data collected by James (2001), global cropland planted with bio-engineered crops increased from 4 million acres, when the crops became commercially available in 1996, to an estimated 109 million acres in 2000, spread over 12 countries. 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, 2000).

Globally, as well as in the United States, the area planted to genetically engineered crops leveled off somewhat between 1999 and 2000. 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 (James, 2001).

Soybeans accounted for approximately 58% of the world’s cropland acres used for transgenic crops, followed by corn with about 23%, cotton with approximately 12%, and canola with about 7%. Globally, the most prominent genetically engineered

trait used in crops is herbicide resistance, accounting for 69% of the total global cropland area planted with transgenic crops in 1999. In the same year, insect-resistant crops accounted for approximately 21% of the world's cropland area sown with transgenic crops, and crops containing both herbicide-resistant and insect-resistant genes accounted for about 7%. Finally, virus-resistant transgenic crops comprised close to 3% of these global cropland acres (James, 2001).

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 small, 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. (2000) and Pretty (1999, 2000), among others.

Supporters of the use of biotechnology in agriculture argue it will improve global and local food security by helping developing nations provide food for their own citizens (McGloughlin, 1999). 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 assert that applications of agricultural biotechnology are necessary to meet a rapidly expanding global demand for food.

Advocates also contend biotechnology improves the environment by reducing the need for chemicals in agricultural production. The reduced application 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.

The potential benefits associated with particular biotechnologies may be accompanied by 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, grain merchandisers 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 handlers can capture or by charges 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 relevant to agricultural biotechnology: cost-reducing and quality-enhancing (Caswell, Fuglie, and Klotz, 1994).

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 by others.

A systemwide 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, Morris, and Hoesington, 2000; Fernandez-Cornejo, Caswell, and Klotz-Ingram, 1999). A specific health concern associated with agricultural biotechnology is the effect on persons with allergies, who 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.

The potential for environmental risks related to agricultural biotechnology has raised serious questions. Among them is the concern referred to as the “super weed” problem, caused by genetic drift to wild relatives of the target species which 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 nontarget species, such as butterflies which depend upon the target species’ ecosystem. A fourth risk associated with using biotechnology is the possible introduction of new viral pathogens and pathogenic bacteria into the environment.

An 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 application 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 likely to crowd out others.

Because biotechnology is likely to affect the structure of agriculture, it is of direct concern to those in production agriculture. Since the introduction of biotechnology in the mid-1990s, its rapid spread in production agriculture already appears to have accelerated 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 seed, 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, 1994). 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

We can use Bt corn to illustrate the possible distribution of selected benefits, costs, and risks among different stakeholders in society. From the schematic provided in figure 1, the entries in the cells 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., 2000; Pretty, 2000). Further, whether any chemical use reductions are lasting will depend in part on how soon resistance to the Bt toxin builds up.

GROUPS AFFECTED	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 (ROW) Farmers		Competition from lower cost imports	
U.S. Consumers			Allergic reactions?
ROW 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	

Figure 1. Schematic overview of perceptions of benefits, costs, and risks of Bt corn, by different segments of society

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 ingredients. In addition, farmers in countries where genetically modified corn is not widely adopted (countries referred to as the rest of the world, or ROW, in figure 1) 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 believe this continued lack of crop biodiversity is unsound from an ecological sustainability standpoint. Further, the StarLink corn incident suggests public agencies (meaning U.S. 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 who found their seed supplies had been contaminated with the Cry9C gene. The owner of the product, Aventis CropScience Company, in turn agreed to reimburse the government for the buy-back program, including costs associated with storage, inspection, transportation, and auditing. The

company also agreed to reimburse farmers and elevators in 17 states for their costs associated with detecting, sorting, shipping, and marketing StarLink (Taylor and Tick, 2001).

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, even though StarLink corn has not been shown to pose a health risk, it entered into the human food system in spite of regulations prohibiting such an occurrence. Similarly, consumers in the ROW countries feel they also face risks of Bt corn finding its way into their food systems without their knowledge, despite various regulations and labeling practices designed to guard against this event in much of Europe.

Another risk is that widespread use of Bt crops may result in resistance to the natural Bt spray 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. Further, although evidence available thus far is mixed, there is concern Bt corn may be toxic to some butterflies and beneficial insects (Ervin et al., 2000).

This illustration showing how different groups throughout society may be either beneficially or adversely affected by agricultural biotechnology demonstrates 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 do not arise simply because of an “uninformed public” or “distortions in the media.” At least in the short run, genetically modified technologies will potentially benefit some groups, but negatively affect others.

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 providing them with the greatest expected returns (described, for example, by Makki, Somwaru, and Harwood, 2001).

In the case of crops, those produced using biotechnology may possess traits different 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 strictly 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 genetically modified crops, producers need to understand costs and benefits associated with

growing the new crops. A comparison should be made 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 side, technology fees would need to be added and inputs no longer necessary would need to be subtracted. If the expected net revenue associated with producing the crop which utilizes the new technology exceeds that of a traditionally produced commodity, an incentive to change to 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, producers who consider contracting their crop may have to identify alternative markets for the crop before finalizing their contract, in case of a harvest shortfall and subsequent inability to meet contract obligations.

Fourth, a genetically modified crop which 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 risk and reduced hedging effectiveness. Finally, local production and marketing systems may also affect producers' decisions about 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 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 various products.

A market is segmented when a variety of products of a similar type have distinguishing characteristics intended to give individual products a different value to consumers. Biotechnology is one avenue for segmenting the market for crops generally regarded as commodities (corn from Iowa is the same as corn from Illinois). The objective of adding a value-enhanced trait—i.e., a characteristic desired by

consumers—is to segment the corn market, thereby allowing for the development of a corn price differential.

Producers have traditionally captured the entire premium from improvements in the quality characteristics of plants using established breeding methods. 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. A producer's premium 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. The existing marketing system may handle the trait, for example, through a protein premium. 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.

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 the Northern Plains, wheat with a low protein content was discounted in price in recent years. The distribution problem 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 various markets today? How are the production and marketing systems responding to segmented and segregated markets? A look at the market structure reveals, while the segment for crops using traditional production methods is real, it may not be very large. Researchers with the U.S. Department of Agriculture's (USDA's) Economic Research Service have offered estimates about the size of the non-biotechnology corn and soybean markets (Lin, Chambers, and Harwood, 2000). They estimate the markets for non-biotechnology corn and soybeans were about 1% and 2%, 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, Chambers, and Harwood (2000) also report 15% of farmers are considering ways to handle their own crops in a segmented form in an effort to capture premiums and/or avoid discounts. About 5% 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¢ per bushel for corn and 54¢ 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 5¢ to 10¢ per bushel in premiums, while non-genetically modified soybeans have received 10¢ to 15¢ per bushel above commodity values (Lin, Chambers, and Harwood, 2000). Data from the USDA's Illinois Marketing News (2002) show premiums of 6¢ to 15¢ for non-genetically modified corn and 10¢ to 30¢ for non-genetically modified soybeans. Further information on market size and prices of value-enhanced grains is provided by the U.S. Grains Council (2001).

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 for transgenic products are expected to be major agenda items in the new 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.

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 justifications often cited for European Union (EU) residents' suspicious attitudes toward genetically engineered food products is a series of well-publicized cases that jeopardized the safety of the EU food supply. For example, food safety concerns arose in response to the Bovine Spongiform Encephalopathy (BSE) or mad cow disease case which 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. Further, most European nations historically have not had central regulatory agencies, or equivalents to the U.S. Food and Drug Administration, to oversee the safety of the food supply. As a consequence, many European nations were left to regulate and impose restrictions on final products, rather than regulate the process by which the product is produced (the approach used in the United States).

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

Even without further mishaps as a consequence of the way agricultural biotechnology is incorporated into the food and fiber system, genetically engineered products have characteristics with the potential to raise concerns among consumers. Prior to the development of modern biotechnology, Lowrance (1976, p. 87) identified general characteristics of products observed to increase the perception of danger among consumers.

These characteristics were further developed by Senauer, Asp, and Kinsey (1993, p. 250). Specifically, consumers perceive a general increase in the risks associated with products: (a) whose risks are unknown, (b) whose consequences are irreversible, (c) which exposed them involuntarily to the risks, (d) where there are many alternatives available, and (e) which 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 to find concerns and misgivings exist among individuals in some of these nations.

The "Precautionary Principle"

Democratic governments differ in the way they decide 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 structured 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 reflects the American philosophy which tends to view science as progress, but contrasts with the somewhat more skeptical view of science held in Europe (McCluskey, 2000).

Consumer concern about risks associated with the use of biotechnology in food production in Europe has led to a regulatory approach resting much more heavily on the “precautionary principle” (Barrett and Flora, 2000; Ervin et al., 2000). The precautionary principle is based on the following premise: “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, 2000, 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 there is, in fact, little or no risk of serious harm. Listed below are core elements included in the precautionary principle (taken directly from Barrett and Flora, 2000, p. 7):

- 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.

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., 2000, 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 the precautionary principle is too restrictive.

These contrasting approaches emphasize differences in values, both among cultures and among individuals within given cultures and societies. Science cannot tell us which “values” are correct. Consequently, although 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. The six questions formulated by Pretty (1999, p. 19) are stated as follows:

- Does the GM process only involve gene transfers within the same or related species?

- Is the GM process fully contained (i.e., does the technology involve no release to the environment of GMOs)?
- If GM 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 GM foods as low or lower than other foodstuffs?
- Is the GM product fundamentally for the public good? Will it be distributed through public extension systems?
- Are claims for environmental benefits arising from GM 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, consideration of these questions by policy and regulatory bodies will lead to conclusions about research and commercialization of various biotechnology procedures which are most appropriate to each application.

Policy Perspectives

In an attempt to put the benefits, costs, and risks associated with biotechnology in perspective, Young (2001) 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—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, or government environments—to acknowledge this fundamental factor. Without this realization, progress will be limited in conducting 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.

Young's second principle notes there are valid concerns about, and potential valid benefits from, the impacts of biotechnology. Acknowledging both benefits and shortcomings of the technology will improve the transparency of the discussion.

The third principle states the evaluation of biotechnology and its uses should be based on generally accepted principles currently applied in the various sciences for conducting comprehensive systemwide analyses.

We suggest the addition of a fourth principle: Both proponents and opponents of biotechnologies should attempt to avoid sensationalism and exaggeration in discussing advantages and disadvantages of the technology; i.e., 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 only in fat—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.

From a research policy perspective, it is not only important to compare the costs, benefits, and risks of biotechnology, but also the resulting net gain or loss from implementing agricultural biotechnology must be weighed against alternative, appropriate, and locally feasible technologies. Ruttan (1999) argues 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 recent *New York Times* article which reported that a mixture of two different rice varieties doubled rice production without additional chemical inputs (Yoon, 2000). Finally, and perhaps most importantly, no amount of change in technology in agricultural production will relieve world hunger without accompanying political reforms designed to facilitate access to food.

Concluding Remarks

There are rational reasons for people's suspicious attitudes toward new technologies. Hence, in democratic societies, public policies dealing with genetic modification technologies must address concerns among citizens at all stages in the demand-supply chain. Such a systemwide 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. Especially valuable disciplines for gaining policy insights about biotechnologies in a systems context are ecology, economics, and sociology.

Contrary to a common belief among some non-economists, the field of 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 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 involvement by 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.

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