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Economics and the Biological Revolution in Agriculture

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The Past Fifty Years

Agricultural innovations in the first half of the twentieth century were dominated by improvements in mechanization together with higher skill levels of farmers and others in the food industry. By the early 1950s, major changes were underway in what is known as the biological revolution in agriculture. In the past 50 years, productivity changes in agriculture, primarily driven by biological innovations, have led to significant changes in standards of living. But today controversies related to food safety, international trade of genetically modified crops, and environmental quality call into question the future of growth in agricultural productivity. This article examines the investments, consumer demand and institutional changes that describe the past and point to the future of the biological revolution.

The Take-Off Phase

Three sectors of North American agriculture were swept ahead by significant genetic innovations in the 1950s: corn hybrids; soybeans as a new, oil-seed crop; and genetically modified poultry to consume the lower-cost feeds. The new corn and soybean varieties had to be tailored for various lengths of growing season and days, as well as for a large set of soil types, so the diffusion process took several decades. A private seed industry grew up as proprietary rights to corn hybrids were established, while a public-sector plant-breeding program developed the local soybean varieties. Prior to these institutional changes, soybeans were grown as a minor fodder crop, and corn plants were not designed to produce high yields. Corn-soybean rotations helped capture more nitrogen, manage weeds, and control major soil pests such as corn rootworms and cyst nematodes. The productivity shifts passed lower feed prices to the poultry industry and finally to consumers. A broiler industry developed and consumers added more protein to their diets.

During the 1960s, the transfer of plant breeding innovations to developing country agriculture began in the form of high-yield wheat and rice varieties developed at international research centers in Mexico and the Philippines. These *green revolution* varieties were shorter and much more responsive to other inputs such as water and fertilizer. Many small farmers adopted these seed and crop production improvements that led to increased yields and lowered consumer prices for these food staples. The technology was duplicated for pulses and millets in more arid areas, and for root crops such as cassava and potatoes to a limited extent. This part of the biological revolution enabled poor farmers to expand output faster than population growth, thereby reducing malnutrition. Higher yields helped relieve pressures on land conversion from forests and pastures to row crops.

However, agricultural intensification also gave rise to numerous side effects. More fertilizer applications and more dense plant canopies increased the growth of some insects, viruses and fungi. Weed pests physiologically similar to the crop were selected and reproduced over multiple generations. Pesticide use became more common as farmers sought to protect the crops with higher value per unit area. There was more uniformity in the genetic makeup of U.S. corn; this made it susceptible to a blight that rapidly spread in the 1970-72 period. Higher pesticide and fertilizer use led to more runoff to water used for recreation and household use. The book *Silent Spring* gave notice of these costs external to the farms and set the stage for higher levels of regulation implemented by the Environmental Protection Agency (EPA). Formed in 1970, the first major pesticide action of EPA banned all uses of DDT and several other organochlorine insecticides. Development and adoption of pesticides changed from an open market industry to one with pre-market assessment for food, water, environmental and worker safety. Clearly, higher incomes were associated with more recreation time and higher demand for safety and environmental quality.

The Biotechnology Phase

The next major commercial development was the discovery, refinement and field testing of agricultural biotechnology. This transformation took place in the 1980s and 1990s, but did not reach commercialization until 1994. A tomato variety with longer shelf life was introduced in 1994. Herbicide-tolerant canola became available in 1995 (in Canada), and limited sales of Bt corn began in 1996. By 1998, Bt corn, potatoes and cotton (making plants toxic to corn borers, potato beetles and budworms, respectively) were available, as were herbicide-tolerant soybeans, corn and cotton. Some varieties possessed multiple or *stacked genes*, providing both herbicide tolerance and insect resistance. These transgenic technologies were developed over long periods by private firms who then patented the modified seeds. The research and development costs are either included in seed prices or else an additional *technology fee* is charged to the farmers by the patent holder.

Clearly the farmer demand for the crop biotechnologies was high in North America because diffusion across farms reached about 70 percent for canola, 60 percent for soybeans and cotton and 30 percent for corn within 3-4 years of commercialization. Farmer benefits came in the form of about 11 percent higher yields and a 72 percent reduction in insecticide applications for Bt cotton farmers in the Southeast. Similar gains have been found after several years of use of Bt cotton in Australia and China. European cornborer suppression led to about 8 percent higher corn yields in 1997, but resulted in lower gains in 1998 and 1999 when smaller insect populations were present. Some soybean producers experienced lower yields using herbicide-tolerant varieties in the first two years, but this was offset by reductions in herbicide expenditures and labor and management time with the simplified weed control program involving the transgenic seeds. Each of the technologies performed better as it was introduced into more local varieties.

Some of the benefits of the new technologies are indirect or occur off the farm. These benefits flow from reduced pesticide use, relief and prevention of insecticide and herbicide resistance, preservation of natural enemies of insects, and suppression of mycotoxins in feed. Herbicide tolerant crops enabled use of herbicides that in most cases are less likely to migrate to surface waters than do alternative herbicides. Often the new herbicide use patterns tend to encourage the use of low-tillage systems with less soil siltation to nearby waterways.

Considerable controversy has developed over whether pesticide use has risen or fallen when Bt or herbicide-tolerant crops are grown. In some cases, the volume of pesticides used declines, and in others more safe pesticides (less toxic, less persistent) are used. For Bt cotton the primary saving has been reduced dependence on synthetic pyrethroids, and this is critical in areas where cotton insects are already or could become resistant to the pyrethroids. A farmer survey in the Southeast shows that replacing resistant insecticides is the leading cause of adoption of Bt cotton. Cotton farmers also like the way Bt saves natural predators of various insects as part of their Integrated Pest Management programs. Bt corn has been shown to suppress toxins such as aflotoxins that can be dangerous to livestock and humans. Additionally, one of the main benefits of Bt corn is that it serves as a type of yield insurance for farmers since populations of cornborers are difficult to detect and treat on an as-needed basis.

Some consumers, organic farmers and environmentalists are strongly opposed to genetically modified (GM) crops and foods. European, Japanese and other higher income groups have expressed concerns about food safety and environmental quality from the production of transgenic crops. Considerable media attention was given to potential harm to butterflies feeding near Bt cornfields following a laboratory feeding study showing that Bt was dangerous to butterfly larvae if they are exposed to it. Organic farmers are worried about drift of pollen from nearby GM fields and development of resistance to sprayable Bt, one of their most commonly used insecticides. Migration of herbicide tolerance to weedy relatives of canola has been found, and Bt will damage some beneficial insects (ladybugs, lacewings).

Some groups are more worried about the dominance of a few multinational firms in the seed and food industries. The U.S. Department of Justice refused to approve the merger of Monsanto and Delta and Pineland (the largest U.S. cottonseed supplier) on antitrust grounds. Several major food processors (Gerbers, Nestle, Seagram, McCain, Frito- Lay) have refused to accept biotech produce. European imports of U.S. corn fell drastically from 96/97 to 97/98. Surveys of North American consumers show that about 80 percent consider food safety as “very important” relative to other safety concerns. Much less is known about the acceptance of GM produce by lower income consumers in developing countries.

As consumer and environmental protests spread from Europe to other countries, the uncertainty of GM crop adoption has led to less financial support of research and deployment of biotech crops. Several of the major agribusiness firms involved with biotechnology – including Monsanto and Novartis – have announced that they are separating their agricultural operations from other parts of their business and cutting employees. European scientists have claimed that biotech specialists are leaving agricultural research for the more lucrative pharmaceutical field. The prospects are not as bright as they were a few years ago for GM researchers, investors and innovators in agriculture.

The Future for Genetically Modified Technologies

Developing Country Prospects

There is speculation that an important set of biotechnology developments will play out in the developing country arena. First, the insect and weed control technologies previously described have direct application to pest problems in the same and similar crops in developing countries. For example, China may have planted as much as 2.5 million acres of Bt cotton in 1999, and use of herbicide-tolerant soybeans is increasing in Argentina and Brazil. Critical to getting these products widely deployed are institutional changes such as biosafety testing, plant breeding to include the technologies into local varieties, and enforcement of property rights of both the biotech traits and the local germplasm.

Secondly, and perhaps more importantly, there are some promising new biotech products in the late stages of field testing that have direct application to the nutrition problems of poor people in developing nations. The most immediate products are *golden* rice (high in vitamin A), high-iron rice, and enriched oil seed crops (rapeseed). These foods have promising nutrition benefits for small farmers, but they may also be grown for export in other parts of the world. For example California rice growers are considering producing the new rice products for export within two years. In addition, the genes that make plants more tolerant to salt and high aluminum have been isolated and incorporated into plants. These problems are extensive in developing countries, and overcoming them would boost food productivity.

Per Pinstup-Andersen, Director-General of the International Food Policy Research Institute argues that more resources are needed to bring biotechnology to developing countries. He indicates that except for limited research in rice, cassava and bananas, there is little research currently directed at the inadequate diets of poor people in developing countries. Both developing country research funds and money to induce private firms or international research organizations to provide appropriately tailored biotechnology will be needed. Currently these countries are only investing about one-half of one percent of agricultural output to research, compared to about four times that level in developed countries. In some cases private seed companies will have a key role to play, but this may not happen if protection of patent holders and local property rights to germplasm are not provided.

Developed Country Prospects

The progress in biotechnology in developed countries in the next 5-10 years will depend upon institutional changes, investments, and consumer demand. Some of the research output is already in the pipeline. Field tests are underway for a plant insecticide to control corn rootworms, the pest target with the largest insecticide expenditure in the U.S. Also, there are tests of a second type of Bt that may help prevent resistance development to the first Bt cotton. Animal feeds may be modified by inclusion of genes for more oil content or lower phytate content. The former may increase feed efficiency, and the latter technology is being introduced to lower odor levels associated with animal manure. The North American science community seems to be strongly supportive of finding technologies in crop and animal agriculture that are both safe and efficient.

The demand for genetically modified foods is likely to depend on refined assessments of risks to human health and the environment. When adopted, the Biodiversity Protocol (Montreal, January, 2000) could negatively influence exports of GM commodities. The protocol does not require separation of bulk commodities from non-GM products, but does require the label "may contain" genetically modified organisms (GMOs). Countries can decide whether to import these commodities based on a scientific risk assessment and socioeconomic factors such as the impact on local farmers. The protocol also states that the agreement "shall not be interpreted" as changing the rights and obligations of countries under other international pacts such as the World Trade Organization. Since this is an environmental agreement, there are more stringent rules for importation of living GMOs such as seeds and fish stocks than bulk commodities.

Pro and con discussion on genetically modified products can be followed at several web sites:
Pro: ificinfo.org; bio.org; and reasonmag.com.
Con: greenpeace.org, purefood.org and biotech-info.net.
More scholarly information is found at gophisb.biochem.vt.edu and acsh.org.

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