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Consumer Effects of Biotechnology

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What Is Biotechnology?

An exact definition of biotechnology is not possible, because of its diversity and its similarities to old technologies. Most scientists include these practices when defining "biotechnology":

- Use of tissue culture to reproduce organisms in controlled settings
- Use of microbes to produce chemicals and special agents
- Use of genetic engineering to control the traits of organisms

Biotechnology is not a product. It is a set of techniques for enhancing existing products and production practices.

Effects of Biotechnologies

Many new biotechnologies will:

- Reduce food costs
- Improve food quality
- Enhance food safety

Only a few will:

- Generate new consumer products
- Revolutionize existing food products

Consumers are likely to be largely unaware that products consumed have a biotechnology component.

Expectations regarding biotechnology have cycled through booms and busts, but biotechnology appears to be growing rapidly. Over time, biotechnology research has moved from university laboratories and small companies to large industrial companies, which are prepared to use the products and processes of biotechnology to improve their production methods and to expand product lines.

I hope to identify here some of the issues and tradeoffs between concerns raised by biotechnology and the problems people hope biotechnology will solve. Recognizing both the visionary promises of agricultural bounty flowing from biotechnology and the fears of catastrophic environmental consequences, I will sketch out the possible economic effects of biotechnology by relying partly on how past revolutions in agriculture have affected society. It takes visionaries of bounty to achieve progress, but it also takes visionaries of catastrophe to protect us from ourselves.

Despite its lack of a clear definition and its subtle revelation to consumers, in 20 years biotechnology will still appear revolutionary because its cumulative effects will have wrought major changes in agriculture and the food processing industry.

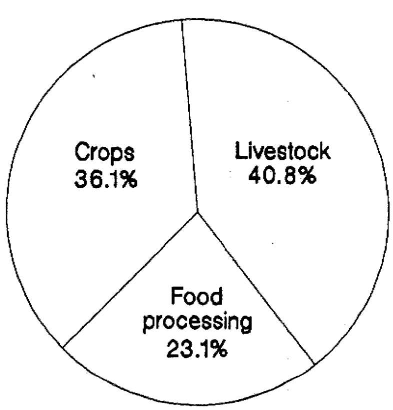
The Direction and Pace of Biotechnology Advance

Biotechnology is a reality in the commercial marketplace and is likely to continue to grow.

Most of the products of agricultural biotechnology that reach consumers will be similar to existing products, by design. About 60 percent of the biotechnology advances cited in the food processing sector have represented new food ingredients, nearly 25 percent better food processing, and less than 20 percent new and improved foods (FDA, 1988).

Consumer effects may result from biotechnology applications in agriculture, veterinary medicine, and food processing. Forty-one percent of biotechnology research and product development activities in 1988 were in livestock, 36 percent in crops, and 23 percent in food processing (fig. 1). Despite the low percentage for food processing, 62 percent of the large established firms using biotechnology were involved in food processing. This may indicate greater biotechnology activity in food processing than is measured by simply counting the activities of the 321 firms involving biotechnology.

Figure 1
Biotechnology activity in agriculture, 1988



Source: BioScan: The Biotechnology Corporate Directory Service, Oryx Press, New York, Dec. 1988 Supplement.

Microbes: The basis of many advances in biotechnology

Because microbes are among the simplest organisms, most of the earliest applications of genetic engineering involve microbes. Microbes are the basis of fermentation processes in the food processing sector. Plant resistance to caterpillar pests occurs through incorporation of the gene coding for the toxin in the microbe *Bacillus thuringiensis* (Bt).

The ability to manufacture commercial quantities of existing and slightly modified microbes under controlled conditions is the key biotechnology aspect of microbe use. Using microbes as bioreactors was patented in the United States in 1956, but commercial use generally requires improved efficiency of production possible through genetic engineering (Lawrence, 1988). For example, with genetic engineering, microbes can be used in a contained industrial setting to produce insect toxins or can be released into the environment to fix nitrogen or to control insects.

Like traditional plant breeding, current efforts depend heavily on finding naturally occurring organisms with useful characteristics. These useful characteristics can then be incorporated into other organisms that more efficiently produce the desired substance or are better suited to the environment in which they must work. Tobacco resistance to the herbicide Atrazine, for example, is based on the transfer of genetic material from *Agrobacterium* (Jaworski, 1988).

Biotechnology Promises Enhanced Pest Resistance and Crop Quality

Consumers may find vegetable, fruit, and other food crops crisper, sweeter, and more flavorful, and production costs may be lower for both food and field crops.

Biotechnology activities in crop production are spread across an array of improvements at 116 firms. The largest shares of activities are in improved crops (19 percent), propagation techniques (17 percent), genetic engineering (13 percent), biological herbicide and insecticide controls (13 percent), pesticide and disease resistance (12 percent), and nitrogen fixation and other soil enrichments and inoculants (7 percent) (fig. 2).

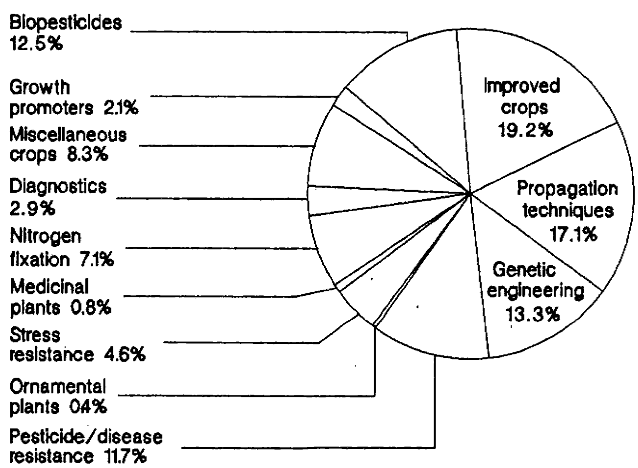
Biotechnology promises enhanced resistance to diseases, pests, and herbicides in major field crops. For biotechnologies applied to feed grain and forage crop production, consumer effects will almost exclusively be cost reductions. Feed grain costs and prices are expected to fall and, hence, meat and dairy production costs as well.

The use of genetic engineering to control pests in plants is headed in two directions. One goal is to enhance pest resistance in plants. Less chemical use may reduce residues in foods and would be a consumer food safety advantage. A second goal is to increase crop tolerance to herbicides, allowing broader applications of these chemicals. Although these new crop varieties might carry more herbicide residues, this is not necessarily the case. For example, glyphosate-resistant plants may reduce the need for other chemicals that pose greater environmental and food safety concerns.

Many new crop varieties are being tested, but the market effects will be gradual. New plant varieties will exhibit resistance to some pests, but other pests will require traditional chemical control technologies. Enhanced nitrogen fixation in alfalfa will reduce nitrogen fertilizer requirements and may ease nitrate contamination of groundwater. The bigger payoff, nitrogen fixation in corn and grains, appears further off, partly due to economic considerations. Nitrogen fixation competes with grain development for available plant nutrients. The savings in costs of nitrogen fertilizer do not appear to make up for lower yields (Johnson and Sasson, 1986). As an alternative, nitrogen-fixing bacteria that reside in the soil are under development.

Other potential crop improvements may more noticeably affect food products. These effects include, for soybean oil, longer shelf life and less saturated fat through genetic alterations in oilseeds (experimental soybean strains have been released), and crisper, sweeter, and less stringy varieties of carrots, celery, and other vegetable crops. Several biotechnology companies are developing higher solids tomatoes, potatoes, and onions to reduce processing costs (Hayenga, 1988). Significant improvements in plants that affect yield and stress tolerance appear to be further off. Advances will require detailed knowledge of the genetic structure of field crops and, for cereal crops, development of efficient methods of tissue culture and plant regeneration (Johnson and Sasson, 1986 and Goodman, et al., 1987). Some recent advances have improved the outlook for cereal crops (Cocking and Davey, 1987).

Figure 2
Biotechnology: Crops



Source: BioScan: The Biotechnology Corporate Directory Service, Oryx Press, New York, Dec. 1988 Supplement.

Biotechnology in Veterinary and Livestock Products Will Have Broad Effects

Many of the biotechnology advances in livestock agriculture are directed toward better diagnosis, control, and treatment of animal diseases and pests.

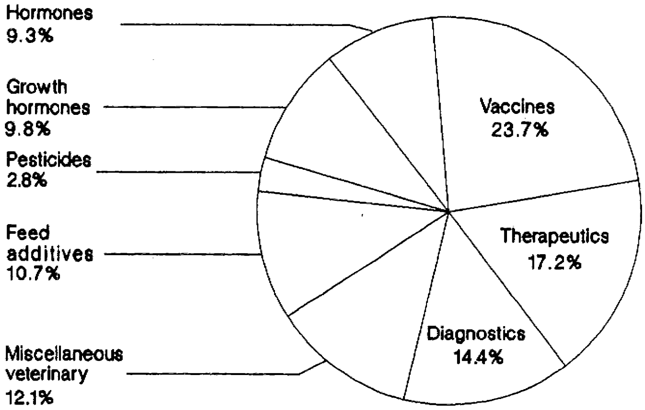
Biotechnology activities at the 131 firms in veterinary and livestock production totaled 24 percent in vaccines, 17 percent in therapeutics, 14 percent in diagnostics, 11 percent in feed additives, 10 percent in growth hormones, and 9 percent in fertility and other hormones (fig. 3).

Animal growth hormones are considered a likely early agricultural biotechnology product. However, their biotechnology component is largely invisible to the consumer. Pork produced with porcine growth hormone (pGH) will be leaner, underscoring a current trend toward leaner meats. Breed selection and diet can generate leaner pork, as has been the tradition in Europe. By increasing feed efficiency, pGH will allow farmers to produce lean meat without giving up fast, efficient weight gain.

Hormonal preparations that induce cows to superovulate, combined with embryo transfer, greatly increase the number of offspring from cows with superior genetic capability. Further developments are aimed at extending the technique to other meat animals. Some disease treatments may also reduce the chance of consumer product contamination. For example, a biotechnology drug near commercialization is effective against a significant share of mastitis cases in dairy cows. This drug leaves no residue in the milk, which permits milk to be marketed without delay.

The complexity of genetic engineering of animals has limited the amount of private research activity in this area. Transgenic animals are not likely to be commercially viable for at least a decade. Scientists are working to produce viable transgenic animals that can reproduce, but there is yet little ability to control and improve their characteristics.

Figure 3
Biotechnology: Livestock



Source: BioScan: The Biotechnology Corporate Directory Service, Oryx Press, New York, Dec. 1988 Supplement.

Biotechnology in Food Processing Enables Manufacture of Food Product Characteristics

The increasing ability to manufacture foods from basic components will compete with conventional onfarm production.

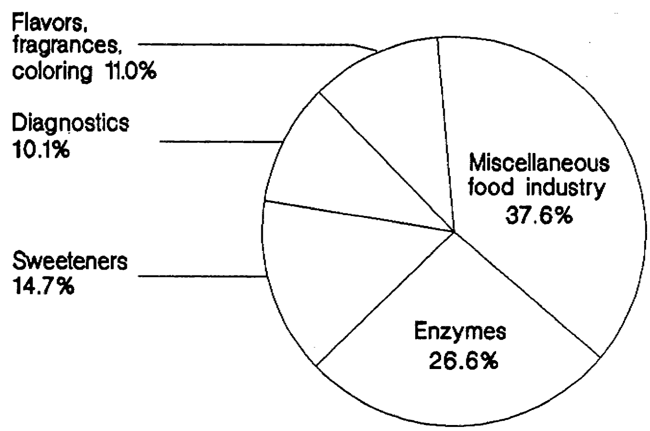
The most significant biotechnology activities at the 74 food processing firms using biotechnology are in research on food enzymes (27 percent); sweeteners (15 percent); flavors, fragrances, and coloring (11 percent); and better detection of food contaminants (10 percent) (fig. 4). Another 38 percent of food processing firms have miscellaneous research and product development activities, including process-oriented improvements such as ultrafiltration and protein synthesis.

Many near-term advances in the food processing sector involve enzyme technology and fermentation. For example, a recent biotechnology advance will help cheese producers improve the availability and lower the cost of high-quality rennet (Lawrence, 1988). A host of artificial flavors and fragrances (banana, butter, peach, nut), thickeners, emulsifiers, and proteins (proline, lysine, leucine) can be produced by microbes through fermentation or enzyme conversion processes. Cell culture techniques to produce "natural" vanilla, grape, and banana flavors from plant cells may be commercialized in the next few years. These advances will contribute to the list of ingredients in prepared foods, a list that has been growing for the past two or three decades.

At one time, scientists and food technologists would have hailed the ability to manufacture these food product characteristics as moving us closer to the day when our entire diets could be manufactured from a few basic raw materials with textures, flavors, sweeteners, carbohydrates, and proteins added to meet taste and nutritional requirements. However, we have become more aware of our limited understanding of dietary requirements and the biochemical characteristics of naturally occurring food components.

Biotechnology developments in the food processing sector, like those in the farm sector, are headed in diverse directions. The ability to better and more cheaply synthesize flavors and food characteristics will face competition from reduced costs of crop production, with advances in biotechnology driving both forces. Commercially produced protein supplements and food additives will face competition from crops with higher protein content. Reductions in chemical residues resulting from development of disease- and pest-resistant varieties may be balanced by possible increases in residues due to development of chemical-resistant varieties. As evidence of the crosscurrents of the revolution, consider that biotechnology can make sustainable, lower input agriculture more economical but at the same time raise new environmental concerns. Biotechnology, like the computer, is neither good nor bad and is only potentially useful, depending on how it is used.

Figure 4
Biotechnology: food processing



Source: BioScan: The Biotechnology Corporate Directory Service, Oryx Press, New York, Dec. 1988 Supplement.

Biotechnology Raises Complex and Sensitive Regulatory Issues

Biotechnology blurs the line between chemical agriculture and organic approaches.

The health and safety concerns associated with agricultural biotechnology are being expressed in regulatory procedures, standards, and safeguards, with the U.S. Department of Agriculture (USDA), the Environmental Protection Agency (EPA), and the Food and Drug Administration (FDA) sharing responsibility.1/ The need for regulation differs by broad categories of biotechnology products. Genetically engineered organisms that could become pathogenic or toxic to humans, multiply in the environment, lead to widespread human exposure to the pathogen or toxin, and be difficult or impossible to control or eradicate have generated the most concern. Engineered organisms that exhibit superior survival characteristics, which could lead them to outperform naturally occurring organisms and to seriously upset the ecological balance, are probably the next level of concern. The result may be a changed environment with fewer wild species, or it could include specific economic control costs. Existing crops could become weeds, or the improved crops' characteristics could transfer to weeds, thus increasing their vigor.

Such effects are difficult to ensure against because it is difficult to predict a new organism's survival characteristics. For both human health considerations and ecological disturbances, release into the open environment is of highest concern. For this reason, the use of living organisms in agriculture has received increased scrutiny. For microbes used in industrial production of agents that are then used in agriculture or food production, efforts can be made to securely confine the living organisms to avoid release into the environment. Larger organisms may also be easier than microbes to confine. The argument is made that transgenic plants and animals are, in principle, no different than the products of traditional plant- and animal-breeding programs that have produced improved animals and disease- and pest-resistant crops (Goodman, et al., 1987).

Substances produced by biotechnology techniques that are then used as food ingredients, veterinary products, soil conditioners, or pesticides are a somewhat lower level of concern because they fit within the existing regulatory framework. These substances offer no greater (and no less) potential threat to consumer health and safety than similar products produced through nonbiological means. Existing regulatory procedures for toxicological testing can be applied to these substances, just as they are for chemically produced agents.

While the regulatory system is prepared to evaluate new ingredients and chemical residues, some have argued that the system is inadequate for basic food changes resulting from genetic alterations of plants and animals. Ames and Gold review studies that show natural pesticides found in vegetables, such as mushrooms, parsley, basil, parsnips, celery, figs, mustard, pepper, and fennel, and in citrus oil, to be carcinogenic in laboratory animals under very high exposures. Human consumption of these vegetables has not been linked to any health concerns, and these vegetables are generally considered part of a balanced diet. Both traditional plant and animal breeding and biotechnology techniques can enhance the level of these and other naturally occurring biochemical components of plant and animal food products, which remain untested and are presumed safe. At high-enough levels, these components could pose health concerns. In a recent case, workers handling celery developed severe skin rashes. A conventionally bred, pest-resistant celery variety containing a tenfold increase in a naturally occurring substance was found to have caused the rashes (Ames and Gold). Such changes in the biochemical components of plants are not subject to the same degree of review as are pesticides used in agriculture. The potential risks posed by

> The example of Bt use to control insects demonstrates how biotechnology has blurred the distinction between chemical pesticides and plant resistance. Unlike inorganic chemicals, Bt is a naturally occurring toxin that has been extracted and made available as a commercial pesticide. As such, Bt toxin was subject to EPA regulatory approval, as are other chemical pesticides. Ongoing research has incorporated Bt into crops where it lives and produces the substance that makes the crop resistant to caterpillar pests. While the substance is the same or similar to the pesticide that must be sprayed on the crop, it is as yet unclear whether such altered crops would be subject to the same regulations as the pesticide.

1/ GAO, 1988; OTA, 1988; Roberts and van Ravenswaay, 1988; and Fleisher, 1989 provide a discussion and review of regulatory issues.

new crop development, chemical use, and the need to assure adequate and affordable food supplies pose a difficult set of tradeoffs for regulation of agricultural technology.

Some scientists have argued for regulation directed toward any product produced using biotechnology techniques (Fleisher). This might be considered a process-based regulatory strategy. The argument for such a strategy is that biotechnology can so dramatically change plants and animals that new varieties developed through breeding biotechnology techniques are a greater threat than those derived through conventional techniques. In fact, the regulatory system continues to evolve as new issues are raised by biotechnology. The procedures for field testing of new organisms, for example, have become clearer, and public concern has been reduced, since the first ice-minus bacteria tests in California, which were the first-ever officially approved field tests using genetically engineered organisms.

Consistent with the recommendations of the National Academy of Sciences, Federal regulation has focused on product-based regulations. This allows biotechnology products to fall generally within the scope of the existing regulatory authority of USDA, FDA, and EPA that assesses the efficacy and risks of new products. As a result, the FDA has determined that bovine growth hormone (bGH) is no threat to human health, partly because the growth hormone has been naturally produced by cattle, the milk has been indistinguishable from the naturally occurring product, and consumers have always consumed small amounts of the growth hormone. FDA approval awaits demonstration of bGH efficacy rather than demonstration that it is safe (Flemming and Kenney).

Biotechnology safeguards are designed to protect the American public from three concerns:

- The consumption of food products that contain agents with potentially detrimental effects on human health and safety;
- Threats from accidental release into the environment of genetically altered organisms; and
- The broader, unintended environmental effects of deliberate release of organisms and products of biotechnology into the environment.

The Economic Effects of Biotechnology Will Likely Be Significant but Felt Gradually

Biotechnology will be necessary to sustain the rates of productivity gain and food cost savings we have seen in the past.

The diversity of biotechnology products and the uncertainty about the near-term prospects of these products make it virtually impossible to provide a comprehensive forecast of the economic effects of biotechnology. Biotechnology's potential economic effects can be understood by examining:

- The cost components of agriculture and food processing as a share of consumer costs;
- Economic assessments of early animal growth hormones; and
- The effects on the U.S. economy of sustained technical advance in the farm and food processing sector.

Together, these approaches provide some broad bounds on the economic effects we can expect from biotechnology advance. While biotechnology will have significant economic benefits, these benefits will bring rates of productivity gain similar to those agriculture has experienced in the past.

Agriculture and Food Costs

The farm commodity component of consumer food costs has fallen steadily, accounting for 25 percent of overall consumer food expenditures in 1988 (Dunham, 1989). A significant change has been an increase in food consumed away from home, which accounts for nearly 40 percent of consumer food expenditures. But even for food consumed at home, the farm value share fell from near 50 percent in 1950 to 30 percent in 1987. Productivity improvements in the processing and distribution sector have thus become increasingly important compared with those in the commodity production sector. A more detailed look at where the food dollar goes shows that food processors and farmers, the food production components directly affected by biotechnology, account for 61 cents of every dollar spent for food at home (fig. 5). Retailing, wholesaling, and transportation account for 39 cents. The farm and food processing share is 31 cents for food eaten away from home.

Imagine a major breakthrough in biotechnology that instantly reduced farm or food processing costs across the entire sector by 10 percent. If these declines were fully transmitted to consumers, the price of food eaten at home would decline by only about 3 percent. Total costs for food eaten both at home and away would decline by about 2.5 percent. No single biotechnology will reduce costs across the entire farm or food processing sector. Instead, specific technologies will affect individual components of farm or food processing costs.

As an example, consider resistance to pests. Total pesticide expenditures, including those on herbicides, insecticides, and fungicides, were $4.5 billion in 1987, but were less than 4 percent of total production expenses (ERS, 1988). Development of plant resistance to caterpillars, for instance, through incorporation of the Bt toxin, could replace only a component of insecticide expenditures, making the aggregate cost reduction much less than 1 percent. Somewhat less labor and machinery may be required as well because there would be no chemical agent to apply and, if pest resistance is more effective in preventing early damage, yields may increase slightly. However, insect-resistant seed is likely to be more expensive as companies recover development costs. Patent protection will allow companies to retain as profits some productivity benefits of new biotechnologies. This will lead to consumer benefits being phased in only gradually as farmers adopt the technologies and effective patent protection expires (Fleisher).

Fertilizer costs are also about 4 percent of production expenses. Various developments aimed at nitrogen fixation or improved nutrient uptake in plants could reduce fertilizer requirements. But, even complete elimination of fertilizer expenditures would, if fully passed through to consumers, reduce consumer food costs by only about 1 percent.

In food processing, any food ingredient or production process is a small component of processing costs. Some new biotechnologies may, however, spread across several sector components. Ultrafiltration techniques that can remove water from liquids without altering flavor, and at less energy costs than existing processing, could affect milk and juice markets by reducing handling, storage, and transportation costs (Flemming and Kenney).

The Case of Growth Hormones

Animal growth hormones are an important first case for a major new agricultural biotechnology. Rather than causing modest cost reductions, the technology was portrayed as "too good:" the entire structure of dairy farming would be threatened, and the country would be awash in milk. Successive analyses have demonstrated these early projections to be overly optimistic about the technology, and, even then, they likely failed to examine fully the moderating economic adjustments. Early projections of increases of up to 40 percent in yields have been scaled back to 20-30 percent during part of the lactation, perhaps 15 percent over the full lactation under experimental conditions, with guesses that in farming situations, the gain may be 10 percent or less (Kuchler and McClelland). The hormone will also be an additional expense. There will be costs of administering the hormone, and additional feed, and particularly protein supplements, will be required to achieve yield gains. Thus, the productivity improvement, accounting for all inputs, will be even less than the 10-percent yield improvement.3/

Differential adoption among regions or among large versus small farms could contribute to regional production shifts and could favor large farms. But, current production costs show the Pacific region, dominated by large Californian dairy operations, has more than a 15-percent production cost advantage compared with the traditional dairy areas, the Northeast and upper Midwest. Regional shifts have been occurring, farms have been getting larger, and these trends will continue with or without bGH. The growth hormones and many of the biotechnologies are not obviously biased against small farms or a particular region. The lesson, as is frequently the case with new technology, is that the actual commercial performance rarely lives up to the early promise. In general, it appears more likely that the biotechnology products will battle for commercial success rather than cause massive structural adjustment.4/

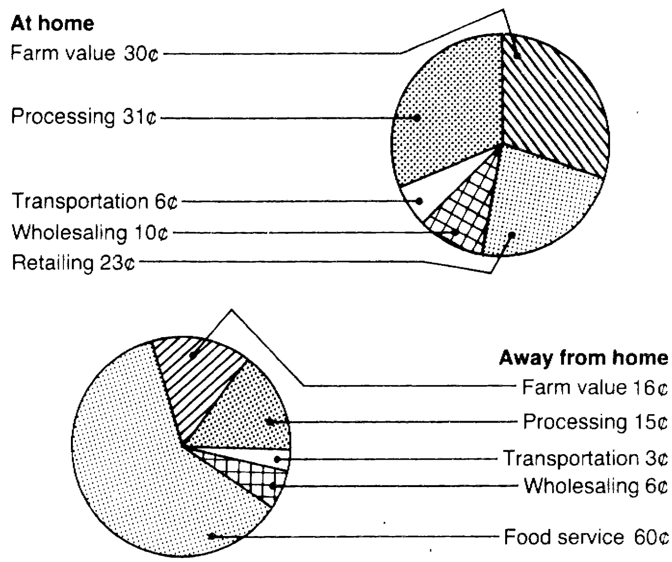
Consumers, the Economy, and Competitiveness

The revolutionary nature of biotechnology indicates that many of the future technology gains will have a biotechnology component. Several major technological advances have occurred to sustain agricultural productivity growth of about 2.2 percent per year, on average, since 1947. Productivity in the food processing sector has grown less, at 0.7 percent per year, on average, since 1949. Individual studies of biotechnology products frequently indicate no significant increase in the productivity improvement rate for a producing sector.

Over the next 25 years, biotechnology will have few competitors for better and less expensive production processes. While it will not be the only force for productivity growth in the next 25 years, biotechnology will be an important component of whatever productivity growth we experience. Everyone gains from productivity growth. Failure to maintain productivity gains will erode agricultural exports, and a closed economy raises food prices and consumer losses.

Figure 5

Where the food dollar goes at home and away



1988 data.

3/ Larson and Kuchler, 1989, describe the relationship between potential yield increases and the economic benefits of the technology.

4/ Fallert, et al., find that under some milk scenarios, using bGH would be uneconomical.

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