Symposium: Assessing the Effects of Agricultural Biotechnology

Socioeconomic Aspects of Agricultural Biotechnology

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After years of promise, agricultural biotechnology is beginning to move from the research laboratories and field trials to the commercialization and adoption phase. However, surveys (2,43) indicate that the general public is either unaware of biotechnology or not well informed on the subject. To some (18,21) biotechnology offers the key to increases in agricultural productivity and efficiency and a means of enhancing the competitive position of the United States in world markets. It may also help solve world hunger and health and environmental problems (11). Yet, others (9,30,31) are alarmed about the potential negative ecological, social, economic, political, and moral implications of agricultural biotechnology. They see biotechnology research and development efforts as something that must be carefully regulated, at best, and in many instances the development and adoption of technologies based on genetic engineering should be prevented.

For many, biotechnology is part of the mysterious, poorly understood world of science. Yet, the principles of this new science are based on the discoveries of over a century of work by geneticists following in the footsteps of Mendel and, more recently, the elucidation of the double-helix structure of deoxyribonucleic acid (DNA) by Watson and Crick. Thus, our increased understanding of the function of genes and our ability to manipulate them, allow researchers to do things today that were previously perceived as being impossible. Genetic engineering promises significant gains in agricultural productivity. The challenge before us is to assess and anticipate the socioeconomic consequences of these technological changes. More than in the past, society wants to know who will gain or lose, before a technology is introduced. People want to know if these technologies are safe and whether they will cause unacceptable harm to the environment, endanger our health and food supply, and alter in an unacceptable way the structure and performance of the economy (42). People also want to know, in quantitative terms, what expected benefits will be realized (28).

This article focuses on the methodologies often used to assess the socioeconomic aspects of agricultural biotechnology, rather than on current efforts of scientists in basic and applied research in genetic engineering. One section provides a brief overview of how agricultural economists and other social scientists have evaluated the socioeconomic consequences of previous agricultural technologies. Attention is given to the analytical tools used by social scientists and their potential for helping us analyze the likely socioeconomic implications of emerging agricultural biotechnologies. The other section reviews case studies on products resulting from agricultural biotechnologies that are to become commercially available to farmers in the early 1990s.

HISTORY AS PROLOGUE

Prior to World War II, assessment of agricultural research was primarily a process of descriptive documentation. Extension agents, farm journalists, and others noted that farmers had substituted capital for labor; for example, tractors and other farm machinery replaced horses and manual labor. By the 1950s most farmers had adopted hybrid corn, the use of commercial fertilizers was common, many were beginning to use pesticides, and improved breeding, nutrition, and management had increased livestock productivity.

As technology adoption has progressed, our research capacity to assess its economic impacts also has improved. Griliches (12,13) was one of the first economists to attempt to statistically analyze the adoption of new technology by farmers. He estimated a logistic curve that accurately explained farmers' adoption of hybrid seed corn. He concluded that as a new technology becomes profitable, farmers adopt it rapidly. Along with Schultz (35) and others, he began to estimate the rate of return to public investment in agricultural research and found it high, often five to 10 times greater than a commercial bank interest rate. Many agricultural economists concluded that society was underinvesting in agricultural research and encouraged additional public and private agricultural research support. Rural sociologists also have contributed to our understanding of the process of technology adoption by focusing on the diffusion of technology and the role of human capital investments, e.g., schooling as an indicator of who will likely be innovators and adopt new technologies (32).

Schultz (35), along with Hayami and Ruttan (14), extended their analysis to the international arena in the 1960s. There too, it was found that the returns to investment in agricultural research as well as human capital, education, and extension are quite high. These efforts to analyze the benefits and costs of agricultural research provided a rationale for the organization, funding, and expansion of the international agricultural research centers. Today there are 13 such centers within the Consultant Group on International Agricultural Research, with efforts under way to embrace other international research centers and broaden the focus to include forestry and natural resources as well as crops and livestock.

Yet, despite the dramatic increases in agricultural productivity in the two decades immediately following World War II, questions were being raised by many concerning the distributional implications of the rapid technological change that was occurring. Cochrane (7) noted that U.S. farmers were on an agricultural treadmill. The early adopters benefited from gains in productivity and efficiency and increased profits, but by the time others adopted the new technologies, market prices had declined as product supplies increased. And despite government farm policy to support prices and reduce production through acreage reduction programs, the structure of agriculture changed rapidly, as farm numbers declined and farm size increased. Rural communities declined in number and size, as many people moved to the larger cities. Many farmers now purchase their farm inputs and household supplies in large cities rather than rural communities. These events alarm many rural and urban people who highly value traditional rural communities and their associated life-styles. This concern continues as some envision agricultural biotechnology as a technological force that will drive many people off the land in the decade ahead (5).

The distribution of the benefits and costs of a new technology depend on institutional and technical relationships. For example, Schmitz and Seckler (34) estimated that the gains to adopters of mechanical tomato harvesters and consumers, who could purchase larger supplies at relatively lower costs, were substantially greater than the losses to the displaced workers. They argue that a technology should be adopted if there is a net gain to society but suggest that efforts should be made to compensate those who are made economically worse off or are displaced by the new technology and must seek alternative employment. Job training and relocation programs are suggested. Martin and Havlicek (26,27) found similar results for the adoption of mechanical cotton harvesters. Yet, Bieri et al (3) caution us that the distribution of the gains from agricultural technology depends on the market structure and influence of input suppliers and food-processing and distribution firms. The questions raised, and analytical approaches suggested by these studies, are also applicable to the socioeconomic assessment of biotechnology.

In 1962, Rachel Carson, in her book *Silent Spring*, alarmed the public about the use of agricultural chemicals. Her legacy remains, as chemical firms and farmers face increased government regulations on the purchase, use, and disposal of agricultural chemicals. Since the establishment of the Environmental Protection Agency (EPA) in the early 1970s, there have been numerous economic studies of pesticide use and associated farming practices. Roth et al (33), with an aggregate production function extending the approach suggested by Griliches (12,13) and Hayami and Ruttan (14), found that the benefits from pesticides in the United States exceeded the costs. However, this approach is unable to capture the distributional or environmental effects of new technologies such as pesticide use. Thus, its application to the analysis of agricultural biotechnology is limited.

Surveys of farmers have provided insights into who adopts new technologies. Thomas et al (40) found that operators of large commercial farms in the eastern Corn Belt with more education were more likely to use integrated pest management and soil-conserving tillage practices than older, less-educated farmers operating smaller farms. Rahm and Huffman (29) found in a survey of Iowa farmers that investments in human capital resulted in the adoption of reduced-tillage systems. More years of schooling, attendance at extension meetings, and reading of technical and trade journals were all associated with the adoption of recommended crop production practices. This same pattern is likely to be true for the adoption of agricultural biotechnology. Better-educated operators of large commercial farms are more likely to be the early adopters of animal growth hormones or plant varieties genetically engineered to resist herbicides, insects, or diseases. This may cause farmers to spin the agricultural treadmill further and speed up the trend toward fewer but larger farms. In other cases, however, agricultural biotechnologies may be more scale-neutral (41), such that production costs per unit can be reduced by similar amounts on both large and small farms; for example, planting an insect-resistant variety could result in less pesticide use per acre, regardless of farm size. Farmer surveys offer a means of anticipating and monitoring the adoption process.

With the recent advances in computer hardware and software and the conceptualization of new modeling approaches, mathematical programming has become widely used to assess agricultural technologies. Linear programming models are routinely used today by agribusiness firms, and by some farmers, to balance livestock rations, select optimal cropping practices, determine land and machinery purchases, and operate food-processing and distribution systems.

Research economists use mathematical programming models to estimate the farm-level, regional, and national impacts of changes in agricultural policies and the adoption of new technologies. These computer models are also helpful in the assessment of the impacts of regulatory actions of governmental agencies, such as the EPA or the Food and Drug Administration (FDA). Cashman et al (6) used this approach to determine the effects of potential EPA bans on herbicide use on corn and soybeans. A recent study by Bahr et al (1) extended this approach to analyze the economic effects of alternative tillage systems, crop rotations, and weed control systems on farm size and income. Burton and Martin (4) estimated the national and regional impacts of changes in pesticide use and associated policies in the United States. A national mathematical programming model approach also can provide insights into the impacts of technological change on income distribution.

Most national mathematical programming models embrace the concept of producers' and consumers' surplus to provide a measure of changes in aggregate economic welfare (8). Simulation models based on econometrically estimated equations offer another quantitative approach to evaluate agricultural technologies. Mathematical programming and simulation models are powerful analytical tools that can be used to assess the potential economic consequences of agricultural biotechnology (39). For example, Kalter et al (17) and Fallert et al (10) have used these approaches to assess the potential economic consequences of the introduction of bovine somatotropin (BST).

ECONOMIC ASSESSMENT OF AGRICULTURAL BIOTECHNOLOGY

The scientific tools underlying agricultural biotechnology may be different from those of previous biological, mechanical, and chemical technologies. However, any agricultural technology, if it is to be adopted, must permit production at a lower cost per unit of production, generate a higher-value product, or improve the quality of the product. Otherwise, the technology will not be adopted. For example, a farmer adopts a disease- or insect-resistant plant, which does not require an insecticide or fungicide, and the cost of production per unit declines, even though total output (i.e., yield) may remain constant. Thus, unless the product price falls by a similar amount, the profit per unit increases. Alternatively, productivity may increase, as with BST, a naturally occurring protein hormone in cows, which stimulates milk production. Again, unless the product price declines enough to offset the decline in production cost per unit, the profit per unit increases.

Hence, whether the products of biotechnology increase output or not, production cost per unit should fall, and unless this cost reduction is offset by a decline in the product price, profits per unit will increase and farmers will be encouraged to adopt the new technology.

The demand for most agricultural products in the United States is price-inelastic. Hence, when the supply curve shifts to the right, as many farmers adopt a new technology, the decline in the product price is proportionately greater than the increase in output. Consequently, in the aggregate, total revenues to the industry fall. Thus, early adopters, firms who initially commercialize the technology, and consumers are usually the primary beneficiaries, not the agricultural sector as a whole. If the government maintains price supports, then surpluses will accumulate, taxpayer costs will increase, and more farmers will benefit from the adoption of the technology. However, consumers will benefit less, and the United States will be less competitive in international markets.

Impacts of animal biotechnology. Initial commercial applications of agricultural biotechnology are occurring in animal production. The availability of data and pressures from private and public sector scientists, regulatory agencies, farmers, and public interest groups have encouraged socioeconomic studies of several biotechnology products for livestock production.

The growth hormones BST and porcine somatotropin (PST) have received the most attention. Somatotropin acts by altering nutrient partitioning to direct more nutrients for milk synthesis (in lactating cows) or for muscle development (in growing animals). In dairy cows, whole-milk yield and nutrient intake both increase, and feed efficiency is improved, because nutrients used for maintenance constitute a smaller portion of total nutrient consumption. In swine, a major portion of the gain in feed efficiency occurs because more nutrients are used for lean tissue accretion and fewer are used for body fat accumulation. However, because more protein is required for the development of lean tissue, hogs treated with PST require more dietary protein, as do dairy cows treated with BST.

Marion and Wills (25) concluded that dairy farmers are likely to adopt BST, since early adopters will realize significantly higher, visible returns in their monthly milk checks, and others will eventually have to adopt to remain competitive. An increase in milk productivity of 10–15% is expected in commercial herds. This increase is not significantly different from gains from other technologies, such as improved cows through genetic selection and milking facilities, but the initial investments and operating costs for the adoption of BST will be much less. Thus, the immediate returns to farmers from BST may be high, and BST adoption will not impose serious capital constraints. However, if the full productivity potential of BST is to be realized, dairy farmers must possess superior management skills.

Fallert et al (10) and Magrath and Tauer (24) reported that the benefits of the adoption of BST will largely depend on the flexibility of the government's milk price support program. Continued high price supports would encourage more dairy farmers to adopt BST; the results would be higher returns to dairymen, larger treasury outlays by the government, accumulation of dairy surpluses, and fewer benefits to consumers of dairy products. To minimize treasury outlays and accumulations of dairy products, reductions of about 15–20% in milk price supports might be required to bring supply and demand into balance. The adoption of BST, along with other dairy management technologies (such as improved genetics, computerized records, and feed analysis, which are available but have not been widely adopted), would reinforce but not fundamentally change the current trend toward fewer but larger dairy operations. This adoption is not likely to significantly alter the regional adjustments that are already under way because of milk and input price incentives. The number of small herds in the the Great Lakes region and the Northeast is likely to decline, and continued herd expansion is likely in California. Fallert et al (10) view management skills as the key determinant of whether dairy farmers will be able to benefit from BST. As has been the case for previous agricultural technologies, investments in human capital—formal and informal education—will be critical to the adoption and success of BST.

Kalter et al (18) constructed a linear programming model of representative dairy farms in New York. They also concluded that, for a supply-demand equilibrium for milk, the number of dairy farms and cows would have to decline, by perhaps 25–30%, and milk support prices would need to be reduced 10–15% within 3 yr after the initial adoption of BST. Kalter (16) suggested that farmers can be divided into three classes. The innovators, who are superior managers and in a secure financial position, will be the first to take advantage of the new technology. Those who are financially stressed and lack management ability will unlikely survive the introduction of major agricultural biotechnology products. The third group, those in the middle, can be characterized as being in good financial position but somewhat deficient in management skills. To survive they will need to invest in human capital.

A study of the adoption of PST by the swine industry (20) concluded that consumers would gain from lower pork prices and leaner pork while producers would benefit from increased feed efficiency, lower production cost per unit, and a premium price for the leaner carcass produced. However, the rate of adoption may depend on the premiums paid for leaner meat and increases in demand, as consumers express their preference for more pork as it becomes leaner. The results also suggest that larger, better-educated pork producers are more likely to be early adopters.

The above-mentioned studies of animal growth hormones were undertaken for several reasons. First, there was considerable demand for the assessment of the likely economic impacts of these two growth hormones, since several major agribusiness companies were testing them and were in the process of seeking FDA approval for commercial sale in the United States. Second, data from test trials in the public sector were available. Mathematical programming models were used to assess the farm-level effects. To explore the sensitivity of the empirical results, simulation analyses were conducted under different assumptions about feed efficiency, milk productivity gains, product prices, and costs of somatotropin. Simulation analysis is especially important in studies where the basic technical data are limited and the policy consequences of adoption are uncertain. Methods must also be devised to project expected adoption rates (22). The animal growth hormone studies were conducted for different farm sizes to better assess the implications of economies of scale and likely structural effects; for example, is the adoption of BST likely to be scale-neutral or biased in favor of larger dairy farms? Biotechnologies such as the somatotropins may be more scale-neutral than previous mechanical innovations.

Impacts of plant biotechnology. Although research leading to commercial sale of biotechnology for animal production is more advanced than that for plant production, the gap is closing rapidly. Advances have occurred in genetic engineering of vectors, which can be used to modify genetic information. Progress has taken place in cell culture techniques to regenerate plants (21). The commercial potential from these techniques includes the development of plants with herbicide resistance; improved resistance to pests (insects, viruses, bacteria, nematodes, and fungi); increased tolerance of drought, salt, and cold; the ability to fix nitrogen (in cereals); improved mechanical harvesting characteristics; and increased photosynthetic efficiency. Resistance to insects and herbicides has already been inserted into the genomes of tomatoes and tobacco. While work is under way, only limited success has been reported for the monocotyledons such as corn, wheat or rice.

Less research has been conducted on the potential socioeconomic impacts of improved plants. The economic impacts will depend on how universal or specific the plant biotechnology is; for example, is it a plant diagnostic technique for a certain disease, or is it a nitrogen-fixation bacterium, which may be applied to several monocotyledons and significantly reduce fertilizer input costs or increase yields? Tauer (38) assessed the potential economic impacts of biological nitrogen-fixation technologies on U.S. agriculture and estimated that they would have a high value to society.

Increasing the nitrogen-fixation efficiency of legumes could result in an annual benefit to the United States in excess of $1 billion, and the use of commercial nitrogen fertilizer would decline by over 1.5 million tons. If all commercial nitrogen used on the major crops were replaced by biological nitrogen fixation technologies, the annual benefit in the United States would be approximately $4.5 billion. A study by Sundquist et al (37) examined the economic impacts of potential new corn technologies.

Insufficient technical information on yield, production practices, and changes in production costs for new, genetically altered plants, such as insect- or herbicide-resistant or drought-tolerant varieties, makes it difficult to conduct accurate research on the economics of biotechnology in plants. Before either an econometric production function or a farm-level mathematical programming study can be conducted, it is essential to have some reasonable information on how a biotechnology would alter production relationships (28). This will require a close working relationship between biological scientists and agricultural economists.

Patent laws now offer agribusiness firms major incentives to invest in biotechnology, since they have greater possibilities of recovering their investments. The Plant Variety Protection Act of 1970 extended patent-like protection to crop varieties. The U.S. Supreme Court, in a 1980 decision, established the legality of patents for novel life forms (36,41). This introduces an additional problem for conducting socioeconomic analysis of biotechnology products. Much of the basic and applied technical research is being undertaken by the private sector. With current patent laws and concerns about trade secrets, these firms are unwilling to release or share this information with agricultural economists in the public sector. Furthermore, many biotechnology firms are either unwilling to commit the resources or do not have trained personnel to conduct socioeconomic analysis. What economic analysis they do conduct is generally in product marketing and internal management and cost analysis. Some agribusiness firms have hired outside consultants to conduct socioeconomic and related public policy research, but usually at the behest of the EPA or the FDA as part of the process of seeking approval for commercial sale of a biotechnology product.

These new patent rulings raise new legal and economic questions on the appropriate role of public agricultural research stations and the extension service (36). For example, some universities are seeking patent protection in an effort to recover research costs and are licensing new varieties to the private sector for further development and commercialization.

SOME CONCLUDING THOUGHTS

Agriculture is entering a new technological era. Many expect new biotechnology products to bring large increases in productivity. Commodity and food prices are likely to fall. The structure of agriculture is likely to continue in the direction of larger and fewer farms run by better managers. Yet there is much we still do not know about the socioeconomic ramifications of biotechnology, in its effects on the farm industry, on the agricultural input and food-processing industries, and on international trade. Some useful socioeconomic studies have been conducted on biotechnology products for animal agriculture. However, these are based on preliminary technical data and key assumptions, often uncertain, on future agricultural policy. Even less is known about the possible socioeconomic impacts of biotechnology products for crop production.

Biotechnology will have long-run impacts on industries that supply agricultural inputs and on processing facilities. Answers to questions concerning the development, patenting, ownership, and control of biotechnology products and genetic material will have important economic effects. Farmers, university administrators and researchers, and many public groups are concerned about these issues.

The implications for public policy are potentially far-reaching. Price support policies, funding for research and extension activities, approval of biotechnology products by regulatory agencies, and changes in international trade policies will influence the rate of development and adoption of agricultural biotechnologies in the United States and other countries. These issues merit the immediate attention of social and biological scientists in the public and private sectors, and substantial interdisciplinary research will be required.

Theoretical and empirical models employed to assess the socioeconomic implications of previous agricultural technology in the post-World War II era provide a fruitful basis for analysis of agricultural biotechnology. In addition, improved data collection and computer-based quantitative procedures should enhance the research process. However, much of the previous technology assessment research was ex post analysis. These studies examined the observed rates of adoption, surveyed farmers, or calculated the benefits and costs of technologies already in place.

The challenge before us is to conduct ex ante research based on the available technical data and informed judgments of biotechnologists and social scientists. Sensitivity analysis will be essential as we examine the economic implications of the emerging agricultural biotechnologies under plausible future agricultural policies and rates of adoption. Also, as noted by Hueth and Just (15), environmental considerations merit considerable attention in any economic analysis of biotechnology. Past research efforts on the economics of pest management provide some guidance on methodology and data requirements for this type of economic analysis. However, these studies tended to emphasize the private benefits and costs and frequently ignored the social benefits and costs of pesticide use. The public is demanding more attention to effects of agricultural biotechnology on the social welfare, including its economic and environmental impacts on and its consequences for rural communities.

Social scientists, especially those who are activists, often call for a mandatory filing of a socioeconomic impact statement before any firm conducts research on or releases a product of biotechnology (41). Calling a halt to biotechnology development until all the social, economic, and political issues are resolved will result in the loss of the competitive edge of the United States in international markets and preclude potential gains to farmers, agribusiness firms, and consumers. On the other hand, a case can be made for more research to help anticipate the potential ecological and socioeconomic impacts of agricultural biotechnology (11,19,23,28,39). The public is no longer willing to accept self-regulation by scientists. Restraint is essential to avoid releasing a genetically engineered organism that might cause irreparable harm to the environment (19). Also, people need time to understand, adopt, and adapt to new technologies (11). Cooperation among social and biological scientists should help us recognize possible socioeconomic impacts and minimize costly short-run adjustments and dislocations while we prepare to reap the benefits promised by the emerging agricultural biotechnologies.

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