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AGRICULTURAL BIOTECHNOLOGY ADOPTION IN DEVELOPING COUNTRIES

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Over the last ten years, modern agricultural biotechnology has been adopted rapidly at the global level, including in several developing countries. This trend has been most apparent for genetically modified (GM) crops. While the first GM crops were officially commercialized in the United States in 1995, in 2004 GM crops were already grown by more than 8 million farmers in seventeen countries on a total area of 81 million hectares (James). This is the fastest diffusion of any new crop technology in the history of humankind. The most widely used GM technologies involve herbicide tolerance (HT) applied in soybean and canola, and insect resistance, based on genes isolated from *Bacillus thuringiensis* (Bt), applied in maize and cotton. Recent studies about the agronomic and economic impacts demonstrate that on average adopting farmers benefit from income increases through reduced pest control costs and higher effective yields (Carpenter et al.; Traxler et al.; Pray et al.; Morse, Bennett, and Ismaël, Thirtle et al.; Qaim and Zilberman, Qaim and de Janvry 2005; Qaim and Traxler). These studies even suggest that the farm-level benefits tend to be bigger in developing than in developed countries.

Nonetheless, the suitability of GM crops for developing countries remains a controversial issue in the public debate. Also, the aggregate area statistics mask the fact that widespread adoption is limited to only a few technologies in a couple of relatively advanced countries (table 1). As GM technologies differ from previous crop innovations, such as the high-yielding varieties (HYVs) of the Green Revolution, it is important to analyze what exactly these differences are, and how they influence the patterns of technology adoption. The major differences are threefold:

- First, while traditionally the supply of improved seeds to smallholder farmers in developing countries was dominated by the public sector, GM crop development and commercialization are driven by the private sector—mostly rich country multinationals. Associated with this, intellectual property rights (IPRs) have gained in importance.
- Second, GM crops are associated with new environmental and health risks, entailing new regulatory procedures at national and international levels. Uncertainty and risk aversion have also led to limited public acceptance and precautious policy approaches in many countries.
- Third, modern biotechnology permits a separation between the act of developing a specific crop trait and the breeding of locally adapted germplasm. Thus, unlike previous HYVs, the outcome of GM research is not a particular new variety, but a transformation event, or a GM trait, which can be used for backcrossing into numerous locally adapted varieties.

As the whole innovation system—from technology generation in the lab to application in farmers' fields—is affected by these phenomena, we take a broad view on the adoption process and consider two aspects, namely technology availability and technology access. Although the boundaries are not clear cut in all cases, this disaggregation is useful for analytical purposes. Within this framework, we review the empirical evidence on GM crop adoption and impacts in developing countries. Furthermore, we analyze adoption constraints and briefly discuss some policy implications.

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Table 1. National Availability of GM Technologies (2004)

Country	Area under GM Crops (Million ha)	Percentage of World Total	Available Technologies[a]
USA	47.6	58.8	HT soybean, Bt maize, HT maize, HT cotton, HT canola (and stacked genes)
Argentina	16.2	20.0	HT soybean, Bt maize, Bt cotton, HT maize
Canada	5.4	6.7	HT canola, Bt maize, HT soybean
Brazil	5.0	6.2	HT soybean
China	3.7	4.6	Bt cotton
Paraguay	1.2	1.5	HT soybean
India	0.5	0.6	Bt cotton
South Africa	0.5	0.6	Bt maize, HT soybean, Bt cotton
Uruguay	0.3	0.4	HT soybean, Bt maize
Australia	0.2	0.2	Bt cotton
Romania	<0.1	<0.1	HT soybean
Mexico	<0.1	<0.1	Bt cotton, HT soybean
Spain	<0.1	<0.1	Bt maize
Philippines	<0.1	<0.1	Bt maize
Colombia	<0.05	<0.1	Bt cotton
Honduras	<0.05	<0.1	Bt maize
Germany	<0.05	<0.1	Bt maize

[a]Technologies are listed for each country in decreasing order of area coverage.
Sources: James, United States Department of Agriculture.

Biotechnology Availability

The range of desirable crop traits that could potentially be developed by use of modern biotechnology is very broad, ranging from biotic and abiotic stress resistances, over higher yield potentials and better nutrient efficiency, up to improved product qualities and new plant ingredients. So far, however, only very few concrete GM traits have been commercialized, and only two have reached significant levels of adoption: of the 81 million hectares of GM crops in 2004, 72% were grown with HT crops and 19% with Bt crops; the rest of the area involves crops with stacked HT and Bt traits. Similarly, the range of GM crop species commercially available up till now is small: soybean, maize, cotton, and canola account for over 99% of the total (James). The main reasons for this narrow focus are the private sector dominance and corporate profitability considerations. Since biotechnology research and especially also testing and approval procedures are expensive, large commercial markets are required to cover initial investments. Public acceptance problems also play an important role in this connection: the American company Monsanto, for instance, had developed and tested GM wheat, but in early 2004 they decided to shelve this technology due to consumer resistance, especially in Europe. Multinationals have little incentive to develop GM crops for small or uncertain markets, so that particular technologies for developing countries are unlikely to emerge, unless targeted public sector activities are increased considerably.

Apart from technology availability at the international level, availability at the national level needs to be considered. Before a certain GM technology commercialized in one country can be used somewhere else, it usually needs to be adapted to the new local conditions. Furthermore, possible IPR restrictions have to be settled, and the technology has to be approved by national biosafety and food safety authorities. Table 1 gives an overview of GM crop technologies commercially available in different countries. The poorest countries in Africa and Asia are still missing from this list. There are widespread concerns that the proliferation of IPRs would limit the access of poor countries to modern biotechnologies. Yet, as IPRs are national, this has not been a major constraint up till now. While strong IPRs restrict the freedom-to-operate among developed country research organizations, many technologies are not patented in developing countries, so they could be freely used. In other cases, private companies have been willing to donate their proprietary technologies for use by resource-poor farmers. IPR issues might become more complex in the future, since members of the World Trade Organization are required to strengthen their national IPR regimes. So far, however, other factors have been more constraining.

Besides a few countries with very strong national agricultural research systems—such as China, India, or Brazil—most of the poorer developing countries suffer from limited capacities and institutional constraints. In a recent survey, Cohen has shown that many developing countries have biotechnology research programs in place. However, except for one Bt cotton event in China, none of these national programs have yet resulted in a commercialized and widely used technology, due to lack of resources and lack of experience with testing and regulatory procedures. The prevailing model for GM crop innovation in developing countries has been that multinationals commercialize their products that were initially developed for rich country markets, either directly or in cooperation with local seed companies. Yet this type of technology transfer only occurs when the recipient country offers sufficient commercial incentives for foreign companies. Effective IPR protection might increase the incentives, but there are other criteria, which are at least as important. These include the size and maturity of the respective crop market and the expected efficiency in technology approval procedures (Qaim and Traxler).

Protracted and uncertain biosafety procedures can certainly discourage the willingness to invest for private companies. While proper testing is essential for GM technologies in every new environment, biosafety procedures have been highly politicized in many countries. Since biosafety approval is usually the last hurdle prior to commercialization, the responsible authorities are often the target of intensive lobbying, regardless of whether or not concerns are related to actual environmental and health risks. In India, for instance, biotechnology opponents managed to convince the authorities that a social impact assessment should become part of biosafety clearance. In other cases, trade concerns have prolonged the approval process, especially in food-exporting countries like Brazil or Thailand. Such instances add significantly to the overall costs for the applicant, both in terms of actual expenditures for further testing and foregone benefits due to unpredictable delays. In the public debate, actual and perceived environmental and health risks are intermingled with broader concerns about globalization and corporate dominance (Paarlberg). Against this background, applications for biosafety approval by foreign multinationals are certainly observed more suspiciously. More public GM technologies and new credible forms of public–private partnerships could help reduce the widespread distrust in this early phase, and thus improve biotechnology availability at the national level.

Biotechnology Access

This section analyzes farmers' access to GM technologies that have been commercialized at the national level. As for other technologies, farmers' access to GM crops and the actual adoption decision depend on technological characteristics as well as the agronomic and socioeconomic context. Again, we will emphasize how the mentioned differences between GM and conventional crop technologies influence observed adoption patterns—this time within countries. The focus is on HT soybeans and insect-resistant Bt cotton, because these are the two most widely adopted GM technologies in developing countries.

Average Profitability

The most important criterion for farmers in their adoption decision is whether the new technology is profitable for them, which can be through cost reductions or revenue increases. Herbicide tolerance and insect resistance were developed to enhance pest control in farmers' fields, so it is not surprising that they lead to significant reductions in chemical pesticide expenditures. Table 2 shows that average pesticide savings range between 33% and 77% for both technologies. While for HT soybeans the cost savings are due to cheaper herbicides that can be used with GM technology, Bt cotton is associated with a proportional reduction in insecticide quantities used by farmers. In addition, Bt cotton adoption results in significant yield gains, which is due to more efficient control of crop losses through insect pests. Owing to higher pest pressure and technical and financial constraints in smallholder agriculture, such yield gains are usually higher in developing than in developed countries (Qaim and Zilberman). Overall, adopting farmers benefit from sizeable net income gains per hectare of GM crops grown.

Table 2. Adoption and Farm Level Benefits of GM Crops in Developing Countries

	Argentina					South Africa
Item	HT Soybean	Bt Cotton	China Bt Cotton	India Bt Cotton	Mexico Bt Cotton	Bt Cotton
Commercialized since	1996	1998	1997	2002	1996	1998
Adoption rate[a] (%)	98	10	66	7	50	85
Change in pesticide cost (%)	−43	−47	−65	−41	−77	−33
Change in yield (%)	0	33	24	34	9	22
Change in seed cost (U.S.$/ha)	4	87	32	56	58	13
Change in net income (U.S.$/ha)	23	23	470	111	295	18
Farmers' benefit share[b] (%)	86	21	94	66	84	58
Companies' benefit share[b] (%)	14	79	6	34	16	42

[a] Share of total national soybean/cotton area under GM technology in 2004.
[b] Consumer benefits are neglected here.
Sources: Qaim and Traxler; Qaim and de Janvry (2003); Pray et al.; Qaim et al.; Traxler et al.; and Thirtle et al.

Related to profitability is the issue of seed prices, which also affect farmers' access. The GM technologies available so far have almost exclusively been commercialized by private companies, so a price premium is charged on GM seeds. The magnitude of the premium largely depends on the strength of IPR protection in a country, and thus the degree of market power of the innovating company. Under current IPR regimes in developing countries, patent protection for GM technologies is rare. Nonetheless, contractual arrangements or technical use restrictions sometimes limit farmers' opportunities to use farm-saved seeds. Table 2 shows the average additional seed costs that farmers face when using GM technologies. Where no legal or technical restrictions apply, as for HT soybean in Argentina and Bt cotton in China, the additional seed cost is relatively small. Contractual use restrictions are employed for Bt cotton in Argentina and Mexico, leading to higher average seed costs. Also in South Africa, cotton farmers are not allowed to reproduce Bt seeds. Nonetheless, the cost increase is small, because the seed-supplying company price discriminates, with small-scale farmers paying significantly less than their larger counterparts (Gouse, Pray, and Schimmelpfennig). India is one of the few countries where the use of cotton hybrids is widespread. Since hybrids can only be reproduced with a notable decline in productivity, there is a technical restriction to use farm-saved Bt seeds.

Unsurprisingly, seed price premiums affect the distribution of technological benefits between farmers and private companies. Additionally, table 2 shows that there is a close negative correlation between average seed cost increases and rates of adoption in a country.[1] This suggests that farmers' demand for GM seeds is price responsive. Indeed, the strength of national IPR protection does affect farmers' access to GM crops and thus technology adoption rates. Yet the widespread public concern that IPRs would inevitably lead to an exploitation of smallholder farmers can be negated on empirical grounds. Farmers do not have to use GM seeds: when price premiums are too high, they simply decide not to adopt the technology and stick to conventional seeds instead.

Farmer Heterogeneity

A high profitability for the majority of adopters does not imply that every single farmer will benefit from a particular GM technology. Especially for insect-resistant crops, the suitability depends on local pest infestation levels, which can vary regionally and seasonally. In China, for instance, infestation levels of lepidopteran pests are highest in the northern and eastern parts of the country, so that the benefits of Bt cotton are most pronounced there. This is reflected in much higher adoption rates, as compared to western China (Pray et al.). In the United States, due to diverging pest infestation levels, Bt cotton adoption rates are lower in California than in other cotton-growing states.

But also within a region, GM crop impacts can vary according to conventional pest control strategies and other farm and household

[1] The relatively low adoption share for Bt cotton in India in 2004 is due to the fact that the technology was only commercialized there in 2002. Adoption rates in India are still increasing rapidly.

Table 3. Adoption and Disadoption of Bt Cotton in a Sample of 375 Indian Farmers

Item	2002–03	2003–04	2004–05	2005–06[a]
Number of adopters	113	108	165	251
Number of disadopters after the season	51	26	18	n.a.
Number of disadopters, who re-adopted in any of the following seasons	38	14	n.a.	n.a.
Average farm size of adopters (ha)	6.6	5.7	6.2	5.6
Average farm size of nonadopters (ha)	4.9	5.3	4.8	5.0

Note: Farmers were sampled randomly from four states: Maharashtra, Karnataka, Andhra Pradesh, and Tamil Nadu. In 2002–03, Bt adopters were purposely oversampled, so the data should not be used to derive overall Bt cotton adoption rates.
[a] Farmers' intention before the 2005–06 season had started.
Source: Own survey.

characteristics. In the early stages of diffusion, farmers usually experiment with a new technology, and they re-consider their adoption decision based on personal experiences made. The adoption dynamics for Bt cotton in India are shown in table 3 for a sample of 375 typical farms. Although adoption levels within the sample increased substantially over the first years of technological diffusion, the process is not unidirectional. After the first season in 2002–03, almost half of the adopters abandoned Bt technology, because they were not fully satisfied. Also in subsequent seasons, some disadoption was observed, albeit the percentage of dropouts has been decreasing over time. Interestingly, a remarkable share of the disadopters re-adopted Bt technology after a break of one or two years. These patterns clearly demonstrate that GM crop adoption and disadoption are not irreversible decisions for farmers; they are part of a normal learning process.

Scale effects of GM technologies have to be assessed case by case. HT soybean technology, for instance, is more appropriate for large and mechanized farms, where weeds are controlled chemically. Hardly any experience with this technology has been made in smallholder agriculture. Bt cotton, on the other hand, has been widely adopted by small-scale farmers in China, India, and South Africa (Pray et al., Qaim et al., Thirtle et al.). Many of these farms have a size of less than one hectare. Since GM seeds are divisible, and insect pests are relevant for both small and large farms, Bt cotton technology is neutral in scale. Productivity gains can even be bigger for small than for large farms (Morse, Bennett, and Ismaël; Qaim and de Janvry 2005). The empirical evidence also suggests that farmers can realize Bt cotton advantages independent of their level of education. The technology is relatively easy to use, because insect resistance reduces the need to spray chemical pesticides.

However, the level of resource endowments can play an important role for farmers' risk considerations and their access to rural finance and extension information (Sunding and Zilberman). Especially where GM seed premiums are high, as for Bt cotton in Argentina, resource-poor farmers might not be able to adopt the technology due to risk aversion and credit constraints (Qaim and de Janvry 2003). Also in other countries, larger farms are often the early adopters of GM technologies, but smaller farms follow suit when the innovation proves beneficial. Table 3 shows that the difference in farm sizes between Bt cotton adopters and nonadopters in India is relatively small, with a decreasing trend over time. Nevertheless, targeted policy support will be needed in situations where resource-poor farmers face serious institutional constraints, as is often the case in developing countries. GM crops and other agricultural technologies cannot substitute for policies to reduce market failures.

Agrobiodiversity and Germplasm Effects

The fact that GM research results in technologies, which can be used in different varieties, is also an important aspect when analyzing access to biotechnology. Farmers located in marginal agroecological areas were largely bypassed by previous crop innovations, because the cost of developing particular varieties for these areas was relatively high compared to the expected productivity gains. This could change with modern biotechnology, since backcrossing available GM traits into locally adapted varieties is relatively straightforward. Marginal farmers could especially gain from crop resistance to biotic and abiotic stress factors. The

Table 4. Estimated Number of GM Varieties Available in Selected Countries (2004)

Country	Technology	Area under Technology (Ha)	Total Number of GM Varieties/ Hybrids	Based on Locally Adapted Germplasm	Based on Imported Germplasm
USA	HT soybean	26 million	1,200	1,200	0
	Bt maize	9.6 million	750	750	0
	Bt cotton	2.3 million	19	19	0
	HT cotton	3.3 million	24	24	0
Argentina	HT soybean	14.5 million	61	50	11
	Bt maize	1.6 million	21	15	6
	Bt cotton	25,000	2	0	2
China	Bt cotton	3.7 million	40	35	5
India	Bt cotton	500,000	4	4	0
Mexico	Bt cotton	30,000	2	0	2
South Africa	Bt maize	395,000	11	4	7
	Bt cotton	38,000	3	0	3

Sources: James, United States Department of Agriculture, Carpenter et al., and communication with various industry representatives.

incorporation of GM traits into many local varieties could also reduce the loss of agrobiodiversity observed in many countries during the Green Revolution. Instead of replacing many local varieties with only a few HYVs, GM versions of these local varieties could be made available at relatively low cost. Whether this will happen in reality is largely a question of institutional arrangements. Table 4 shows the estimated number of varieties available for different GM technologies in selected countries.

Unsurprisingly, the number of available GM varieties is positively correlated with the area under the technology. A minimum market size per variety appears to be necessary to justify the additional cost for backcrossing. Furthermore, IPRs play an important role. When a GM technology is patented, breeders need to get a license before they can use it in their germplasm. Non-exclusive licenses can result in a large number of GM varieties, as HT soybean and Bt maize in the United States demonstrate. An exclusive license with only one seed company, however, can potentially result in a loss of agrobiodiversity, especially when the GM trait is so powerful that farmers adopt it even when it is not incorporated into varieties optimally suited for their conditions. This can also be associated with a re-structuring in seed markets. For instance, Delta and Pineland's exclusive license for Monsanto's Bt cotton in the United States and South Africa led to a notable increase in the company's seed market share (Carpenter et al., Gouse et al.).

When a GM technology is not IPR protected in a country, local breeders can use it without a license. A case in point is China, where Bt cotton varieties are produced and marketed by several local breeding stations and seed companies. In India, Bt cotton is not patented, but every single Bt hybrid has to be approved by the national Genetic Engineering Approval Committee, also when it is based on an already sanctioned transformation event. In the first years after Bt cotton commercialization in India, only three Bt hybrids had been approved, which were grown on large areas in different regions. Since these hybrids were not well adapted to all environments, the productivity advantage associated with the Bt gene was partly offset by general germplasm disadvantages in some locations (Qaim et al.). However, thirteen new Bt hybrids were approved in 2005 for different regions of India, and further hybrids are at the stage of large-scale field trials. Hence, negative effects through unadapted germplasm will be reduced in subsequent seasons. This example from India clarifies that biotechnology cannot be seen as a substitute for conventional crop improvement approaches. A GM technology can only unfold its full potential when incorporated into the best varieties and hybrids available from local breeding programs.

The experience with GM crop adoption in poorer developing countries is still scant. National biotechnology availability presupposed, limited local breeding capacities in these countries could potentially lead to a loss of agrobiodiversity and technology access problems for farmers located in marginal environments. Public policy support, including from the international community, should be targeted at reducing related institutional constraints. A monopolization of seed markets with a narrow germplasm base would be highly undesirable on economic, social, and environmental grounds.

Summary and Conclusions

We have analyzed and explained the adoption patterns of modern agricultural biotechnology in developing countries by reviewing the empirical evidence. The major differences with respect to previous crop technologies are that GM crops are mainly developed by the private sector, that they are associated with new risks and thus regulatory requirements, and that GM traits can be incorporated into different varieties adjusted to local conditions. These features influence technology availability and technology access by farmers.

Although GM crops have been rapidly adopted in recent years, the portfolio of available technologies is still rather small, because private companies focus on large and lucrative markets. At the national level in developing countries, commercial technology availability is further hampered by protracted biosafety procedures, which in many cases are highly politicized. The fact that almost all GM technologies tested so far have been developed by multinational corporations does not help to overcome the public distrust, which is widespread in many countries. More public research and innovative models of public-private partnerships—in research, testing, and commercialization—are required for improving the international and national availability of promising biotechnologies for developing countries.

In countries where GM crops have been commercialized already, farmers have widely adopted them. IPRs and technical use restrictions affect GM seed prices and the distribution of benefits. However, since farmers retain the option to use conventional varieties, their GM seed demand is price responsive, and the companies' monopoly power is limited. Recent impact studies demonstrate that GM crop adoption is associated with sizeable benefits for farmers and the environment in developing countries. Nonetheless, public support will be needed to improve technology access for marginalized growers. Like any agricultural technology, GM crops should not be seen as a substitute for policies aimed at improving the functioning of rural input and output markets.

In summary, biotechnology holds great potentials for developing countries, including for the small farm sector. Suitable GM technologies, which are incorporated into locally adapted germplasm, can contribute to income growth and sustainable agricultural development. Yet successful examples are still limited to only a few concrete applications in relatively advanced developing countries. The empirical evidence suggests that the private sector can and should play an important role for biotechnology innovation among the poor. But realizing the benefits on a larger scale requires complementary public endeavors in research and institutional design.

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