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Technological Abundance for Global Agriculture: The Role of Biotechnology

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TECHNOLOGICAL ABUNDANCE FOR GLOBAL AGRICULTURE: The Role of Biotechnology⁸

Calestous Juma

Introduction

Science and innovation have always been the key forces behind agricultural growth in particular and economic transformation in general. More specifically, the ability to add value to agricultural production via the application of scientific knowledge to entrepreneurial activities stands out as one of the most important lessons of economic history. The Green Revolution played a critical role in helping to overcome chronic food shortages in Latin America and Asia. The Green Revolution was a result of both the creation of new institutional arrangements aimed at using existing technology to improve agricultural productivity, as well as new scientific breakthroughs leading to superior agricultural inputs, particularly improved strains of wheat and rice.

In the wake of the recent global economic crisis and continually high food prices, the international community is reviewing its outlook on human welfare and prosperity. Much of the current concern on how to foster development and prosperity in developing countries reflects the consequences of recent neglect of sustainable agriculture and infrastructure as drivers of development. But all is not lost. Instead, those developing countries that have not yet fully embraced agricultural technology now have the chance to benefit from preexisting scientific advances in agriculture, particularly in biotechnology. Areas of the developing world lagging in the utilization and accumulation of technology have the ability not only to catch up to industrial leaders in biotechnology, but also to attain their own level of research growth.

The Critical Role of Biotechnology

Biotechnology—technology applied to biological systems—has the promise of leading to increased food security and sustainable forestry practices, as well as improving health in developing countries by enhancing food nutrition. In agriculture, biotechnology has enabled the genetic alteration of crops, improved soil productivity, and enhanced natural weed and pest control. Unfortunately, such potential has largely been left untapped by many developing countries, particularly in Africa.

In addition to increased crop productivity, biotechnology has the potential to create more nutritious crops. About 250 million children suffer from vitamin A deficiency, which weakens

⁸ Article adapted from *New Harvest: Agricultural Innovation in Africa*, Oxford University Press, 2010, “Chapter 2: Advances in Science, Technology, and Engineering.”

their immune systems and is the biggest contributor to blindness among children.⁹ Other vitamins, minerals, and amino acids are necessary to maintain healthy bodies, and a deficiency will lead to infections, complications during pregnancy and childbirth, and impaired child development. Biotechnology has the potential to improve the nutritional value of crops, leading to both lower health care costs and higher economic performance (because of improved worker health).

Tissue culture has not only helped produce new rice varieties in Africa and South Asia but has also helped the Western Hemisphere, East Africa, and South Asia produce pest- and disease-free bananas at a high rate. The method's ability to rapidly clone plants with desirable qualities that are disease-free is an exciting prospect for current and future research on improved plant nutrition and quantities. Tissue culture has also proved to be useful in developing vaccines for livestock diseases, especially the bovine disease rinderpest. Other uses in drug development are currently being explored.

In East Africa, tissue culture of bananas has had a great impact on the region's economies since the mid-1990s. Because of its susceptibility to disease, bananas have always been a double-edged sword for the African economies such as that of Uganda, which consumes a per capita average of one kilogram per day. For example, when the Black Sigatoka fungus arrived in East Africa in the 1970s, banana productivity decreased by as much as 40 percent. Tissue culture experimentation allowed for quick generation of healthy plants and was met with great success. Since 1995, Kenyan banana production has more than doubled, from 400,000 to more than one million tons in 2004, with average yield increasing from 10 tons per hectare (ha) to 30–50 tons.

Marker-assisted selection helps identify plant genome sections linked to genes that affect desirable traits, which allows for the quicker formation of new varieties. This technique has been used not only to introduce high-quality protein genes in maize but also to breed drought-tolerant plant varieties. An example of a different application of this method has been the development of maize resistant to maize streak virus. While the disease has created a loss of 5.5 million tons per year in maize production, genetic resistance is known and has the potential of greatly raising production. The uptake of genetically modified (GM) crops is the fastest adoption rate of any crop technology, increasing from 1.7 million hectares in 1996 to 134 million hectares in 2009, an 80-fold increase over the period.¹⁰

Recent increases among early adopting countries have come mainly from the use of “stacked traits” (instead of single traits in one variety or hybrid). In 2009, for example, 85 percent of the 35.2 million hectares of maize grown in the United States was genetically modified, and three-quarters of this involved hybrids with double or triple stacked traits. Nearly 90 percent of the

⁹ I. Potrykus, “Nutritionally Enhanced Rice to Combat Malnutrition Disorders of the Poor,” *Nutrition Reviews* 61, Supplement 1 (2003): 101–104.

¹⁰ C. James, *Global Status of Commercialized Biotech/GM Crops: 2009*. ISAAA Brief No. 41. Ithaca, NY: International Service for the Acquisition of Agri-biotech Applications.

cotton growth in the United States, Australia, and South Africa is GM and, of that, 75 percent has double-stacked traits.

Increasing Adoption of GM Crops

In 2009, there were 14 million farmers growing GM crops in 25 countries around the world, of whom over 90 percent were small and resource-poor farmers from developing countries. Most of the benefits to such farmers derive from cotton. For example, over the 2002–08 period, *Bacillus thuringiensis* (Bt) cotton added US\$5.1 billion worth of value to Indian farmers, cut insecticide use by half, helped to double yield, and turned the country from a cotton importer into a major exporter.¹¹

Countries once left outside, or willingly avoided genetically modified crops, are steadily joining the biotechnology revolution. In Africa, the continent where the adoption of GM crops has been the slowest, South Africa's GM crop production in corn stood at 2.1 million hectares in 2009, an increase of 18percent from the previous year. Burkina Faso grew 115,000 hectares of Bt cotton the same year, up from 8,500 in 2008. This was the fastest adoption rate of a GM crop in the world that year. In 2009, Egypt planted nearly 1,000 hectares of Bt maize, an increase of 15percent over 2008.¹²

Many of the countries that have been slow to adopt GM crops are now, by virtue of being latecomers, enjoying the advantage of using second-generation GM seed. Monsanto's Genuity™ Bollgard II® (second generation) cotton contains two genes that work against leaf-eating species such as armyworms, budworms, bollworms, and loopers. They also protect against cotton leaf perforators and saltmarsh caterpillars. Akin to the case of mobile phones, African farmers can take advantage of technological leapfrogging to reap high returns from transgenic crops while reducing the use of chemicals. In 2010 Kenya and Tanzania announced plans to start growing GM cotton in light of the anticipated benefits of second-generation GM cotton. The door is now open for revolutionary adoption of biotechnology that will extend to other crops as technological familiarity and economic benefits spread.

There is also a rise in the adoption of GM crops in Europe, which has also been slow to enjoy their benefits. In 2009, six European countries (Spain, Czech Republic, Portugal, Romania, Poland, and Slovakia) planted commercial Bt maize. Trends in Europe suggest that future decisions on GM crops will be driven by local needs as more traits become available. For example, crops that tolerate various stresses such as drought are likely to attract interest among farmers in Africa. The Water Efficient Maize for Africa project, coordinated by the African Agricultural Technology Foundation in collaboration with the International Centre for the Improvement of Maize and Wheat (CIMMYT) and Monsanto and supported by the Howard

¹¹ Ibid.

¹² Ibid.

Buffett Foundation and the Bill and Melinda Gates Foundation, is an example of such an initiative that also brings together private and public actors.¹³

This case also represents new efforts by leading global research firms to address the concerns of resource-poor farmers, a subtheme in the larger concern over the contributions of low-income consumers.¹⁴ Other traits that improve the efficiency of nitrogen uptake by crops will also be of great interest to resource-poor farmers. Other areas that will attract interest in developing new GM crops will include the recruitment of more tree crops into agriculture and the need to turn some of the current grains into perennials.¹⁵

Regulating GM Crops

Trends in regulatory approvals are a good indicator of the future of GM crops. By 2009, some 25 countries had planted commercial GM crops and another 32 had approved GM crop imports for food and feed use and for release into the environment. A total of 762 approvals had been granted for 155 events (unique DNA recombinations in one plant cell used to produce entire GM plants) for 24 crops. GM crops are accepted for import in 57 countries (including Japan, the United States, Canada, South Korea, Mexico, Australia, the Philippines, the European Union (EU), New Zealand, and China). The majority of the events approved are in maize (49), followed by cotton (29), canola (15), potato (10), and soybean (9).¹⁶

Because of pest attacks, cotton was, until the early 1990s, the target of 25 percent of worldwide insecticide use.¹⁷ Recombinant DNA engineering of a bacterial gene that codes for a toxin lethal to bollworms resulted in pest-resistant cotton, increasing profit and yield while reducing pesticide and management costs.¹⁸ Countries such as China took an early lead in adopting the technology and have continued to benefit from reduced use of pesticides.¹⁹

Although GM crops have the potential to greatly increase crop and livestock productivity and nutrition, a popular backlash against GM foods has created a stringent political atmosphere under which tight regulations are being developed. Much of the inspiration for restrictive

¹³ C. Pray, "Public-Private Sector Linkages in Research and Development: Biotechnology and the Seed Industry in Brazil, China and India," *American Journal of Agricultural Economics* 83, no. 3 (2001): 742–47.

¹⁴ R. Kaplinsky et al., "Below the Radar: What Does Innovation in Emerging Economies Have to Offer Other Low-income Countries?" *International Journal of Technology Management and Sustainable Development* 8, no. 3 (2009): 177–97. Indian entrepreneurs have figured ways of doing more with less based on the principles of affordability and sustainability: C. P. Prahalad and R. A. Mashelkar, "Innovation's Holy Grain," *Harvard Business Review*, July–August (2010): 1–10.

¹⁵ J. D. Glover and J. P. Reganold, "Perennial Grains: Food Security for the Future," *Issues in Science and Technology* 26, no. 2 (2010): 41–47.

¹⁶ James, *Global Status of Commercialized Biotech/GM Crops: 2009*.

¹⁷ A. M. Showalter et al., "A Primer for Using Transgenic Insecticidal Cotton in Developing Countries," *Journal of Insect Science* 9 (2009): 1–39.

¹⁸ D. Zilberman, H. Ameden, and M. Qaim, "The Impact of Agricultural Biotechnology on Yields, Risks, and Biodiversity in Low- Income Countries," *Journal of Development Studies* 43, no. 1 (2007): 63–78.

¹⁹ C. E. Pray et al. "Five Years of Bt Cotton in China—The Benefits Continue," *Plant Journal* 31, no. 4 (2000): 423–30.

regulation comes from the Cartagena Protocol on Biosafety under the United Nations Convention on Biological Diversity.²⁰ The central doctrine of the Cartagena Protocol is the “precautionary principle” that empowers governments to restrict the release of products into the environment or their consumption even if there is no conclusive evidence that they are harmful.

These approaches differ from food safety practices adopted by the World Trade Organization (WTO) that allow governments to restrict products when there is sufficient scientific evidence of harm.²¹ Public perceptions are enough to trigger a ban on such products. Those seeking stringent regulation have cited uncertainties such as horizontal transfer of genes from GM crops to their wild relatives. Others have expressed concern that the development of resistance to herbicides in GM crops results in “super-weeds” that cannot be exterminated using known methods. Some have raised fears about the safety of GM foods to human health.²² Other concerns include the fear that farmers would be dependent on foreign firms for the supply of seed.

The cost of implementing these regulations could be beyond the reach of many low-income countries.²³ For example, in Africa such regulations have extended to many countries, and this tends to conflict with the great need for increased food production. As rich countries withdraw funding for their own investments in agriculture, international assistance earmarked for agricultural science has diminished.²⁴

In June 1999, five European Union members (Denmark, Greece, France, Italy, and Luxembourg) formally declared their intent to suspend authorization of GM products until rules for labelling and traceability were in place. This decision followed a series of food-related incidents such as “mad cow disease” in the UK and dioxin contamination in Belgium. These events undermined confidence in regulatory systems in Europe and raised concerns in other countries. Previous food safety incidents tended to shape public perceptions over new scares.²⁵ In essence, public

²⁰ R. Falkner, “Regulating Biotech Trade: The Cartagena Protocol on Biosafety,” *International Affairs* 76, no. 2 (2000): 299–313.

²¹ L. R. Ghisleri et al., “Risk Analysis and GM Foods: Scientific Risk Assessment,” *European Food and Feed Law Review* 4, no. 4 (2009): 235–50.

²² T. Bernauer, *Genes, Trade, and Regulation: The Seeds of Conflict in Food Biotechnology*. Princeton, NJ: Princeton University Press, 2003. Most of the studies on the risks of agricultural biotechnology tend to focus on unintended negative impacts. But evidence of unintended benefits is emerging. See, for example, W. D. Hutchison et al., “Areawide Suppression of European Corn Borer with Bt Maize Reaps Savings to Non-Bt Maize Growers,” *Science* 330, no. 6001 (2010): 222–25.

²³ C. E. Pray et al., “Costs and Enforcement of Biosafety Regulations in India and China,” *International Journal of Technology and Globalization* 2, nos. 1–2 (2006): 137–57 ; C. E. Pray, P. Bengali, and B. Ramaswami, “The Cost of Regulation: The India Experience,” *Quarterly Journal of International Agriculture* 44, no. 3 (2005): 267–89.

²⁴ R. Paarlberg, *Starved for Science: How Biotechnology Is Being Kept Out of Africa*. Cambridge, MA: Harvard University Press, 2008, 2.

²⁵ E. van Kleef et al., “Food Risk Management Quality: Consumer Evaluations of Past and Emerging Food Safety Incidents,” *Health, Risk and Society* 11, no. 2 (2009): 137–63.

reactions to the GM foods were shaped by psychological factors.²⁶ Much of this was happening in the early phases of economic globalization when risks and benefits were uncertain and open to question, including the very moral foundations of economic systems.²⁷

Much of this debate occurred at a time of increased awareness about environmental issues and there had been considerable investment in public environmental advocacy to prepare for the 1992 United Nations Conference on Environment and Development in Rio de Janeiro. These groups teamed up with other groups working on issues such as consumer protection, corporate dominance, conservation of traditional farming practices, illegal dumping of hazardous waste, and promotion of organic farming to oppose the introduction of GM crops. The confluence of forces made the opposition to GM crops a global political challenge, which made it easier to try to seek solutions through multilateral diplomatic circles.

The moratorium was followed by two important diplomatic developments. First, the EU used its influence to persuade its trading partners to adopt similar regulatory procedures that embodied the precautionary principle. Second, the United States, Canada, and Argentina took the matter to the WTO for settlement in 2003.²⁸ Under the circumstances, African countries opted for a more precautionary approach partly because they had stronger trade relations with the EU and were therefore subject to diplomatic pressure. Their links with the United States were largely through food aid programs.²⁹

In 2006, the WTO issued its final report on the dispute; the findings were largely on procedural issues and did not resolve the root cause of the debate, such as the role of the “precautionary principle” in WTO law and whether GM foods were substantially equivalent to their traditional counterparts.³⁰ But by then a strong anti-biotechnology culture had entrenched itself in most African countries.³¹ For example, even after developing a GM potato resistant to insect damage, Egypt refused to approve it for commercial use. This resistance grew to the point that Africa ceased to accept unmilled GM maize from the United States as food aid. A severe drought in 2001–02 left 15 million Africans with severe food shortages; countries such as Zimbabwe and Zambia turned down shipments of GM maize, fearing that the kernels would be planted instead of eaten. Unlike the situation in rich countries, GM foods in developing countries have the potential to revolutionize the lots of suppliers and consumers. In order to

²⁶ L. J. Frewer et al., “What Determines Trust in Information about Food-related Risks? Underlying Psychological Constructs,” *Risk Analysis* 16, no. 4 (1996): 473–85.

²⁷ P. Jackson, “Food Stories: Consumption in the Age of Anxiety,” *Cultural Geographies* 17, no. 2 (2010): 147–65.

²⁸ S. Lieberman and T. Gray, “The World Trade Organization’s Report on the EU’s Moratorium on Biotech Products: The Wisdom of the US Challenge to the EU in the WTO,” *Global Environmental Politics* 8, no. 1 (2008): 33–52.

²⁹ N. Zerbe, “Feeding the Famine? American Food Aid and the GMO Debate in Southern Africa,” *Food Policy* 29, no. 6 (2004): 593–608.

³⁰ I. Cheyne, “Life after the Biotech Products Dispute,” *Environmental Law Review* 10, no. 1 (2008): 52–64.

³¹ E. J. Morris, “The Cartagena Protocol: Implications for Regional Trade and Technology Development in Africa,” *Development Policy Review* 26, no. 1 (2008): 29–57.

take full advantage of the many potentials of biotechnology in agriculture, Africa should consider whether aversion and overregulation of GM production are warranted.³²

In Nigeria, the findings of a study on biotechnology awareness demonstrate that although respondents have some awareness of biotechnology techniques, this is not the case for biotechnology products. Most of the respondents are favorably disposed to the introduction of GM crops and would eat GM foods if they are proven to be significantly more nutritious than non-GM foods. The risk perception of the respondents suggests that although more people are in favor of the introduction of GM crops, they do not consider the current state of Nigeria's institutional preparedness satisfactory for the approval and release of genetically modified organisms (GMOs).³³

It is important, however, to consider that farmers will not grow successful crops if prices are low or dropping. Additionally, in far too many countries complications with regulation and approval of GM crops make obtaining commercial licenses to grow certain crops difficult. In some regions, neighboring countries must often approve similar legislation to cover liabilities that might arise from cross-pollination by windblown pollen, for example. Biosafety regulations often stall developments in the research of GM crops and could have negative impacts on regional trade.³⁴

Benefits of GM Crops

For these reasons, approval and use of potentially beneficial crops are often difficult. Despite potential setbacks, however, biotechnology has the potential to provide both great profits and the means to provide more food to those who need it in Africa. Leaders in the food industry in parts of Africa prefer to consider the matter on a case-by-case basis rather adopt a generic approach to biosafety.³⁵ In fact, the tendency in regulation of biotechnology appears to follow more divergent paths reflecting unique national and regional attributes.³⁶ This is partly because regulatory practices and trends in biotechnology development tend to co-evolve as countries seek a balance between the need to protect the environment and human safety and fostering technological advancement.³⁷

³² D. Wield, J. Chataway, and M. Bolo, "Issues in the Political Economy of Agricultural Biotechnology," *Journal of Agrarian Change* 10, no. 3 (2010): 342–66.

³³ J. O. Adeoti and A. A. Adekunle, "Awareness of and Attitudes towards Biotechnology and GMOs in Southwest Nigeria: A Survey of People with Access to Information," *International Journal of Biotechnology* 9, no. 2 (2007): 209–30.

³⁴ E. J. Morris, "The Cartagena Protocol: Implications for Regional Trade and Technology Development in Africa," *Development Policy Review* 26, no. 1 (2008): 29–57.

³⁵ C. Bett, J. O. Ouma, and H. Groote, "Perspectives on Gatekeepers in the Kenya Food Industry toward Genetically Modified Food," *Food Policy* 35, no. 4 (2010): 332–40.

³⁶ D. L. Kleinman, A. J. Kinchy, and R. Autry, "Local Variations or Global Convergence in Agricultural Biotechnology Policy? A Comparative Analysis," *Science and Public Policy* 36, no. 5 (2009): 361–71.

³⁷ J. Keeley, "Balancing Technological Innovation and Environmental Regulation: An Analysis of Chinese Agricultural Biotechnology Governance," *Environmental Politics* 15, no. 2 (2000): 293–309.

Advancements in science have allowed scientists to insert characteristics of other plants into food crops. Since the introduction of GM crops in 1996, over 80–90 percent of soybeans, corn, and cotton grown in the United States today comes from GM crops. Despite their widespread use, there are limited data on their environmental, economic, and social impact.³⁸

Herbicide-resistant GM crops have fewer adverse effects on the environment than natural crops, but often at the cost of farming efficiency. The growth of most crops requires the use of toxic chemical herbicides, but GM crops utilize an organic compound called glyphosate to combat weeds. While less dangerous toxins are entering the environment, weeds are developing a resistance to glyphosate in soybean, corn, and cotton crops, reducing farming efficiency and raising prices on these goods.

GM corn and cotton have helped reduce the amount of insecticides entering the environment. Insecticides are harmful to most insects, regardless of their impact, positive or negative, on crops. Genetically engineered corn and cotton produce *Bacillus thuringiensis* (Bt) toxins, which kill the larvae of beetles, moths, and flies. New genetic hybrids are introduced frequently to reduce the threat of a Bt-resistant pest. Since 1996, insecticide use has decreased while Bt corn use has grown considerably. Although the environmental benefits are clear, GM crops pose a threat to farmers who rely on nonengineered crops. Interbreeding between crops is difficult to stop, so regulatory agencies must set clear standards on how much GM material is allowed to be present in organic crops.

The rapid adoption of GM crops seems to indicate that they offer great economic benefits for farmers. In general, farmers experience lower production costs and higher yields because weed control is cheaper and fewer losses are sustained from pests. GM crops are safer to handle than traditional chemical pesticides and herbicides, increasing worker safety and limiting the amount of time workers spend in the field. Although the supply-side benefits for farmers are clear, it is not completely understood how genetic modification affects the market value for these crops. Holding technological achievement constant, any gains tend to dissipate over time.

The United States has benefited by being among the first adopters of GM crops. In a similar vein, it is not clear what economic effects planting GM crops will have on farmers who do not adopt the technology. Livestock farmers are one of the largest customers of corn and soybean for feed and should receive the largest benefits of the downward pressure on prices from transgenic crops, yet no study has been conducted on such effects. Similarly, it is possible that the growing use of GM crops leaves many pests resistant to chemicals to ravage the fields of nonadopters, forcing them to use higher concentrations of dangerous chemicals or more expensive forms of control. In the future, new public policy will be needed to develop cost-effective methods of controlling the growing weed resistance to glyphosate.

³⁸ National Research Council. *Impact of Genetically Engineered Crops on Farm Sustainability in the United States*. Washington, DC: National Academies Press, 2010.

It is important to recognize that developing countries face a separate set of risks from those of industrialized countries. For example, new medicines could have different kinds and levels of effectiveness when exposed simultaneously to other diseases and treatments. Similarly, “new technologies may require training or monitoring capacity which may not be locally available, and this could increase risks associated with the technology’s use.”³⁹ This has been demonstrated where a lack of training in pesticide use has led to food contamination, poisoning, and pesticide resistance. In addition, the lack of consistent regulation, product registration, and effective evaluation are important factors that developing Africa will need to consider as it continues its exploration of these platform technologies. Probably the most significant research and educational opportunities for developing countries in biotechnology lie in the potential to join the genomics revolution when the costs of sequencing genomes drop. When James Watson, co-discoverer of the DNA double-helix, had his genome sequenced in 2007, the price tag was US\$1 million. A year later a California-based firm, Applied Biosystems, revealed that it had sequenced the genome of a Nigerian man for less than US\$60,000. In 2010 another California-based firm, Illumina, announced that it had reduced the cost to about US\$20,000.

Dozens of genomes of agricultural, medical, and environmental importance to countries in the developing world have already been sequenced. These include human, rice, corn, mosquito, chicken, cattle, and dozens of plant, animal, and human pathogens. The challenge facing many low-income countries and regions, most notably sub-Saharan Africa, is building capacity in bioinformatics to understand the location and functions of genes. It is through the annotation of genomes that scientists can understand the role of genes and their potential contributions to agriculture, medicine, environmental management, and other fields.

Technology monitoring, prospecting, and research

Much of the debate on the place of Africa in the global knowledge economy has tended to focus on identifying barriers to accessing new technologies. The basic premise has been that industrialized countries continue to limit the ability of developing countries to acquire new technologies by introducing restrictive intellectual property rights. But more critically, the focus on new technologies as opposed to useful knowledge hindered the ability of developing countries to create institutions that focus on harnessing existing knowledge and putting it to economic use.

In fact, the Green Revolution and the creation of a network of research institutes under the Consultative Group on International Agricultural Research (CGIAR) represent an important example of technology prospecting. Most of the traits used in the early breeding programs for rice and wheat were available but needed to be adapted to local conditions. This led to the creation of pioneering institutions such as the International Maize and Wheat Improvement

³⁹ G. Conway and J. Waage, *Science and Innovation for Development*. London: UK Collaborative on Development Sciences, 2010, 54.

Center (CIMMYT) in Mexico and the International Rice Research Institute (IRRI) in the Philippines.⁴⁰

Today, the challenge for most developing countries is not technological scarcity but rather the management of an abundance of scientific and technological knowledge. Moreover, technology assessments must now take into account social impacts, a process that demands greater use of the diverse disciplines.⁴¹ Given the high rate of uncertainty associated with the broader impact of technology on environment, it has become necessary to incorporate democratic practices such as public participation in technology assessments.⁴² Such practices allow the public to make necessary input into the design of projects. In addition, they help to ensure that the risks and benefits of new technologies are shared widely.

Conclusion

Reliance on imported technology, including GM crops, is only part of the strategy. Low-income countries are just starting to explore ways to increase support for domestic research. If low-income, developing countries intend to catch up with agricultural industry leaders, they will need to create more permissive regulatory regimes that allow for the research, development, and use of genetically modified crops. They will also need to harmonize these policies regionally, and consider joint investments in domestic scientific capacity, which will help them evaluate and adapt outside technology as well as generate new, local innovations.

⁴⁰ J. Perkins, *Geopolitics and the Green Revolution: Wheat, Genes, and the Cold War*. New York: Oxford University Press, 1997.

⁴¹ W. Russell et al., "Technology Assessment in Social Context: The Case for a New Framework for Assessing and Shaping Technological Development," *Impact Assessment and Project Appraisal* 28, no. 2 (2010): 109–116.

⁴² L. Pellizoni, "Uncertainty and Participatory Democracy," *Environmental Values* 12, no. 2 (2003): 195–224.