Suppressing Growth: How GMO Opposition Hurts Developing Nations

BY L. VAL GIDDINGS, ROBERT D. ATKINSON, AND J. JOHN WU | FEBRUARY 2016

ITIF estimates that the current restrictive climate for agricultural biotech innovations could cost low- and lower-middle-income nations up to $1.5 trillion in foregone economic benefits through 2050.

Campaigns against genetically modified organisms (GMOs), originating primarily in Europe, have created significant obstacles to the development and adoption of genetically modified crops. While the policies and practices resulting from these campaigns impose considerable costs on the economies of origin, they disproportionately hurt those nations with the greatest need for more productive agriculture—particularly the developing nations of sub-Saharan Africa. The Information Technology and Innovation Foundation (ITIF) estimates that the current restrictive climate for agricultural biotech innovations could cost low- and lower-middle-income nations up to $1.5 trillion in foregone economic benefits through 2050. In short, anti-GMO activists have erected significant barriers to the development of the poorest nations on earth.

Over the past three decades, a number of campaign groups have pressed successfully for restrictions or bans on the growth or import of crops and foods improved through biotechnology. Most recently, in October 2015, 19 European countries announced bans on growing GM crops, despite strong opposition from the scientific community.[1]

These restrictions lower farmers' productivity and raise food prices—not just in the countries where the campaigns originate, but in nations that avoid GMO crops so they can export to countries with policies banning or limiting GMOs. Experience and data show that crops improved through biotechnology provide significant benefits for farmers, and restrictions on biotech crops slow the growth of agricultural productivity. This is particularly acute in low-income nations where farmers have less ability to mechanize production and where biotech-improved seeds offer a low-priced way to boost yields and rural incomes.[2] In sub-Saharan Africa, for example, annual farm household income in 2012 was approximately $3,000.[3]

Opponents of agricultural biotechnology initially argued that GMOs would benefit only industrialized nations, and would price farmers from developing nations out of the market. These largely left-of-center opponents could thus oppose innovation without inviting the charge that they were hurting the very people they claimed to be concerned about.

But the opponents were wrong: GM seeds are even more important for farmers in developing countries than in developed nations, because the former could often ill afford other innovations that boost productivity (e.g., modern tractors, etc.), but they can afford improved seeds. This is why farmers in developing nations plant more biotech-improved seeds than farmers in industrial nations, despite massive European and advocacy group efforts to discourage them.[4] Two decades of concerted efforts led by European countries, multinational organizations like the United Nations UNEP/GEF Global Project for Development of National Biosafety Frameworks, and anti-GMO advocacy groups have denied the benefits of agricultural biotechnology and suppressed its diffusion. If not for this, the level of adoption in developing countries, particularly in Africa, which has closer trading ties with Europe, would no doubt be far higher, given the current adoption rate of GMO seeds wherever farmers do not fear export limitations. This report documents how anti-GMO rules and policies work to perpetuate underdevelopment and poverty in developing economies.

WHAT ARE "GM" AND "GMO" IN AGRICULTURE?

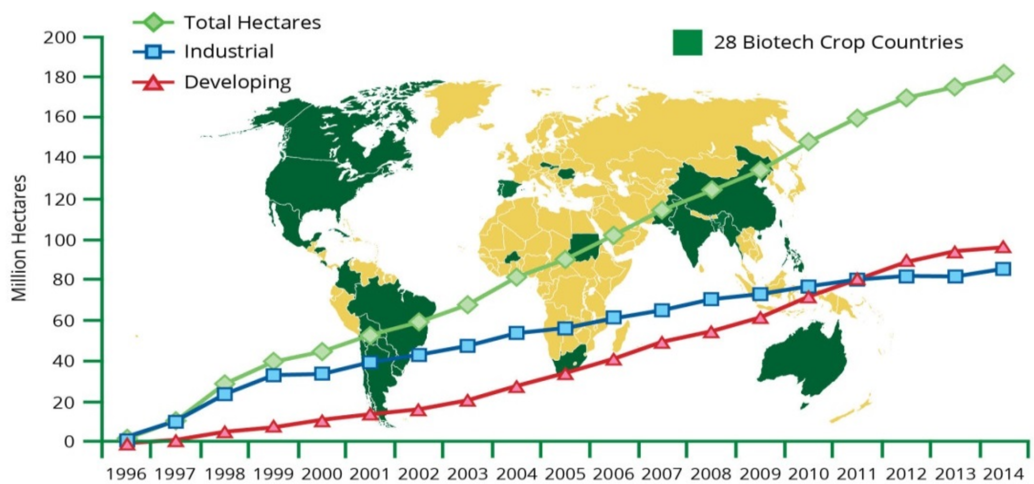
Discussions of modern agriculture loosely use the terms "GMO" and "GM," abbreviations for "genetically modified organisms" or "genetic modification." GMOs are commonly defined as plants or animals that have been "modified in a way that does not occur naturally."[5] More specifically, opponents of biotech innovations use these terms to single out organisms modified in the laboratory by transferring genes from one organism into the genome of another.

Though commonly used, such a definition seriously misleads policymakers and the public, and from a scientific point of view, it is wrong.[6] The "GM" techniques used to produce "GMOs" are derived directly from phenomena we find ubiquitous in nature. Our own "human" genome is thoroughly interspersed with genes shared with and imported from other organisms, and humans are both the product of, and constantly surrounded by the results of such entirely natural processes of "genetic modification."[7] But while the terms GM and GMO are used by opponents of agricultural innovation to wrongly stigmatize the category to which they refer, they do highlight one substantial (if arbitrary) subset of crops improved through biotechnology that has exploded onto the agricultural landscape over the past two decades. But from the points of view of farmers, the environment, and consumers, what matters is the trait or characteristics of the crop variety, and not the method by which it was produced.[8]

Over the past two decades, increased yields credited to these biotech-improved seeds added $133 billion in agricultural value to the global economy, and delivered an average increase in farmer income of 62 percent due to superior and more efficient pest and weed control.[9]

As shown in Figure 1, farmers in many nations have rapidly and repeatedly adopted biotech-improved seeds because of the simplicity in application, favorable returns on investment, and reduced environmental impacts.[10] In fact, for crops with biotech-improved seed varieties and in regions where governments have approved their planting (much of the world outside Europe and Africa), GM technology has become the new "conventional" standard for seeds, supplanting the older varieties, having rendered them largely obsolete.

Figure 1: Global Area of Biotech Crops (1996-2014).[11]



EXTENT OF GMO USE IN THE DEVELOPING WORLD

In 2014, seeds improved through biotechnology were grown by 16.5 million small farmers in 20 developing countries on 230 million acres (53 percent of the global total).[12] India was home to 7.7 million of these smallholders, and China to 7.1 million. These smallholders enjoyed increased income amounting to $16.7 and $16.2 billion, respectively, while benefitting from a 50 percent reduction in pesticide applications on their crops.[13] But these considerable benefits derive primarily from a very limited number of crops: corn, cotton, soybeans, and canola. No biotech-improved varieties of major crops such as rice, wheat, and sorghum have yet been commercialized, to say nothing of the wide variety of fruits and vegetables so important in developing nations' diets.

Despite the substantial benefits of biotechnology-improved crops, Figure 1 clearly shows two regions lagging in their adoption: Europe and Africa. Indeed, only 3 of the 54 countries in Africa grow any biotech-improved crops. As discussed below, this is primarily due to opposition led by European and European-funded NGOs, manipulation via foreign aid, and trade pressures.[14]

ECONOMIC BENEFITS

The most recent data show that biotech-improved seeds have increased the productivity of farming and farmer incomes around the world. [15] From 1996 to 2013, biotech crops added $133 billion in value to global agricultural production.[16] Over the same period, the integrated pest control measures these seeds enable and provide reduced the application of pesticide active ingredients by 500 million kilograms, significantly boosting farmers' incomes despite the higher costs of biotech seeds. The most recent meta-analysis of the economic impacts of biotech-improved crops concluded that "GM technology has, on average, reduced chemical pesticide use 37 percent, increased crop yields 22 percent, and increased farmer profits 68 percent during the 20 year period of 1995 to 2014."[17] A series of representative cases demonstrates the widespread and consistent economic benefits resulting from farmers adopting biotech-improved seeds in the developing world.

Biotechnology-Improved Seeds in South Africa

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South Africa was the first sub-Saharan country to approve commercial planting of biotech crops, with Bt (insect-resistant) maize leading the way in 1997, followed by cotton in 1998, and white maize in 2001. This was the first example of subsistence farmers growing a crop for their own use, and South Africa has even begun to export surplus production to neighboring countries.[18] Herbicide- tolerant maize for improved weed control was introduced in 2005. By 2010, biotech varieties covered nearly 70 percent of the area devoted to maize production in South Africa. Consistently superior yields and return on investment have led to high repurchase rates of biotech-improved seed by resource poor and risk-averse smallholders.

Biotech cotton in South Africa has been another success.[19] First planted in 1998 on 7,200 acres, biotech cotton expanded to 120,000 acres in the following year, thanks to the lower costs, higher yields, and superior health benefits for farmers from reduced pesticide applications. Although cotton acreage has declined in recent years due to global market conditions, market penetration by biotech varieties remains at or near 100 percent.[20] Biotech soybeans have also been introduced, and covered 1.3 million acres in 2013, 92 percent of which were herbicide-tolerant varieties.

Insect-Resistant Cotton in China

China was quick to move into modern plant breeding to improve seeds. As the largest global producer and consumer of cotton,[21] the country first launched efforts with the crop in 1991, moving to commercialization in 1997.[22] Historically, pest losses have been a major constraint on cotton yields and quality, and the Chinese have therefore focused on insect- resistant varieties. The results have been higher yields and higher quality cotton, coupled with reduced applications of foliar pesticide sprays (with concomitant reductions in farmers' input costs).[23]

In addition to the expected impacts, China enjoyed further benefits that had not been fully anticipated. Major economic and public health gains followed from the dramatic reduction in pesticide sprays, and farmer suicides by pesticide overdoses plummeted dramatically.[24] Chinese agricultural biodiversity has been a major beneficiary of the adoption of biotech-improved varieties of pest-resistant cotton, as reduced pesticide sprays led to a surge in beneficial insect populations.[25]

Insect-Resistant Cotton in India

The experience with biotech-improved cotton varieties in India parallels that of China. After successful field trials showing yield increases of as much as 80 percent, with pesticide reductions on the order of 70 percent, the first commercial plantings took place in 2002 on 50,000 hectares (120,000 acres).[26] In subsequent years, Indian farmers' demand for biotech seeds led to widespread piracy and fraud, during which some conventional cotton seed was sold as biotech varieties, leading to some reports of poor crop performance.[27] But purchases of approved varieties have delivered such consistently superior results that biotech cotton has rapidly displaced competitors. Repeated claims from opponents that biotech cotton failure has driven an increase in Indian farmers' suicides have been thoroughly disproven.[28]

India cultivated a record 11.6 million hectares of Bt cotton planted by 7.7 million small farmers in 2014, with an adoption rate of 95 percent, up from 11.0 million hectares in 2013. The increase from 50,000 hectares in 2002 (when Bt cotton was first commercialized) to 11.6 million hectares in 2014 represents an unprecedented 230-fold increase in 13 years. Brookes' and Barfoot's latest provisional estimate indicated that India had increased farm income from Bt cotton by US$16.7 billion in the 12-year period 2002 to 2013 and US$2.1 billion in 2013 alone, similar to 2012.[29]

These sizable economic benefits have helped attract younger workers in India into agriculture, bucking international trends.[30] In a survey of 2,400 small farmers, the Indian Society for Cotton Improvement found "Bt cotton technology attracted young farmers to cotton farming, with more than 50 percent of the surveyed farmers coming from the lower middle age group in Maharashtra, Andhra Pradesh and Punjab." [31]

POLICIES AND PRACTICES TO LIMIT GMO USE IN DEVELOPING COUNTRIES

Adoption of biotech-improved seeds by farmers in developing countries has been impeded by two main factors: scientifically indefensible regulations limiting GMO use and export limits, largely driven by Europe. The former have been driven by NGO campaigns to demonize GMOs, European foreign aid and other pressures aimed at reducing GMO use, and mixed impacts from various United Nations programs.

As Figure 1 shows, despite widespread adoption of biotech-improved crops, uptake has lagged in Eurasia and Africa, and the number of different biotech improved crops on the market is limited. Despite the dramatic preponderance of benefits over risks, and the wide adoption of biotech-improved crop varieties in many parts of the world, Europe and Africa remain the exceptions, lagging far behind the rest of the world in adopting these technologies.[32]

This underutilization of GM crops is not because the farmers in these regions benefit more from non-GM crops. It is the direct result of organized opposition in their nations and in major export markets, particularly Europe. As a result, many African governments have been slow to approve, or have sometimes even banned, GM crops, in order not to lose export markets and to maintain positive relations with the EU, especially given its development aid. In other cases, African nations are pressured by "green imperialism" exported by NGOs who claim to support development while in fact opposing it de facto.[33] Such NGO action plays a key role in creating anti-GM political pressure in these nations.[34]

Given that there are relatively few farmers in Europe and that their productivity even without GMOs is relatively high, at least compared to Africa (European farmers are able to afford mechanization, fertilizers, herbicides, and pesticides to raise productivity), the economic cost to Europe of banning GMOs is mostly in the form of modestly higher prices for some foods. But given that almost 60 percent of African workers are on a farm and that they have very low levels of agricultural productivity, reduced access to improved seeds imposes significant costs to them. As Paarlberg writes:

> Political leaders in Africa pay a price for simply 'doing what Europeans do.' Europe imposes stifling regulations on GMO foods and crops because Europeans have little need for this new technology. European farmers are already highly productive without it and European consumers are already well-fed… In Africa, however, where farmers are not yet productive and where so many consumers are not yet well fed, the potential gains GMO crops can provide are more costly to do without.

And as Wafula et al. write, "Laws that stifle scientific and technological innovations in any country pose a major threat [to] sustainable development aspirations and achievements of Millennium Development Goals."[35]

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European Pressures

The most important vehicle through which European anti-GM forces have impeded GMO use in developing nations, particularly in Africa, is the widespread use of nontariff trade barriers for GMO exports. In March 2015, the EU adopted a proposal that would allow individual member states to "opt out" of the community-wide approval process stipulated by the unified European market. Under this proposal, 19 of the 28 EU member states moved to ban the cultivation of biotech-improved seeds within their borders.[36]

Meanwhile, Europe depends on imports for almost half of the vegetable protein it consumes, and "imports millions of tons of GE [genetically engineered] soybean and corn products every year."[37] Despite this dependence, the largest EU importer of rice from Southeast Asia, based in France, made it clear to Thai government officials that if the country allowed any biotech crops to be approved at all, French buyers would stop buying rice from Thailand (whether or not it was GM).[38] As the UN Food & Agriculture Organization notes, nations like France, Germany, Netherlands, and Italy have intercepted GMO imports at the border and destroyed the food, with groups like Greenpeace and Friends of the Earth reporting the "crime."[39] But some African nations also block imports as a way to stay in favor with Europe. For example, Zimbabwe and Zambia block imports of biotech crops in the form of both commodity imports and food aid.[40] This is due to pressure from EU importers of beef from Zambia who pressured local exporters. As Wafula et al. write, "The threat of losing export markets in major destinations such as Europe has been a key issue in blocking adoption of GM crops."[41]

European hostility to some kinds of GMO imports has had a disproportionate impact on African agriculture because, as Parlberg notes, "Africa's farm exports to Europe are six times as large as exports to the United States, so it is European consumer tastes and European regulatory systems that Africans most often must adjust to."[42] Applicable rules under the World Trade Organization prohibit countries from discriminating against imports and require that measures to manage a hazard must be based on data showing harm, that they must be proportional to the potential for harm, and that they must not be unduly stringent or disruptive. The WTO has found that European regulations violate these requirements.[43] The negative consequences of these repeated and widespread violations of international trade norms have, in the end, created far more hardship for the nations violating the rules than for major agricultural exporters like the United States.[44] There has to date been no meaningful corrective action to stem this steady erosion of the rules-based system of international trade painstakingly built over the past century.

DEVELOPMENT ASSISTANCE TIED TO ANTI-GMO ACTIVITIES

European nations have also used informal pressures to lean on African nations to shun GMOs.[45] As Robert Parlberg writes, "Governments in Europe have used their ODA (overseas development aid) to encourage African governments to draft and implement highly precautionary European-style regulatory systems for agricultural GMO."[46] For example, Germany threatened Zimbabwe that it would lose overseas development assistance unless the country shut down its agricultural biotechnology research efforts—a proud program that was once among the most advanced in the developing world.[47]

But there has been a second channel of external influence to persuade African regulators to restrict GMO crops: multilateral technical assistance through the UNEP/GEF Global Project for Development of National Biosafety Frameworks (NBFs). As Parlberg notes, Europe provides three times the funding for UNEP than does the United States and therefore is able to influence the organization to adopt EU-style restrictions on GMOs.[48]

Under the Cartagena Protocol to the United Nations Convention on Biodiversity, the United Nations Environment Programme has spent millions of (European) dollars encouraging and assisting developing countries to adopt restrictive "biosafety" legislation that limits the use of safe and more productive GM seeds.[49] These barriers are regulatory restrictions that discriminate against "GM" products in violation of the established rules of international trade.[50] The result is that farmers in most African nations are denied access to GM seeds, and even where they can gain access, they are often disinclined to use them due to fears driven by imported European myths.

For example, rather than clearly stating the global scientific consensus that GMO foods are no less safe for human consumption than non-GMO foods, the UN Food and Agriculture Organization (FAO) writes: "In the survey, countries also asked us to help them assess whether GM crops are safe to eat and we would like to see countries sharing any scientific findings they have on the subject."[51] The FAO goes on to write:

> FAO is also aware of the concern about the potential risks posed by certain aspects of biotechnology. These risks fall into two basic categories: the effects on human

> and animal health and the environmental consequences. Caution must be exercised in order to reduce the risks of transferring toxins from one life form to another, of creating new toxins or of transferring allergenic compounds from one species to another, which could result in unexpected allergic reactions.[52]

Such statements by the UN FAO reinforce the factually incorrect message to developing nations that the science is unclear on this issue and that GMOs may be unsafe to eat.[53]

Opposition Within Developing Nations Fomented by Developed Nation NGOs

A third driver of reduced GMO use in Africa is political discord fomented by activist groups that continues to stymie African agricultural innovation efforts. For example, Greenpeace International and Friends of the Earth International, both based in Europe, have campaigned heavily in Africa against agricultural GMOs. This opposition has been sustained, relentless, and continual, driven not only by Greenpeace, but also Friends of the Earth Europe, EcoNexus, GeneWatch UK, TestBiotech, Bee-life European Beekeeping Coordination, Corporate Europe Observatory, and Via Campesina, and has lately been extended to the newest generation of innovative techniques.[54]

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As Wafula et al. write, "Anti-biotechnology activists have also invested heavily in negative publicity. This has in turn formed an important factor for the cautious approach to adoption of GMOs in African countries."[55] And Paarlberg notes, "Zambian officials were told by Greenpeace that if GMOs were let into their country, organic produce sales to Europe would collapse. An organization named Genetic Food Alert warned Zambia in 2002 of the 'unknown and unassessed implications' of eating GM foods, and a British group named Farming and Livestock Concern warned them that GM corn could form a retrovirus similar to HIV. These assertions were not backed by any evidence, but they frightened the Zambians into banning GMOs completely."[56]

One result of this pressure was that countries like Kenya and Uganda have struggled for years to adopt legislation and regulations that would allow field trials and eventual commercialization of domestically developed transgenic crops, including staple crops of cassava and bananas. Even when laws enabling regulation were finally adopted in Kenya, the government still banned GMOs on the basis of unsubstantiated claims of health risks. NGOs continue to try to prevent persuade farmers from against using biotech-improved seeds. Kenyan Organic Consumers Alliance National Coordinator Peter Mokaya recently claimed, "The worst mistake Kenya can make is to introduce GMOs. Don't be cheated … GMOs cannot create food security. This is just a political and marketing strategy."[57] This has led to Kenyan scientists working with biotechnology to charge that "…donor funds, as opposed to facts, [are] influencing those opposed to the technology."[58]

Uganda provides one of the most striking cases of the suppression of biotechnology.[59] Like most African countries, Uganda ratified the Cartagena Protocol, which contains language some have construed to justify draconian restrictions on GMOs, in violation of the Protocol's stated objectives.[60] But over the last decade Uganda has been unable to enact a law that would enable it to review, and approve or reject transgenic crops. The main obstacle has been fear-based propaganda campaigns mounted by opponents of the technology, some of which are foreign NGOs such as the UK-based Action Aid, which argues that GMO crops threaten basic human rights and do not help small farmers.[61] These groups have lobbied against any law that would allow for the approval of transgenic crops.[62] Other critics of the technology have argued that what Uganda needs is a law that bans the cultivation or sale of transgenic crops, despite the fact that the country has a vibrant biotechnology research program focused on local needs, and the country's president has recently weighed in with his overt support.[63]

Biotechnology research in Uganda is carried out in national agricultural research institutes and addresses specific problems relevant to the country. In one project, researchers at the Kawanda Agricultural Research Institute are using biotechnology to find a solution to the spread of banana wilt disease caused by *Xanthomonas*, a bacterial disease that leads to discoloration and premature ripening of bananas.[64] Bananas are a staple crop in Uganda and of little interest to foreign firms, but this disease alone costs the African Great Lakes region nearly US$500 million annually. As a result, national labs are researching a solution to the disease, for which there is currently no effective treatment. Scientists at KARI (Kenya Agricultural Research Institute) have developed a transgenic banana by inserting a gene from a green pepper, which provides protection against the disease. Planting this banana would be far more efficient than relying on labor-intensive methods of isolating and destroying affected conventional bananas.

In 2012 the government of Uganda introduced the National Biotechnology and Biosafety Bill in Parliament, intended to enable the regulation and ultimately the introduction of transgenic crops. The bill was opposed by a list of 127 NGOs (46 of which are based in Europe, the United States, or Australia) led by the Alliance for Food Sovereignty in Africa (AFSA), and academics who resorted to scaremongering, resulting in the bill's defeat.[65] Opponents argued that the bill appeared to legitimize the commercial research of transgenic crops and did not provide sufficient safeguards against the technology's risks. They also argued that the bill should be based on the (European) precautionary principle and provide strong measures against any introduction of transgenic crops.

Opponents demanded the bill be published in local newspapers for broad debate, violating the usual practice and precedents set with other bills. The latest iteration of the bill provides for expedited review in the case of crops that have already been adopted in other countries with comparable ecosystems. Opponents have demanded this clause be deleted from the bill. They also want unprecedented "strict liability" provisions because they claim the bill gives foreign firms too much freedom to introduce new crop varieties in Uganda, failing to notice that this would in fact be a good thing if it happened.[66] They also demand mandatory labeling of all the products of genetic modification.

Other objections to the bill include the claim that the law will introduce intellectual property rights that would harm farmers. Opponents have relied on pseudoscience and papers that have been retracted by the journals that originally published them.[67] Critics have also charged—without evidence—that government officials supporting the bill have been bribed by foreign multinationals. They claim Uganda has no capacity to manage biotechnology risks and should therefore not pursue developing transgenic crops.

Given this opposition, the Ugandan Parliament has not been able to reach agreement about adopting the bill. What is striking in this case is that a small number of groups using misinformation have been able block the adoption of a law that could help the country to determine if transgenic technology could help save Uganda's staple crop. This is a clear case where the suppression of biotechnology though foreign and foreign-funded local groups has blocked a local solution that would benefit small farmers.

In Zambia, Catholic priests campaigning for social justice under the inspiration of liberation theology spread false tales of the dangers of agricultural biotechnology, which the regime used to strengthen its political position.[68] This is perhaps one reason why the Zambian government lists as the guiding principles of its biotechnology and biosafety policy: "the Precautionary Principle; Advance Informed Agreement; recognition of undesirable effects of GMOs; Risk Assessment; Socio-economic Impact; Public Participation; Liability and Redress; recognition of possible conflict between conservation of biodiversity and trade; as well as recognition of rights of both developers and innovators over genetic resources and technologies."[69] In other words, these principles will make it harder for farmers to use biotechnology. This is why the Namibian Agronomic Board (NAB) has "reprimanded those responsible for producing and marketing maize products that a consumer lobby alleged contain so-called genetically modified maize."[70]

Another example, in this case from India, is eggplant, known in the region as "brinjal." India is a center of origin for brinjal, where hundreds of different varieties are grown and consumed.[71] Loved by many herbivorous insects, conventional brinjal production requires heavy pesticide applications, as many as 100 or more in a growing season. These would be significantly reduced by a biotech-improved insect-resistant variety. Field trials had been approved and were about to launch when the environment minister caved to opposition demands and canceled the approval by administrative fiat in what he admitted was "a political decision."[72] Although the government of Prime Minister Modi announced a resumption of field trials shortly after it took office, this has yet to materialize. Meanwhile, NGO-based opposition, driven and funded largely from Europe, continues and has begun to be exported from India to other developing countries.[73] The problem has reached such proportions that the Indian government recently barred Greenpeace India (and nearly 9,000 other NGOs) from accepting foreign funds, arguing they actively work to undermine national interests and policies, as other countries are also increasingly noticing.[74]

NGOs have been similarly active in the Philippines. The government approved biotech-improved pest-resistant maize in 2003.[75] Providing an effective means for nontoxic control of the Asiatic corn borer, a serious pest, it was quickly and widely adopted. Researchers found that small farmers gained the biggest benefits. This result suggests that Bt corn could be a "pro-poor" technology, since most of the lower-yielding farms in the Philippines are held by poor smallholders with low incomes.[76]

Such a clear and visible success attracted the attention of many in the NGO community, who mounted strong attempts to manufacture and impose a negative narrative. Campaigners representing themselves as scientists claimed in a press conference that villagers next to a field planted in Bt maize had suffered an array of negative health effects that they blamed on the biotech crop.[77] The activist echo chamber amplified and continues to redistribute the claims,[78] but a closer look showed no evidence that anything unusual had happened, and that villagers near the Bt maize field and removed from it suffered from the same respiratory issues at similar rates.

The scientific community was dismayed at the false and unwarranted claims by opponents designed to mislead and foment fear, and pushed back, sending an open letter to the activists requesting they publish their data in the scientific, peer-reviewed literature.[79] More than a decade later, this has yet to happen.

Because of NGO opposition, progress toward making Golden Rice available, and the myriad of health benefits from it, has been set back significantly.

Opposition groups have since maintained an intense focus on the Philippines, agitating against every significant potential biotech-based advance there. In 2012, Greenpeace filed a lawsuit[80] against the University of the Philippines at Los Baños to block field trials of insect-resistant eggplant that had been approved by the appropriate regulatory authorities. Greenpeace alleged falsely that the trial threatened biodiversity and presented undue risks to human health. This "toxicity" claim is particularly ironic, given that the pesticidal protein involved is approved for use in organic production, and has contributed to a vast reduction in the exposure of farmers around the world to alternative pest control agents, which are in fact toxic and can be misused. The Philippine Appeals Court, however, held in Greenpeace's favor, through an "astonishing leap beyond reason." It found that the field trials of Bt eggplant "could not be declared… safe to human health and to our ecology with full scientific certainty"[81]—a threshold impossible to meet anywhere, at any time, for anything. The Supreme Court recently upheld the lower court ruling, despite strong objections from the local scientific community to the factual errors underlying the decision, and its innovation-quashing impacts.[82]

But the most egregiously abusive opposition in the Philippines took place in August, 2013, when Greenpeace attacked and destroyed field trials of vitamin A-fortified "Golden Rice."[83] The original claims by campaigners that the destruction was carried out by local farmers quickly fell apart in the face of evidence that the vandals were imported for the purpose, to the strong dismay of local farmers.[84] Scientists from the Philippines,[85] and thousands more from around the world, condemned this attack in the strongest terms.[86] But because of this NGO opposition, progress toward making Golden Rice available, and its myriad health benefits, has been set back significantly. Estimates are that the costs of this opposition in the Philippines alone "have to be at least US$199 million" per year.[87]

The World Health Organization estimates that 124 million people suffer from a vitamin A deficiency (VAD) and one to two million die each year from it, with 250,000 to 500,000 irreversible cases of blindness annually, mainly in children, half of whom die within a year of becoming blind.[88] Golden rice offers one of the best opportunities to reduce this unacceptable toll.[89] The opposition campaigns encouraging these political moves against biotech-improved seeds have been severely criticized, correctly labeled a crime against humanity, and charged with "taking food off the plates of the hungry."[90]

THE ECONOMIC COSTS OF SUPPRESSING INNOVATION IN AFRICAN AGRICULTURE: LAGGING PRODUCTIVITY GROWTH

We have seen above that African nations lag in the adoption of biotech-improved seeds, and that this has been heavily influenced by a variety of efforts originating in and exported from Europe. It is difficult to estimate the full economic impact of these pressures on African agricultural productivity, but some estimates can be made.

In 2013,[91] the average global adoption rates for biotech-improved seed were 79 percent for soybean, 32 percent for maize, and 70 percent for cotton.[92] To estimate the opportunity costs borne by countries that have not yet adopted biotech crops, we calculated the gains they would have seen had they adopted biotech varieties starting in 2008 at rates comparable to those in adopting countries. Next we use the global average of a 22 percent yield increase for biotech crops (per endnote 7), although this number represents a conservative estimate for developing countries. Discounting African nations that are already growing biotech crops (South Africa, Burkina Faso, Sudan), we superimpose 2013's global adoption rates onto other African countries' production in soybean, maize, and cotton, while holding prices constant:

- African nations produced roughly $1.01 billion worth of cotton. If 70 percent were of biotech-improved stock, higher yields would increase harvest value by $156 million.

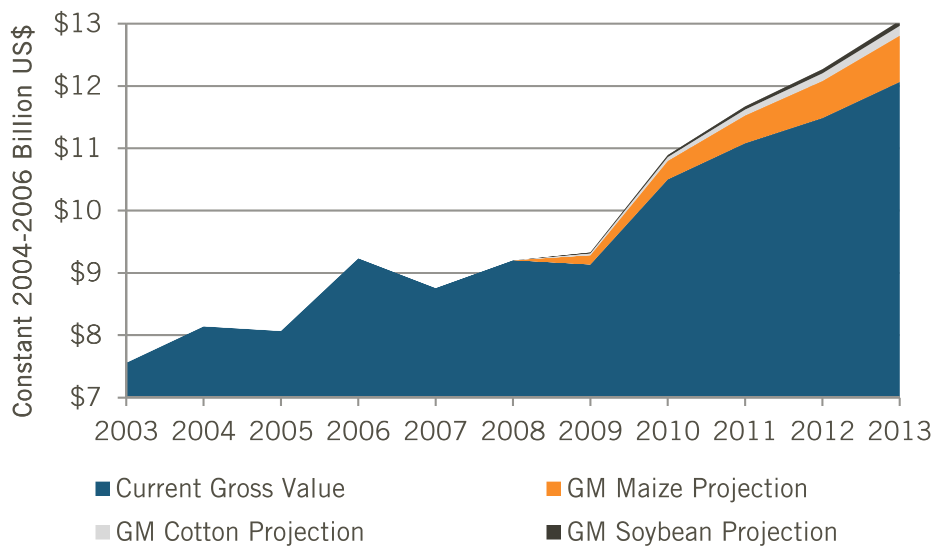
- African nations produced roughly $482 million worth of soybeans. If 79 percent were of biotech-improved stock, the total value would increase by $84 million.

- For maize, African nations produced roughly $10.6 billion worth of the crop. If 32 percent were of biotech-improved stock, the total value would increase by $744 million.

These projections provide a conservative estimate based on the adoption of biotech-enhanced seeds, and leads to an overall increase in the total gross value added of maize, cotton, and soybeans planted in Africa by 8 percent more than 2013 levels, or an absolute amount of $984 million.[93]

Figure 2 projects the growth of biotech crop added value to the African agricultural sector, assuming a constant growth rate of biotech seed adoption from 2008 onward, the year that Egypt and Burkina Faso approved biotech-improved maize and cotton respectively.

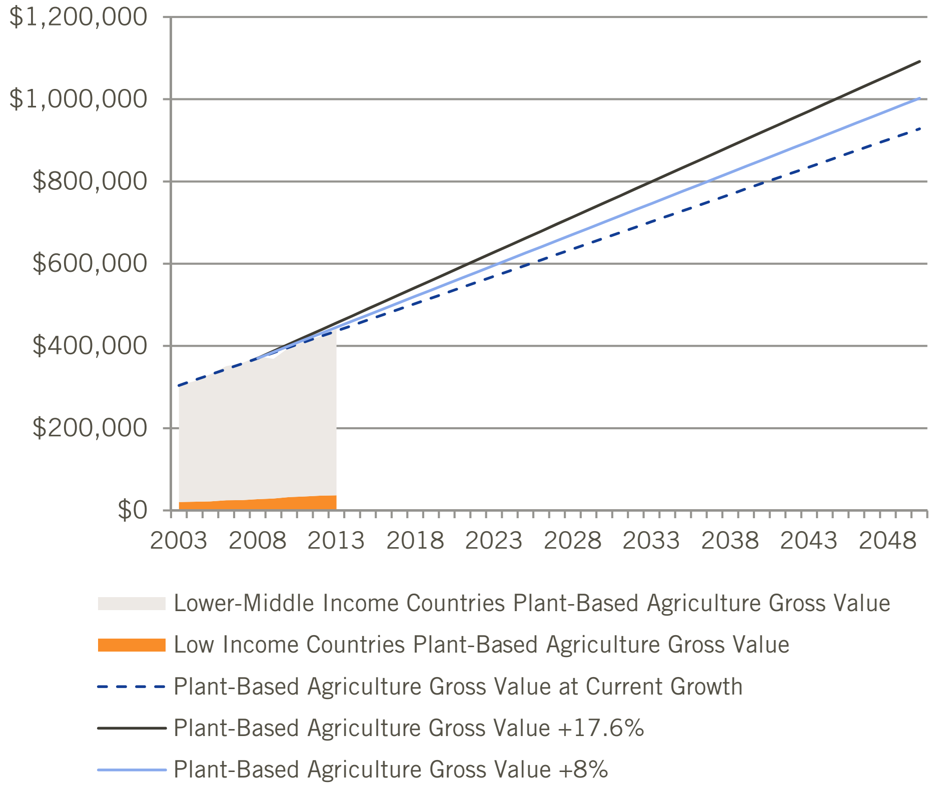
Figure 2: Gross Value of African Maize, Soybean, and Cotton Production from 2003 to 2013; and Estimated Production increases through GM Maize, Soybean, and Cotton Adoption pre-dated to 2008.[94]



Maize, cotton, and soybeans comprise approximately 9 percent of total African agricultural value.[95] This leaves a huge market share of crop production so far untouched by biotech improvements, with opportunities for further research and development.

Figure 3 provides an illustration of how continued development and adoption of biotech-improved varieties of all crops would impact the agricultural economies of sub-Saharan Africa. We provide a simple linear growth estimate based on current growth rates (the business-as-usual case); a growth estimate assuming current rates of biotech-enhanced crop adoption as seen across all other crop varieties, leading to an overall 8 percent increase in gross value of all plant-based agriculture in 2050; and a growth estimate of 80 percent biotech adoption across all crop varieties, leading to an overall 17.6 percent increase in gross value by 2050.

Figure 3: Total Gross Value of Plant-Based Agriculture through 2050 for Low and Lower-Middle Income Nations (in constant 2004-2006 Million US$)[96]
***Figure is an underestimate: Agriculture Data only available for 51 of the 82 Low-Income, and Lower-Middle Income Nations, provided in the Appendix.**



In 2013, lower-middle income countries of the world produced $405 billion worth of plant-based agriculture products, while low-income countries produced $36 billion.[97] If the gross value of agricultural production by these nations continues to increase at historical rates, it will reach a total of $928 billion by 2050.

ITIF postulates two possible scenarios for economic growth driven by the deployment of agricultural biotechnology in Africa by mid-century. We project that by 2050, most low- and lower-middle income nations will to some degree have developed and adopted biotech enhanced varieties for all crops:

- Scenario 1 (8 percent increase in gross value): The 8 percent growth estimate is based on a mix of current adoption rates for biotech-improved maize, soybean, and cotton, with an average 22 percent improvement to yields as a conservative estimate applied across all other crop varieties (based on experience to date).

- Scenario 2 (17.6 percent increase in gross value): This growth projection is based on our estimate that by 2050, biotech-improved varieties will consist of 80 percent of all grown crops. An 80 percent adoption rate is a reasonable scenario given the popularity of biotech-improved varieties, increasing demands for higher production, the advent of new, more efficient techniques for crop improvement, and the fact that adoption rates for biotech-enhanced crops already exceeds 80 percent in many developing countries.

Under scenario one, low- and lower-middle income nations will produce $1 trillion in total plant-based agriculture. Under scenario two, these same nations will produce $1.1 trillion in total plant-based agriculture from the wide-scale adoption of biotech-enhanced seeds.

The economic literature shows that the agriculture sector has a positive multiplier, especially significant in the rural sector.[98] In sub-Saharan Africa, this multiplier value is estimated at 1.5, meaning that for every dollar increase in the agriculture sector, other sectors outside of agriculture see a $1.50 benefit.[99] The magnitude of the multiplier effect depends on many factors, including the size of the country and its openness to trade. For example, scholars from Tanzania, a country where agriculture goods contribute about 50 percent of exports, estimated a multiplier around 2.[100]

A wide array of NGOs, more interested in pursuing an anticorporate agenda than a pro-development agenda, have worked to convince nations to ban or otherwise limit productivity-enhancing GMOs.

Proportional rates of adoption of biotech-improved cotton, soybean, and maize by the countries that have not yet approved these innovations, in relation to African nations that did adopt biotech enhanced varieties, would have increased Africa's agricultural income by $984 million in 2013. With a conservative economic multiplier of 1.5, this would generate an additional $1.5 billion benefit.

A healthier agricultural industry in these countries will provide a boost to the rest of the nation's economy. If all other factors were constant, ITIF estimates that the continued suppression of biotech innovations in agriculture has cost African agricultural economies alone at least $2.5 billion from 2008-2013, and as illustrated in Figure 3 (by the difference between the areas captured by the solid gray and dotted blue lines from 2015-2050), will cost low- and lower-income countries worldwide as much as $1.5 trillion from 2015-2050 in agriculture value forgone.

CONCLUSION

Crops improved through biotechnology have been widely adopted by farmers around the world wherever farmers have been able to secure access to the seeds and where they do not fear loss of export markets. However, governments in some regions have created significant impediments to farmers' use of GMO-improved seeds, most conspicuously in Europe, which has exported restrictive regimes wherever they can, with particular success in sub-Saharan Africa. African farmers' access to biotech-improved seeds has been severely and directly limited by threats from Europe to close their access to export markets; and by regulatory barriers to innovation erected through a global effort by EU and member states to create regulations in other countries that block farmers' access to biotech-improved seeds. And on top of that, a wide array of NGOs, more interested in pursuing an anticorporate agenda than a pro-development agenda, have worked to convince nations to ban or otherwise limit productivity-enhancing GMOs. Consequently, in most cases, seeds for GM versions of African crops simply don't exist. Even in the few cases where biotech-improved seeds do exist, it is difficult or impossible for farmers to gain access.

Despite the strongly positive track record of biotech-derived crops for farmers, consumers, and the environment, unexploited opportunities for additional, widely shared benefits are considerable. We estimate the economic value forgone in Africa from restrictive regulation at $1 billion in 2013. If such regulations continue to restrict and suppress innovation in agriculture, the cumulative costs to low- and lower-middle income countries worldwide will be approximately $1.5 trillion by 2050. In view of the unprecedented demands to increase agricultural production and productivity over the next 30 years, it is critical that such restrictive regimes be rolled back everywhere as rapidly as possible.

APPENDIX

Table 2: List of Countries in the Low-Income and Lower-Middle Income World Bank classification, and agricultural data availability from the Food and Agriculture Organization of the United Nations.

Low-Income Countries		Lower-Middle Income Countries	
Country	Data Availability	Country	Data Availability
Afghanistan	No	Armenia	Yes
Benin	No	Bangladesh	Yes
Burkina Faso	Yes	Bhutan	Yes
Burundi	Yes	Bolivia	Yes
Cambodia	Yes	Cabo Verde	Yes
Central African Republic	No	Cameroon	Yes
Chad	No	Congo, Rep.	Yes
Comoros	No	Côte d'Ivoire	Yes
Congo, Dem. Rep	No	Djibouti	No
Eritrea	Yes	Egypt, Arab Rep.	Yes
Ethiopia	Yes	El Salvador	Yes
Gambia, The	Yes	Georgia	Yes
Guinea	Yes	Ghana	Yes
Guinea-Bisau	No	Guatemala	No
Haiti	No	Guyana	Yes
Korea, Dem Rep.	No	Honduras	Yes
Liberia	No	India	Yes
Madagascar	Yes	Indonesia	Yes
Malawi	Yes	Kenya	Yes
Mali	Yes	Kiribati	No
Mozambique	Yes	Kosovo	No
Nepal	Yes	Kyrgyz Republic	Yes
Niger	Yes	Lao PDR	Yes
Rwanda	Yes	Lesotho	No
Sierra Leone	No	Mauritania	No
Somalia	No	Micronesia, Fed. Sts.	No
South Sudan	No	Moldova	Yes
Tanzania	Yes	Morocco	Yes
Togo	Yes	Myanmar	No
Uganda	No	Nicaragua	Yes
Zimbabwe	No	Nigeria	Yes
		Pakistan	Yes
		Papua New Guinea	No
		Philippines	Yes
		Samoa	No
		São Tomé and Principe	No
		Senegal	Yes
		Solomon Islands	No
		Sri Lanka	Yes
		Sudan	Yes
		Swaziland	No
		Syrian Arab Republic	No
		Tajikistan	Yes
		Timor-Leste	No
		Ukraine	Yes
		Uzbekistan	No
		Vanuatu	Yes
		Vietnam	Yes
		West Bank and Gaza	Yes
		Yemen, Rep.	Yes
		Zambia	Yes

ENDNOTES

1. Mark Lynas, "With G.M.O. Policies, Europe Turns Against Science," *The New York Times*, October 24, 2015, http://www.nytimes.com/2015/10/25/opinion/sunday/with-gmo-policies-europe-turns-against-science.html?_r=0; "News and Comment: Letter to Scottish Government from Research Organisations," Sense About Science, August, 18 2015, http://www.senseaboutscience.org/news.php/451/letter-to-scottish-government-from-research-organisations; Giovanni Tagliabue, "The Nonsensical GMO Pseudo-Category and a Precautionary Rabbit Hole," *Nature Biotechnology* 33 (2015): 907–908. DOI:10.1038/nbt.3333.
2. Elena Holodny, "Which Countries Are Most Affected by Higher Food Prices?" *World Economic Forum,* September 1, 2015, https://agenda.weforum.org/2015/09/which-countries-are-most-affected-by-higher-food-prices/.
3 Gallup, "One in Five African Adults Work on Farms," April 23, 2014, http://www.gallup.com/poll/168593/one-five-african-adults-work-farms.aspx.
4. Clive James, International Service for the Acquisition of Agri-Biotech Applications (ISAAA) "Global Status of Commercialized Biotech/GM Crops," brief 49, 2014, http://www.isaaa.org/resources/publications/briefs/49/default.asp.
5. "Food, Genetically Modified" World Health Organization, accessed June 29, 2015, http://www.who.int/topics/food_genetically_modified/en/. The terms "GM" and "GMO" are used throughout for convenience, though they are scientifically indefensible. See Tagliabue, "Nonsensical GMO Pseudo-Category."
6. Giovanni Tagliabue, "The Meaningless Pseudo-Category of "GMOs", *EMBO Reports* 17, no. 1 (2016): 1469–3178, http://dx.doi.org/10.15252/embr.201541385;
7. Matt Ridley, *Genome: The Autobiography of a Species in 23 Chapters* (Harper Collins, New York, 2000), 1999; Carl Zimmer, "Genes are Us. And Them." National Geographic, accessed January 31, 2016., http://ngm.nationalgeographic.com/2013/07/125-explore/shared-genes; L. Val Giddings, "Hey, Chipotle! Don't Look Now, But It's 'Turtles All the Way Down!'" *ITIF Innovation Files*, April 30, 2015, http://www.innovationfiles.org/hey-chipotle-dont-look-now-but-its-turtles-all-the-way-down/.
8. US National Academy of Sciences, *Introduction of Recombinant DNA-Engineered Organisms into the Environment: Key Issues* (Washington, DC: National Academy Press, 1987), 24, https://books.google.com/books?id=IUErAAAAYAAJ&pg=PA5&lpg=PA5&dq=Introduction+of+Recombinant+DNA-engineered+organisms+into+the+environment:+Key+issues.&source=bl&ots=FvDOVZwNVZ&sig=_IJ_zcaXjYnsq656AXpiFK-mTXE&hl=en&sa=X&ved=0CCoQ6AEwAmoVChMI6Mi8zKzgyAIVSjM-Ch3EpQ29#v=onepage&q=Introduction%20of%20Recombinant%20DNA-engineered%20organisms%20into%20the%20environment%3A%20Key%20issues.&f=false.
9. Wilhelm Klümper and Matin Qaim, "A Meta-Analysis of the Impacts of Genetically Modified Crops," *PLoS ONE* 9, no. 11 (November 2014). DOI: 10.1371/journal.pone.0111629.
10. Peter Barfoot and Graham Brookes, "Key Environmental Impacts of Global GM Crop Use 1996–2012) *GM Crops and Food: Biotechnology in Agriculture and the Food Chain*, 5, no. 2, (April, May, June 2014: 1–12, https://www.landesbioscience.com/journals/gmcrops/article/28449/.
11. James, "Global Status of Commercialized Biotech."
12. Ibid.
13. Ibid.
14. Calestous Juma, "How the EU Starves Africa into Submission," CAPX, October 26, 2015, http://www.capx.co/how-the-eu-starves-africa-into-submission/.
15. James, "Global Status of Commercialized Biotech."
16. Klümper and Qaim, "Meta-Analysis Genetically Modified Crops."
17. Ibid.
18. Marnus Gouse, "GM Maize as Subsistence Crop: The South African Smallholder Experience," *AgBioForum* 15, no. 2 (2012), http://www.agbioforum.org/v15n2/v15n2a05-gouse.htm.
19. R. Bennett et al., "Bt cotton, Pesticides, Labour and Health - A Case Study of Smallholder Farmers in the Makhathini Flats, Republic of South Africa," *Outlook on Agriculture*, 32, no. 2 (2003): 123–128, http://centaur.reading.ac.uk/3253/; Yousouf Ismael, Richard Bennett, and Stephen Morse, "Benefits from Bt Cotton Use by Smallholder Farmers in South Africa," *AgBioForum* 5, no. 1 (2002), http://www.agbioforum.org/v5n1/v5n1a01-morse.htm.

20. “Biotech Country Facts & Trends: South Africa,” (International Service for the Acquisition of Agri-Biotech Applications (ISAAA), 2014), https://www.isaaa.org/resources/publications/biotech_country_facts_and_trends/download/Facts%20and%20Trends%20-%20South%20Africa.pdf.
21. Index Mundi, Cotton Production by Country in 1000 480 lb. Bales (agriculture, cotton; accessed February 1, 2016), http://www.indexmundi.com/agriculture/?commodity=cotton.
22. Jikun Huang et al., “Plant Biotechnology in China,” *Science* 295, no. 5555 (2002): 674–676, http://www.researchgate.net/profile/Scott_Rozelle/publication/11549366_Plant_biotechnology_in_China/links/00b495187fab5a9282000000.pdf.
23. Carl E. Pray et al., 2002. “Five Years of Bt Cotton in China - The Benefits Continue,” The Plant Journal, 31, no. 4 (2002): 423–430, http://onlinelibrary.wiley.com/doi/10.1046/j.1365-313X.2002.01401.x/abstract; Jikun Huang et al., “Bt Cotton Benefits, Costs, and Impacts in China,” *AgBioForum* 5, no. 4 (2002), http://www.agbioforum.org/v5n4/v5n4a04-huang.htm.
24. Pray et al., “Five Years Bt Cotton China”; Jikun Huang et al., “Biotechnology as an Alternative to Chemical Pesticides: A Case Study of Bt Cotton in China,” *Agricultural Economics* 29, no. 1 (July 2003): 55–67, http://www.sciencedirect.com/science/article/pii/S0169515003000446; Ferdaus Hossain et al., “Genetically Modified Cotton and Farmers' Health in China,” *International Journal of Occupational and Environmental Health* 10, no. 3 (July 1, 2004): 296–303, http://www.maneyonline.com/doi/abs/10.1179/oeh.2004.10.3.296.
25. “…we show here a marked increase in abundance of three types of [beneficial insects] (ladybirds, lacewings and spiders) and a decreased abundance of aphid pests associated with widespread adoption of Bt cotton and reduced insecticide sprays in this crop. We also found evidence that the predators might provide additional biocontrol services spilling over from Bt cotton fields onto neighboring crops (maize, peanut and soybean). Our work extends results from general studies evaluating ecological effects of Bt crops by demonstrating that such crops can promote biocontrol services in agricultural landscapes. ” Yanhui Lu, Kongming Wu, Yuying Jiang, Yuyuan Guo & Nicolas Desneux, “Widespread Adoption of Bt Cotton and Insecticide Decrease Promotes Biocontrol Services,” *Nature* 487 (July 19, 2012): 362–365. DOI: 10.1038/nature11153.
26. John Whitfield, “Transgenic Cotton a Winner in India: Insect-Resistant Varieties Show Big Yield Improvements,” *Nature* (February 7, 2003). DOI: 10.1038/news030203-12; Bhagirath Choudhary and Kadambini Gaur, “Bt Cotton in India: A Country Profile,” (International Service for the Acquisition of Agri-Biotech Applications (ISAAA), July 2010), http://isaaa.org/resources/publications/biotech_crop_profiles/bt_cotton_in_india-a_country_profile/download/Bt_Cotton_in_India-A_Country_Profile.pdf.
27. Guillaume P. Gruère, Purvi Mehta-Bhatt, and Debdatta Sengupta, “Bt Cotton and Farmer Suicides in India: Reviewing the Evidence” (discussion paper, International Food Policy Research Institute, 2008) 64, http://www.ifpri.org/publication/bt-cotton-and-farmer-suicides-india;
28. Ibid; Keith Kloor, “The GMO-Suicide Myth,” *Issues in Science & Technology XXX*, no. 2 (Winter 2014), http://issues.org/30-2/keith/.
29. James, “Global Status of Commercialized Biotech.”
30. Indian Society for Cotton Improvement, “Bt Cotton Technology Attracting Younger Farmers to Farming in India,” press release, December 15, 2013 http://www.isaaa.org/india/media/ISCI_Templeton_Survey_Pressrelease_15Dec2013-English.pdf; Boo Chanco, “Who Will Plant Our Rice?,” *The Philippine Star*, July 6, 2015, http://www.philstar.com/business/2015/07/06/1473597/who-will-plant-our-rice.
31. Ibid.
32. James, “Global Status of Commercialized Biotech.”
33. Juma, “EU Starves Africa”; Robert Paarlberg, “Consequences of the Anti-GMO Campaigns,” *Bread and Brain, Education and Poverty*, (2014) 4–6, http://www.casinapioiv.va/content/dam/accademia/pdf/sv125/sv125-paarlberg.pdf.
34. Robert Paarlberg, *Starved for Science: How Biotechnology is Being Kept Out of Africa*, (Cambridge, MA: Harvard University Press, 2008), 235; Paul Driessen, *Eco-Imperialism: Green Power Black Death*, (Bellevue, WA: Free Enterprise Press, 2010), 179; Jon Entine ed., *Let Them Eat Precaution*, (Washington, DC: AEI Press, 2006), 203.

35. David Wafula et al., "Biosafety Legislation and Biotechnology Development Gains Momentum in Africa," *GM Crops & Food* 3, no. 1 (2012): 72–77. DOI: 10.4161/gmcr.19708.
36. Arthur Nelson, "Half of Europe Opts Out of New GM Crop Scheme," *The Guardian*, October 1, 2015 http://www.theguardian.com/environment/2015/oct/01/half-of-europe-opts-out-of-new-gm-crop-scheme; Dave Keating, "Europe's GMO Compromise: Bound to Unravel?" *Deutsche Welle*, October 2, 2015, http://www.dw.com/en/europes-gmo-compromise-bound-to-unravel/a-18477896.
37. United States Department of Agriculture (USDA) Foreign Agricultural Service (FAS), "EU 28 Agricultural Biotechnology Annual, 2015 GAIN Report," (Washington, DC: FAS, July 23, 2015), http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Agricultural%20Biotechnology%20Annual_Paris_EU-28_7-23-2015.pdf.
38. L. V. Giddings, personal communication. This story was confirmed in 2013 by four different high-level Thai authorities who were not authorized to speak on the record, one of whom showed the letter described from the French rice buyer, which he was not authorized to allow to be copied.
39. Food and Agriculture Organization of the United Nations (FAO), "Technical Consultation on Low Levels of Genetically Modified (GM) Crops in International Food and Feed Trade," (technical background paper, FAO, Rome, March 2014) 20–21.
40. Craig Timberg, "A Bounty of Food Relief Sits Unused in Zimbabwe: Claim of Bumper Crop Ties Aid Groups' Hands," *The Washington Post,* July 20, 2004, reprinted on AgBioWorld, AgBioView Archives (European Commission approves biotech maize; The myth about organic food; Food relief sits unused in Zimbabwe) http://www.agbioworld.org/newsletter_wm/index.php?caseid=archive&newsid=2198; also Katie Mantell, "Zimbabwe Shuns US Gift of Transgenic Maize," *SciDevNet*, June 5, 2002 http://www.scidev.net/global/gm/news/zimbabwe-shuns-us-gift-of-transgenic-maize.html; "Government Has No Intention of Allowing GMO Foods-Lubinda," *Lusaka Times*, July 8 2015, http://www.lusakatimes.com/2015/07/08/government-has-no-intention-of-allowing-gmo-foods-lubinda/.
41. Wafula et al. "Biosafety Legislation and Biotechnology Africa," 72–77.
42. Robert Paarlberg, *Starved for Science*.
43. World Trade Organization, "European Communities—Measures Affecting the Approval and Marketing of Biotech Products," Dispute Settlement: DS291, January 17, 2008, https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds291_e.htm.
44. Simonetta Zarrilli, "International Trade in Genetically Modified Organisms and Multilateral Negotiations: A New Dilemma for Developing Countries," (United Nations Conference on Trade and Development, July 5, 2000), http://unctad.org/en/Docs/poditctncdd1.en.pdf.
45. Greg Bodulovic, "Is the European Attitude to GM Products Suffocating African Development?" 32 (2005): 1069–1075, http://globalseminarhealth.wdfiles.com/local--files/nutrition/Bodulovic.pdf.
46. Robert Paarlberg, "GMO Foods and Crops: Africa's Choice," *New Biotechnology* 27, no. 5 (November 30, 2010): 609–613.
47. Christopher J. Chetsanga, "Zimbabwe: Exploitation of Biotechnology in Agricultural Research," *Agricultural Biotechnology and the Poor* (Consultative Group on International Agricultural Research and US National Academy of Sciences, October 1999), 21–22, http://library.cgiar.org/bitstream/handle/10947/5580/chetsanga.pdf;jsessionid=B7FD12719704A457B4B6C2C49EB33136?sequence=1?sequence=1; Robert Paarlberg, *Starved for Science*; Paul Driessen, *Eco-Imperialism*; Jon Entine ed., *Let Them Eat Precaution*.
48. Robert Paarlberg, *Starved for Science*.
49. United Nations Environment Programme (UNEP), Convention on Biological Diversity, "The Cartagena Protocol on Biosafety," adopted January 29, 2000, https://bch.cbd.int/protocol; "Building Biosafety Capacity: The Role of UNEP and the Biosafety Unit," UNEP and Global Environment Facility (GEF), December 2006, http://www.unep.org/biosafety/Documents/UNEPGEFBiosafety_BrochureDec2006.pdf; Rebecca Leanne Connolly, "The Fragmentation of International Law Has Given Rise to a Conflict of Jurisdiction for Trade Disputes Involving Agricultural Biotechnology Products," (PhD thesis, University of Sydney Faculty of Law, February 25, 2015), http://ses.library.usyd.edu.au/handle/2123/13744; "BCH Projects," UNEP, accessed February 1, 2016, http://www.unep.org/biosafety/BCH_Projects.aspx.

50. Robert Paarlberg, *Food Politics: What Everyone Needs to Know* (New York: Oxford University Press, 2010).
51 A. Nicolia, A. Manzo, F. Veronesi, and D. Rosellini, "An overview of the last 10 years of genetically engineered crop safety research," *Critical Reviews in Biotechnology* 34, no. 1 (March, 2014):77-88, doi:10.3109/07388551.2013.823595, https://www.geneticliteracyproject.org/wp-content/uploads/2013/10/Nicolia-20131.pdf; GENetic Engineering Risk Atlast (GENERA) at http://genera.biofortified.org/ (accessed February 1, 2016); "Review of 10 years of GMO research – no significant dangers," *Skeptical Raptor's Blog*, November 12, 2013, http://www.skepticalraptor.com/skepticalraptorblog.php/review-10-years-gmo-research-no-significant-dangers/; L. Val Giddings, "Points to Consider: The Worldwide Scientific Consensus on GMO Safety," *Innovation Files* (blog) ITIF, May 22, 2014, http://www.innovationfiles.org/points-to-consider-the-worldwide-scientific-consensus-on-gmo-safety/; Jon Entine and Rebecca Randall, "Scientific consensus on GMO safety stronger than for global warming," *Genetic Literacy Project*, January 29,2015, https://www.geneticliteracyproject.org/2015/01/29/pewaaas-study-scientific-consensus-on-gmo-safety-stronger-than-for-global-warming/; Food and Agriculture Organization of the United Nations (FAO), "Steady increase in incidents of low levels of GM crops in traded food and feed," March 13, 2014, http://www.fao.org/news/story/en/item/216311/icode/.
52. Food and Agriculture Organization of the United Nations (FAO), "FAO Statement on Biotechnology," statement, March 2000, http://www.fao.org/biotech/fao-statement-on-biotechnology/en/.
53. Val Giddings, "A Policymaker's Guide to the GMO Controversies" (Information Technology and Innovation Foundation, February 23, 2015), https://itif.org/publications/2015/02/23/policymakers-guide-gmo-controversies.
54. Francesco Panella et al., (open letter to the commission on new genetic engineering methods, Corporate Europe Observatory (CEO), January 27, 2015), http://corporateeurope.org/sites/default/files/attachments/new_breeding_techniques_-_open_letter_27_jan_2015-1.pdf.
55. David Wafula et al., "Biosafety Legislation and Biotechnology Africa," 72–77.
56. Robert Paarlberg, *Starved for Science*.
57. "Debate Rages after Ruto Announces Plan to Lift Ban on GM Food," *The Daily Nation*, October 26, 2015, http://www.nation.co.ke/news/Debate-rages-over-plan-to-lift-ban-on-GM-food/-/1056/2930078/-/view/printVersion/-/dhop8e/-/index.html.
58. Ibid.
59. Judith Chambers, "Biosafety of GM Crops in Kenya, Uganda, and Tanzania: An Evolving Landscape of Regulatory Progress and Retreat" (Center for Strategic and International Studies, December 2013), http://csis.org/files/publication/131127_Chambers_BiosafetyGMCrops_Web.pdf.
60. E. Jane Morris, "The Cartagena Protocol: Implications for Regional Trade and Technology Development in Africa," *Development Policy Review* 26, no. 1 (2008): 29 – 57. DOI: 10.1111/j.1467-7679.2008.00397.x; UNEP, "Cartagena Protocol on Biosafety."
61. Liz Orton, "GM Crops – Going Against the Grain" (ActionAid, May 2003), https://www.actionaid.org.uk/sites/default/files/doc_lib/against_the_grain.pdf.
62. Isaac Ongu, "ActionAid in Africa Ensnared by Its Own Ugly GMO Cancer Scare Tactics" (Genetic Literacy Project, March 30, 2015) http://www.geneticliteracyproject.org/2015/03/30/actionaid-in-africa-ensnared-by-its-own-ugly-gmo-cancer-scare-tactics/; Isaac Ongu, "As Disease Threatens Uganda's Banana Crop, ActionAid and Anti-GMO Groups Fan Fears" (Genetic Literacy Project, July 27, 2015, http://www.geneticliteracyproject.org/2015/07/27/as-disease-threatens-ugandas-banana-crop-actionaid-and-anti-gmo-groups-fan-fears/.
63. Michael J. Ssali, "President's Speech on Biotech was Spot On," *Daily Monitor*, November 18, 2015 at http://www.monitor.co.ug/Magazines/Farming/President-s-speech-biotech-spot-/-/689860/2959828/-/csb1c7/-/index.html; Clet Wandui Masiga, "President Museveni's Commitment to Adoption of Genetically Modified Organisms (GMOs) Could Earn Him Another Term," *Uganda New Vision*, November 5, 2015,http://www.newvision.co.ug/new_vision/news/1329849/musevenis-commitment-gmo-adoption-earn-term; Isaac Ongu, "Uganda's President Museveni Endorses GMOs, Tipping Scales in Reluctant Parliament" (Genetic Literacy Project, October 28,

2015), http://www.geneticliteracyproject.org/2015/10/28/ugandas-president-museveni-endorses-gmos-tipping-scales-in-reluctant-parliament/#.VjIHT5n7im8.twitter.

64. Enoch Kikulwe, Justus Wesseler, and Jose Falck-Zepeda, "Introducing a Genetically Modified Banana in Uganda: Social Benefits, Costs, and Consumer Perceptions," (discussion paper 00767, International Food Policy Research Institute, 2008).
65. Bridget Mugambe, (open letter opposing human feeding trials involving GM banana, Alliance for Food Sovereignty in Africa (AFSA), December 09, 2014), http://afsafrica.org/afsa-open-letter-opposing-human-feeding-trials-involving-gm-banana/; Isaac Ongu, "African Elites Blame Early Puberty on GMOs, Sabotaging Nutrition-Enhanced Cassava, Matooke" (Genetic Literacy Project, January 30, 2015), https://www.geneticliteracyproject.org/2015/01/30/african-elites-blame-early-puberty-on-gmos-sabotaging-nutrition-enhanced-cassava-matooke/.
66. "Strict liability" is a legal term of art referring to liability that is enforced without regard to actual fault or responsibility; see The Free Dictionary, accessed February 1, 2016, http://legal-dictionary.thefreedictionary.com/Strict+Liability.
67. A. Wallace Hayes, letter to G. E. Séralini, November 19, 2013, http://www.gmwatch.org/files/Letter_AWHayes_GES.pdf.
68. Philip Pullella, "African Priests Criticize Vatican GMO Conference," *Reuters*, November 11, 2003, reprinted on Mindfully.org, http://www.mindfully.org/GE/2003/African-Priests-GMO11nov03.htm; Noah Zerbe, "Feeding the Famine? American Food Aid and the GMO Debate in Southern Africa," *Food Policy* 29 (2004): 593–608, http://staff.washington.edu/jhannah/geog270aut07/readings/GreenGeneRevolutions/Zerbe%20-%20GMOs%20in%20food%20aid.pdf.
69. Convention on Biological Diversity, Biosafety Clearing House, (finding information, record details, authorized focal point entry for Zambia); accessed February 1, 2016), http://bch.cbd.int/database/record.shtml?documentid=9602.
70. Hilma Hashange, "Namibia: Agronomic Board Condemns Genetically Modified Maize in Retail Products," *AllAfrica*, February 22, 2013 http://allafrica.com/stories/201302220915.html.
71. Jocelyn Shing-Jy Tsao and Hsiao-Feng Lo, "Vegetables: Types and Biology," in *Handbook of Food Science, Technology, and Engineering*, Volume 1, ed. Y. H. Hui, (Boca Raton, FL: CRC Press/Taylor & Francis, 2006), http://www.crcnetbase.com/doi/abs/10.1201/b15995-23.
72. Jairam Ramesh, "Decision on Commercialisation of Bt Brinjal," (New Dehli: Ministry of Environment and Forests, February 9, 2010), http://www.moef.nic.in/downloads/public-information/minister_REPORT.pdf; T.V. Padma, "India Braced for Fireworks over GM Aubergine Ban," *The Guardian*, January 31, 2011, http://www.theguardian.com/environment/blog/2011/jan/31/gm-aubergine-india.
73. Chetan Chauhan, "Govt Approves Field Trials for Varieties of GM Crops," *Hindustan Times*, July 15, 2014, http://www.hindustantimes.com/india-news/modi-led-government-approves-field-trials-for-21-new-varieties-of-gm-crops/article1-1240373.aspx; K. Vijayaraghavan, "India the epicenter of GM crops," *FnBnews*, April 21, 2015, http://www.fnbnews.com/Agriculture/India-the-epicenter-of-GM-crops.
74. Phillip Sherwell, "India Bans Foreign Funds for Greenpeace in Latest Crackdown on Charities with Western Ties," September 4, 2015, *The Telegraph* http://www.telegraph.co.uk/news/worldnews/asia/india/11845586/India-bans-foreign-funds-for-Greenpeace-in-latest-crackdown-on-charities-with-Western-ties.html; Colin Bettles, "Greenpeace under Tax-Free Fire," *Stock and Land*, November 26, 2015, http://www.stockandland.com.au/story/3519253/greenpeace-under-tax-free-fire/?cs=4590; Ezra Levant, "Taxman Audits, Enviro Groups Panic," *Toronto Sun*, February 10, 2014, http://www.torontosun.com/2014/02/10/taxman-audits-enviro-groups-panic.
75. Jose M. Yorobe, Jr. and Melinda Smale, "Impacts of Bt Maize on Smallholder Income in the Philippines," *AgBioForum* 15, no. 2 (2012), http://www.agbioforum.org/v15n2/v15n2a04-yorobe.htm.
76. Jose M. Yorobe, Jr. and Cesar B. Quicoy, "Economic Impact of Bt Corn in the Philippines," *The Philippine Agricultural Scientist* 89, no. 3 (September 2006): 258–267, http://www.isaaa.org/kc/Publications/pdfs/documents/Economic%20Impact%20of%20Bt%20Corn%20in%20the%20Philippines.pdf; Maria Mutuc, Roderick Rejesus, and Jose M. Yorobe, Jr., "Which Farmers Benefit the Most from Bt Corn Adoption in the Philippines? Estimating Heterogeneity Effects,"

(selected poster prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguaçu, Brazil, 18–24, August 2012), http://ageconsearch.umn.edu/bitstream/126363/2/IAAE_Bt_Corn_Het.pdf; Santi Sanglestsawaia, Roderick M. Rejesus, and Jose M. Yorobe, "Do Lower Yielding Farmers Benefit from Bt Corn? Evidence from Instrumental Variable Quantile Regressions," *Food Policy* 44 (February 2014):285–296, http://www.sciencedirect.com/science/article/pii/S0306919213001395.

77. David Tribe and Bruce Chassy, "1.7—No Evidence that Pollen Causes Disease," (Academics Review), http://academicsreview.org/reviewed-content/genetic-roulette/section-1/1-7-bt-corn-pollen-is-safe/.
78. John Vidal, "Philippine Study on Frankencorn Allergenicity Generates Controversy," *The Guardian*, February 27, 2004, reprinted in Organic Consumers Association, https://www.organicconsumers.org/old_articles/ge/philippine-allergy.php; John Aglionby, "Filipino Islanders Blame GM Crop for Mystery Sickness," *The Guardian*, March 2, 2004 http://www.theguardian.com/environment/2004/mar/03/food.gm; Terje Traavik and Jeffrey Smith, "Bt-Maize (Corn) During Pollination, May Trigger Disease in People Living Near the Cornfield," *Mindfully*, February 24, 2004, http://www.mindfully.org/GE/2004/Bt-Corn-Human-Disease24feb04.htm.
79. Rick Roush, et al., (open letter to Terje Traavik, AgBioWorld, March 8, 2004), http://www.agbioworld.org/biotech-info/pr/traavik.html.
80. DJ Yap, Jerome Aning, "Court of Appeals Stops Field Trials of Genetically Modified Eggplant," *Philippine Daily Inquirer*, May 25, 2013 http://business.inquirer.net/123697/court-of-appeals-stops-field-trials-of-genetically-modified-eggplant.
81. David Ropeik, "Filipino Ruling on Bt Eggplant," *Scientific American Gust Blog*, June 3, 2013, http://blogs.scientificamerican.com/guest-blog/filipino-ruling-on-bt-eggplant/.
82. "GM Crops Are Safe, Scientists Say," (Nueva Ecija, Philippines: Philippines Department of Agriculture Philippine Rice Research Institute, September 30, 2011), http://www.philrice.gov.ph/gm-crops-are-safe-scientists-say/; "Genetically Engineered Crop Research Backed," *Philippine Daily Inquirer*, October 3, 2013 http://business.inquirer.net/145723/genetically-engineered-crop-research-backed; Michael Purugganan, "The SC Kills Bt Talong, and Takes Down Philippine Science as Well," *The Rappler*, December 9, 2015, http://www.rappler.com/thought-leaders/115436-sc-kills-bt-talong-takes-down-philippine-science.
83. Kai Kupferschmidt, "Activists Destroy 'Golden Rice' Field Trial," *Science*, August 9, 2013, http://news.sciencemag.org/asiapacific/2013/08/activists-destroy-golden-rice-field-trial.
84. Mark Lynas, "The True Story About Who Destroyed a Genetically Modified Rice Crop," *Slate*, August 26, 2013, http://www.slate.com/blogs/future_tense/2013/08/26/golden_rice_attack_in_philippines_anti_gmo_activists_lie_about_protest_and.html.
85. "NAST Philippines Statement on the Sabotage of the Golden Rice Multilocational Trial in Pili, Camarines Sur," (Taguig City, Philippines: Republic of the Philippines, Department of Science and Technology), http://region4a.dost.gov.ph/news/644-nast-philippines-statement-on-the-sabotage-of-the-golden-rice-multilocational-trial-in-pili-camarines-sur.
86. Channa Prakash, "Global Scientific Community Condemns the Recent Destruction of Field Trials of Golden Rice in the Philippines," Change.org, https://www.change.org/p/global-scientific-community-condemns-the-recent-destruction-of-field-trials-of-golden-rice-in-the-philippines.
87. Justus Wesseler and David Zilberman, "The Economic Power of the Golden Rice Opposition," *Environment and Development Economics* 19, no. 6 (December 2014): 724–742, http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=9402215&fileId=S1355770X1300065X.
88. World Health Organization, Micronutrient Deficiencies, Vitamin A Deficiency, (programmes, nutrition, nutrition topics; accessed February 1, 2016), http://www.who.int/nutrition/topics/vad/en/.
89. Golden Rice Humanitarian Board, The Golden Rice Project, Vitamin A Deficiency-Related Disorders (VADD), (why, vitamin A deficiency; accessed February 1, 2016), http://www.goldenrice.org/Content3-Why/why1_vad.php.
90. Hembree Brandon, "Former Greenpeace Activist Terms Opposition to GMOs 'Crime Against Humanity'," *Farm Press Blog*, April 6, 2015, http://deltafarmpress.com/blog/former-greenpeace-activist-terms-opposition-gmos-crime-against-humanity; Michael Dzakovich, "GMO 'Right to Know'

Movement Takes Food Off of Plates of Hungry in Africa, Asia" (Genetic Literacy Project, June 25, 2015), http://www.geneticliteracyproject.org/2015/06/25/gmo-right-to-know-movement-takes-food-off-of-plates-of-hungry-in-africa-asia/.

91. 2013 is the most recent year for which data is available.
92. James, "Global Status of Commercialized Biotech"; Naglaa A. Abdallah, "The Story Behind Bt Cotton: Where Does Sudan Stand?" *GM Crops & Food* 5, no. 4 (2014), http://www.tandfonline.com/doi/ref/10.1080/21645698.2014.997119.
93. This estimation assumes prices and all other factors hold constant. ITIF uses a yield increase of 22% and the biotech improved variety crop adoption rates of maize, soybean, and cotton to provide an average adoption rate for biotech improved crops.
94. Food and Agriculture Organization of the United Nations Statistics Division Data, (production, value of agricultural production; accessed September 28, 2015), http://faostat3.fao.org/home/E.
95. United Nations Statistics, (national accounts main aggregates database, value added by economic activity constant 2005 US$, Africa, 2013; accessed September 28, 2015), http://unstats.un.org/unsd/snaama/resQuery.asp
96. The World Bank, Country and Lending Groups (country groupings based on World Bank data; accessed February 1, 2016), http://data.worldbank.org/about/country-and-lending-groups; Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT) (value of all production, gross production value, constant 2004–2006 US$; accessed February 1, 2016), http://faostat3.fao.org/home/E.
97. Ibid.
98. Don Snodgrass, "Agricultural Transformation in Sub-Saharan Africa and the Role of the Multiplier" (Washington, DC, United States Agency for International Development (USAID), August 2014), https://www.microlinks.org/sites/default/files/resource/files/Ag_Transformation_in_SSA_and_the_Role_of_the_Multiplier_0.pdf.
99. Ibid.
100. Aloyce R. Kaliba et al., "Economic Multipliers for Tanzania: Implications on Developing Poverty Reduction Programs."

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ABOUT THE AUTHORS

L. Val Giddings is a senior fellow at ITIF with three decades of experience in science and regulatory policy relating to biotechnology innovations in agriculture and biomedicine. He is also president and CEO of PrometheusAB, Inc., providing consulting services on biotechnology issues to governments, multilateral organizations, and industry clients. Before founding PrometheusAB, he served eight years as vice president for food & agriculture of the Biotechnology Industry Organization (BIO) and a decade as a regulatory official with the U.S. Department of Agriculture. Giddings received his Ph.D. in genetics and evolutionary biology from the University of Hawaii in 1980.

Robert D. Atkinson is the founder and president of the Information Technology and Innovation Foundation. He is also the co-author of the book *Innovation Economics: The Race for Global Advantage* (Yale, 2012). Atkinson received his Ph.D. in City and Regional Planning from the University of North Carolina at Chapel Hill in 1989.

J. John Wu joined ITIF in September 2015 as an economic research assistant. Prior to this, he graduated from The College of Wooster with a Bachelor of Arts in economics and sociology, with a minor in environmental studies. His research interests include green technologies, labor economics, and time use.

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