Economic Considerations on Agricultural Biotechnology in Developing Countries

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Abstract

The global production of genetically modified crops (GM crops) has been increasing at a relatively fast pace for the past 15 years, and so far more than 95 percent of the area devoted to GM crops is located in four countries: the United States, Brazil, Argentina and India (James 2009).

In the same period, a growing movement of opposition against transgenic crops – mainly in Europe – started to take form, leading to the development of strict legislation and regulations on the import and release of GM crops into the environment and on the market for food and feed uses. These restrictions and the lack of demand for these products has limited the expansion of agrobiotechnology in developing countries.

Modern biotechnology is a great challenge for countries and societies worldwide, not only due to the difficulties in defining a strategy able to take into account any possible or potential risks related to these new technologies but also on account of the need to establish a careful decision-making process able to guarantee that society can enjoy the benefits brought by this technology while minimizing its costs. In this article I will make some economic considerations on the applications of agricultural biotechnology in developing countries.

Poverty is a multi-dimensional problem,
which needs to be approached through several strategies.

Agrobiotechnology poses a great challenge for the global economy: the economies of all the countries taking advantage of this technology are in certain respects connected and mutually influence each other.

Despite its diffusion in the past 20 years, biotechnology still has enormous potential to create additional changes in agriculture, and this is even more the case when we refer to developing countries. In many developing countries, in fact, agrobiotechnology is still moving its first steps and transgenic products have not yet reached the commercialization phase. Moreover, there is no other application in agriculture that is so emotionally debated by citizens, scientists and even the stakeholders or governments concerned. The topic thus affects not only the economics of agricultural production, but also the organization and development of research, consumer welfare and the political debate concerning potential risks or threats posed to the environment, human and animal health.

The concerns of consumers and environmentalists permeate the debate on the topic, in some cases even affecting its commercial application and dissemination, and manifesting differently in developed and developing countries.

Worldwide agricultural biotechnology between 2008 and 2010

The global financial crisis hit the overall global economy, and the biotechnology industry was no exception. The disproportionate fall in the stock market impacted the smallest industrial firms and caused their valuation to fall steeply.

The market turmoil caused a strong reduction in cash availability in 2008: biotechnology company gains fell by 46 % from USD 30 billion in 2007 to USD 16 billion in 2008 and the biggest losses took place in public funding. What can be observed is a loss in net income (-53 %), a reduction in the number of employees (-5 %) and a reduction in the number of companies, both private (-2 %) and public (-5 %) (BiotechCorp 2010) both in the United States and Europe. On the other hand, Asia-Pacific revenues grew by 25 % in 2008, led by strong growth in Australia (Ernst & Young 2009).

The Asian biotechnology industry continued to grow, despite the effects of the financial crisis, mainly due to the investments made by governments and foreign investors, and by a growing number of cross-border collaborations. The Asia-Pacific biotechnology market value grew by 7.10 %, corresponding to USD 45.1 billion in 2008, the leaders of this growth being China with 14 % and Japan with 41.2 % (BiotechCorp 2010).

The major advantage of the Asian economy is that it is cost-competitive, but this is not the only criterion requested for being able to compete with the Western market. For this reason, governments in the whole Asia-Pacific region are working to develop strategic plans or national biotechnology policies, to revisit existing regulations and implement new rules for boosting innovation and commercialization, R&D and human capital development.

The Asia-Pacific region has been investing more and more every year in R&D, fundamental for the development of the biotechnology industry, but the amount of money allocated is lower than that of its global counterparts, and the main funding comes typically from governments. To give an idea, biotechnology R&D expenditure in Asia-Pacific was USD 601 million in 2008, with an increase of 14 % from the amount allocated in 2007 (USD 401 million), but it represented only 2 % of the global expenditure of USD 31.8 billion in 2008 (BiotechCorp 2010).

Another very important parameter for the biotechnology industry is human capital: it is in fact essential for industries to rely on knowledge and expertise in loco. In 2008, Asia-Pacific had only 7.7 % of the 15,530 total employees in the biotechnology industry, even though more than a third of the world's population lives in this area (Ernst & Young 2009). To overcome the problem, many Asian countries like Singapore, China, India and Australia have started programmes and allocated money to attract foreign talent, for university student exchange programmes and to retain skilled researchers in the field of business and science; strategies that should enable them to become even more competitive in the biotechnology field against Western countries. Australia with its business programmes extended to postgraduate students and young scientists, and Singapore with its strong network activities and initiatives driven by A*STAR (Agency for Science Technology and Research) scholarship programmes, combined with the high level of infrastructure and quality of life, are perfect examples of how other Asian countries should act to become really competitive in the international biotechnology market.

Focusing specifically on agricultural biotechnology, the International Seed Federation estimates that the global seed market accounted for USD 36.5 millions in 2008 (of which 64 % in OECD countries – excluding

Iceland, Norway and Luxemburg) (International Seed Federation 2008) and for USD 37 millions in 2010 (of which 62.5 % in OECD countries – excluding Iceland, Norway and Luxemburg – and 20.3 % in China and India; data updated to August 2010) (International Seed Federation 2010).

Data on cultivation shows a huge increase in hectares planted with transgenic crops in 2009 despite the effects of the economic crisis. According to Clive James, 'more than three-quarters (77 %) of the 90 million hectares of soybean grown globally were biotech; for cotton, almost half (49 %) of the 33 million hectares were biotech; for maize, over a quarter (26 %) of the 158 million hectares grown globally were biotech; and finally for canola, 21 % of the 31 million hectares were biotech' (James 2009), and developing countries play an important role in the above quoted percentages. In fact, Brazil, Argentina, India, China, Paraguay, South Africa, Uruguay and Bolivia cultivated a total of 60.7 millions hectares of biotech crops in 2009. The Philippines with its 0.5 millions hectares of plantation land is the only country of South-East Asia ranking among the 25 major biotech crop growing countries named by James in the report. Specifically in the Philippines, double stacked maize, engineered with both pest resistance and herbicide tolerance, is considered responsible for the increase from 57 % of transgenic crops cultivated in 2008 to 69 % in 2009.

If we consider the global biotech area cultivated in 2009 (134 million hectares), soybean accounted for 69.2 millions hectares, followed by maize with 41.7 million hectares, cotton with 16.1 million hectares and canola with 6.4 million hectares. Herbicide tolerance has been the dominant trait expressed in GM crops since 1996; herbicide tolerant soybean, canola, cotton, maize, sugar beet and alfalfa represent 62 % of the whole range of transgenic crops cultivated in 2009.

Up to August 2009, 20 varieties of GM crops destined for commercialization (versus 74 already approved) had a pending status according to USDA data: alfalfa (1), cotton (2), bentgrass (1), eucalyptus (1), maize (10), papaya (1), rose (1) and soybean (3). Interestingly, 14 of them are engineered for so-called first generation traits such as herbicide tolerance, insect resistance or a combination of both, while the remaining 6 have second generation traits, i.e. agronomic and product quality traits (e.g.

yield enhancement, tolerance to adverse growing conditions, altered ripening characteristics) and male sterility (Arundel & Sawaya 2009).

Although GM varieties of more than 10 different plant species have been approved for cultivation all around the world, only a few of them are extensively cultivated and dominate the market, as shown in Table 1. This table gives an overview of the main transgenic crops cultivated in 2009 and the main GM traits, each broken down into the area of cultivation and the percentage of total area cultivated with transgenic crops.

Table 1. Overview of the biotech crops cultivated worldwide in 2009

Main GM crops cultivated in 2009	Area (million hectares)	Percentage of total GM cultivated area
Soybean	69.2	52 %
Maize	41.7	31 %
Cotton	16.1	12 %
Canola	6.4	5 %
Total	**133.4**	**100 %**
Main traits present in GM crops cultivated in 2009	**Area (million hectares)**	**Percentage of total GM cultivated area**
Herbicide tolerance	83.6	62 %
Stacked double and triple traits	28.7	21 %
Insect resistance	21.7	15 %
Total	**134.0**	**98 %**

Source: James (2009), rearranged.

Field trials around the world had been conducted for more than 130 transgenic plant species by the end of 2008. However, 94.5 % of these trials (in terms of number of hectares) were carried out for only 25 species, with maize accounting for almost 40 %, wheat for 4.3 %, and rice for only 1.5 %. Table 2 shows the 10 species with the largest number of trials, 85.4 % of the total.

Table 2. Total field trials broken down into plant species

Species	Number of field trials*	Percentage
Maize	8.170	38.1
Rapeseed	2.120	9.9
Soybean	1.770	8.2
Potato	1.628	7.6
Cotton	1.242	5.8
Wheat	921	4.3
Tomato	770	3.6
Alfalfa	685	3.2
Beet	540	2.5
Tobacco	462	2.2
Total	**18.308**	**85.4**

** data updated to the end of 2008.*
Source: Data UNU-MERIT (United Nations University Maastricht Economic and Social Research and Training Centre on Innovation and Technology), rearranged.

Costs, risks and benefits

A consideration of the economic aspects of biotechnology in agriculture must take many issues into account. One of the most important in my view, is the analysis of how risks and benefits connected to agricultural biotechnology will affect the different stakeholders (i.e. the universities or private institutes developing the technology), the farmers as main users of the technology, and the consumers as main recipients of the final product obtained through the technology.

Many uncertainties and financial risks deriving from the application of biotechnology to agriculture are related to the costs of the whole process: from developing new transgenic crops to placing them on the market; these costs and risks are spread among all the stakeholders mentioned above.

The costs for dealing with the entire process of commercializing transgenic crops are indeed influenced by the regulatory framework and the documentation requested from the authorities in charge of the final decision. It is common for private companies investing in agrobiotech to register patents and other intellectual property rights (IPRs) for biotechnological inventions, a normal route for covering the investment costs and making profits. This situation can create an imbalance between public and private research, especially in view of the fact that public research rarely has the same facilities and availability of money as the private sector. Many new forms of public-private partnerships are a consequence of the growing involvement of private companies in agrobiotechnology research, but there is great concern that the independence of public research could be compromised.

At the farm level, other costs and uncertainties have to be faced. Some costs are related to the need to buy transgenic seeds covered by IPRs every year, but these costs are not the only ones. The price of GM crops can vary compared to the price of conventional crops, depending on government regulations or the public acceptance of transgenic crops; the yields are unpredictable and can be influenced by external factors (unpredictable climate conditions for example), thus making it impossible for the farmer to recover their investment. Hence, in the long run, the risks posed by the release into the environment of transgenic crops are unpredictable. Gene flow in plants can enable domesticated plants to become pernicious weeds, or it can enhance the fitness of wild plants (turning them into weeds and shifting the ecological balance in a natural plant community), or new viruses could develop from virus-containing transgenic crops. Plant-produced insecticides might have harmful effects on unintended targets. While some of these scenarios are highly unlikely, and many scientists are ready to deny any potential impact on the environment, little is known about the overall impact that transgenic crops can have on biodiversity, ecosystem balance and the environment in the long run (Wesseler 2007).

Consumers, on the other hand, can perceive transgenic crops as risky for different reasons. Besides the potential threat to human health – although not proved, the potential idea alone that a product might well be *not safe* is enough to discourage many consumers. Transgenic crops can also be rejected for ethical reasons, including the discriminatory action against developing countries posed by the patenting system or the idea that transgenic crops could help in fighting famine in developing countries, perceived as false and hypocritical by many consumers. Moreover, the first generation of transgenic crops (engineered for insect resistance or herbicide tolerance) do not provide any important benefit for the customer; a different approach towards second generation biotech crops, modified to improve nutritional content, could take place especially if perceived more useful for people in developing countries.

Addressing the potential benefits deriving from the introduction of transgenic crops is very complex and requires competence in statistics and economics plus the use of analytical, deterministic and stochastic models beyond my means; in this chapter, anyway, I will report some considerations on this point.

Criticism of the idea that transgenic crops could benefit poor or subsistence farmers with small holdings or marginal lands are mainly due to two main factors: the nature of GMOs that have been developed and commercialized so far (specifically the traits they are engineered with), together with the features of the patenting system and regime of prices applied by the leading corporations on the market.

The main traits present in the so called first-generation GMOs, i.e. insect resistance and herbicide tolerance, are designed to reduce losses from pests and weeds – and not specifically developed to address more pressing needs from the poor (staple crops such as cereals with improved yields or enhanced nutritional values; traits such as drought or salinity resistance that would allow crops to grow better in marginal environments). A concern is that companies will develop products that can pay back their investments, for which there is a strong market for large farmers in developed countries rather than subsistence farmers in developing countries; moreover, corporations may charge more for GM seeds than conventional ones, and most of these are even covered by patents that limit their accessibility for small-scale farmers, typically from developing countries.

Many studies, however, report that high seed prices and the limited variety of GM crops available have not entirely prohibited small farmers in Asia and other parts of the developing world from using – and benefiting from – GMOs (Food and Agriculture Organization of the United Nations 2004). In some countries, adoption of GM crops has occurred when small farmers have applied technology already developed for larger-scale operations. For example, *Bt*-cotton has been adopted in several developing countries in Asia, and farmers in the Philippines are now growing *Bt*-maize (La Vina & Fransen 2004).

In developed and developing countries, many empirical economic studies tend to reveal income gains for farmers who plant GM seeds (Huang & Wang 2002; Pray, Huang, Hu, & Rozelle 2002; Qaim 2010; Traxler 2004) and will be described in more detail in the next paragraph.

Empirical studies on costs and benefits of agrobiotechnology have been conducted in the United States, where transgenic corn, cotton, rapeseed, and soybean were introduced in the mid-1990s. Specific analyses of benefits from the introduction of *Bt*-crops showed that farmers benefit most, followed by the agrobiotech industry and then consumers, and that developing countries importing transgenic products from the USA are found to share the benefits, even if the urban-rural population ratio, and the level of net-food production, have to be taken into consideration in evaluating the total benefits at national level (Wesseler 2005; 2007).

Economic benefits of agricultural biotechnology in developing countries

The world's economic landscape has significantly changed over the past 15 years when GM crops started to be cultivated extensively. Here are some considerations on the economic implications this technology has brought along.

In 1996, a total of 1.66 million hectares of transgenic crops were planted around the world, and cultivation increased substantially during the following 14 years. In 2009 the global area cultivated with transgenic crops reached almost 134 million hectares, with four transgenic crops accounting for virtually all of the biotech area cultivated: soybean – 51.6 %, corn – 31 %, cotton – 12 %, and canola – 4.6 % (James 2009).

These data describe an interesting panorama: the increase in cultivation of transgenic crops has been definitely huge in the past 15 years, but the percentage of transgenic crops cultivated is not so high compared with the area cultivated with conventional crops (it should be noted that the above four crops represent 99 % of total transgenic crop cultivation, but they do not by any means represent 99 % of total crops cultivated around the world).

Transgenic crops were first cultivated in Argentina in 1996. So far, 99 % of the soybean cultivated in Argentina is engineered for herbicide tolerance (HT). Since Monsanto was not able to obtain patent protection for its transgenic crops, Argentine farmers were free to save and use biotech seed without paying any technology fees or royalties (on farm-saved seed) for many years and saved even more from the reduction of expenditure on herbicides, spray runs and machinery expenses. Moreover, they benefited from the possibility of cultivating two crops (wheat followed by soybean) in one season due to the adoption of low/no tillage production systems reducing the time required for harvesting and drilling subsequent crops (Brookes & Barfoot 2010).

Herbicide tolerant soybean was first cultivated in Brazil in 1997 and the benefits obtained by the farmers are very similar to those described for Argentina. Specifically, the total benefits obtained by farmers and corporate owners of the technology in the past 13 years were approximately USD 3.6 billion, with GM soybean accounting for 78 %, GM maize (introduced in 2008/2009) for 18 % and cotton (introduced in 2004/2005) for 4 %. Interestingly, 63 % of these USD 3.6 billion result from cost savings due to the introduction of transgenic crops and 18 % from the increase in yield production compared to conventional crops (Celeres 2010). This means that 81 % of the benefits really reached the farmers, while the remaining 19 % went to the industries involved.

While the introduction of herbicide tolerant soybean has been found convenient for countries with GM soybean cultivation, the same conclusion cannot be drawn for herbicide tolerant corn. Although undoubted benefits have been obtained by farmers, mainly due to reduced costs for herbicides and expenses related to weed control, the farm income benefit from 1997 to 2008 was USD 1.9 billion (92 % due to cost savings and only 8 % to yield gains) – 82 % of this went to US farmers, leaving roughly 15 % to farmers in developing countries. South Africa represents an even more negative example. Herbicide tolerant corn has been grown in South Africa since 2004. In 2008, a total of 640,000 hectares of GM corn were planted (almost 25 % of the total corn planted). Due to the significant rise in the global price of glyphosate, South African farmers suffered a total net farm loss of USD 1.43 million arising from the use of herbicide tolerant corn (Brookes & Barfoot 2010).

Corn and cotton engineered for insect resistance, however, seemed to provide even more benefits than disadvantages to farmers both in developed and in developing countries compared to herbicide tolerant crops.

Insect resistant (IR) corn has been cultivated in South Africa since 2000; in 2008, 56 % of the total corn cultivated was GM corn (IR corn). The estimated increase in farm income in 2008 due to the cultivation of GM corn was USD 117.7 million and the net increase in national maize production amounted to 5.9 % (Van der Weld 2009). The Philippines has cultivated GM corn (specifically IR corn) since 2003. In 2008, a total area of 280,000 hectares was cultivated with insect resistant corn with a national farm income benefit of roughly USD 33.5 million (James 2009).

Insect resistant (IR) cotton, namely *Bt*-cotton, has been cultivated in China since 1997, representing 64 % of the total 5.95 million hectares grown in 2008 with a net national gain to farm income of roughly USD 859 million. The most important benefits derived mainly from the higher yields of transgenic crops (increase of 8 to 10 %) and the reduction of costs for insecticides and the labour involved in spraying. *Bt*-cotton has been cultivated in India since 2002. In 2008, 6.97 million hectares of *Bt*-cotton were planted resulting in a farm income gain of USD 1.79 billion. From 2002, the total farm income gain has been USD 5.14 billion (Brookes & Barfoot 2010).

When arguing the case of the economic benefits due to the introduction of agrobiotechnology, some other factors beyond the figures cited above have to be taken into consideration. There are in fact some indirect impacts, which are therefore less quantifiable economically, but interesting to be considered in an overall estimation. According to the literature (Brookes

2008; Rice 2004; Raney 2006; Vain 2007), some reasons leading to the introduction of biotech crops in both developed and developing countries have been identified, and have a huge impact on the decision of many farmers to cultivate transgenic crops, as summarized in the following table.

Table 3. Indirect economic impacts due to the introduction of GM crops

Herbicide Tolerant Crops	Insect Resistant Crops
Increased management flexibility due to the combination of the use of broad-spectrum herbicides and longer window of time for spraying.	Increase in the insurance value of the harvest due to a reduced risk of pest damage.
Introduction of low/no tillage production systems, causing a reduction in the time required for harvesting and drilling subsequent crops.	Reduction in costs for insecticides, manual labour and machinery use for applying insecticides.
Reduction of harvesting costs due to improved weed control.	Shorter growing seasons that allow farmers two harvests in one season (e.g. India*, cotton followed by maize).
Reduced persistence of herbicides in the soil that could be incorporated in the following cultivation or cause weeds to grow.	Best quality of crops, when demonstrated (many articles indicate reduced mycotoxin levels in transgenic corn**)

** IMRB (2007); Pray et al. (2002).*
*** To cite some examples: Abbas et al. (2008); Wu (2006).*
Source: Brookes & Barfoot (2010); Fransen et al. (2005), rearranged.

Small-scale farms: Economic benefits due to the introduction of transgenic crops

A number of articles from the literature (Anderson & Jackson 2005; FAO 2009; Qaim 2010; Raney 2006) underline that the widely diffused perception that only large farms will benefit from the introduction of biotech crops is not supported by economic evidence. In this paragraph I will describe the situation of small-scale farms in India after the introduction of *Bt*-cotton, showing some of the results obtained.

India is the country with the largest *Bt*-cotton cultivation area, specifically 8.4 million hectares in 2009, followed by China with 3.7 million hectares (James 2009). Most of these areas are cultivated with Monsanto's Bollgard I (modified with the Cry1Ac gene), but Bollgard II (engineered with both Cry1Ac and Cry2Ab genes) has also made its appearance in several countries. So far, more than 5 million Indian farmers have been growing *Bt*-cotton on almost 90 % of the total cotton area of the country, and most of the cotton farms are small-scale, mainly in the central and southern part of India: the average size of these farms is less than 5 hectares, with an average cotton area of roughly 1.5 hectares (Qaim 2010).

The next table shows the results of a comparative analysis of *Bt*-cotton versus conventional cotton in three growing seasons: 2002–2003, 2004–2005, 2006–2007.

Table 4. Advantages of *Bt*-cotton compared to conventional cotton in India

	Season 2002–2003	Season 2004–2005	Season 2006–2007	Average
Insecticide use	-50 %	-51 %	-21 %	-41 %
Yield	+34 %	+35 %	+43 %	+37 %
Seed costs	+221 %	+208 %	+68 %	+166 %
Total variable costs	+17 %	+11 %	+24 %	+17 %
Gross revenue	+33 %	+37 %	+40 %	+37 %
Profit	+69 %	+129 %	+70 %	+89 %

Source: Sadashivappa & Qaim (2009).

Farm-level economic gain from the introduction of agrobiotechnology results from the combination of cost reductions and the subsequent return in terms of production compared to the other available alternatives.

According to the figures reported in Table 4, we can observe undoubted benefits for the farmers due to the reduction in insecticide use (average reductions in *Bt* cultivations were 41 % over the three growing seasons considered) and a substantial increase in yields, due to lower crop losses and reduction in crop damage as a consequence of improved pest control (average yields 37 % higher).

Higher yields, crop revenues and reduction of expenses for pesticides compensated for the significant seed costs and turned out to bring benefits to small-scale farms.

Cases of positive economic impacts have also been reported for China (Pray et al. 2002), South Africa (Van der Weld 2009), Mexico (Raney 2006) and Argentina (Qaim & Traxler 2004), as shown in Table 5. In these countries, as well as India, *Bt*-cotton is normally grown by small farms (even less than three hectares of land), but the overall trend observed in India is confirmed in other countries as well (Qaim 2010).

Table 5. Results of the introduction of *Bt*-cotton in different countries

	China	S. Africa	India	Argentina	Mexico
Yield	+19 %	+65 %	+34 %	+33 %	+11 %
Revenue	+23 %	+65 %	+33 %	+34 %	+9 %
Pesticide costs	-67 %	-58 %	-41 %	-47 %	-77 %
Seed costs	+95 %	+89 %	+17 %	+530 %	+165 %
Profit	+340 %	+229 %	+69 %	+31 %	+12 %

Source: Raney (2006), rearranged.

What must be pointed out, however, is that farmers in developing countries might benefit from the introduction of transgenic crops, but this is a highly complicated process when it is not supported by a relatively high level of national institutional capacity, and the policies adopted by the governments in developing countries can make a truly significant difference here.

I would like to draw attention to the high seed costs shown in Tables 4 and 5. A cost reduction could significantly increase the net profit for the farmers. These costs are mainly due to intellectual property rights and trade agreements and represent a key topic in the debate among civil societies, non-governmental organizations and governments on the ethical issues related to agricultural biotechnology.

Conclusions

Genetic engineering applied to agriculture has great potential although the analysis of impacts and benefits is undoubtedly complex and should be done on a case-by-case basis, both in terms of products and countries taken into consideration. Genetic engineering products can differ very significantly, and it is therefore very important not to discuss the impacts of GM crops in general, but to differentiate between the countries involved, different crops and specific contexts. Small-scale farms in developing countries seem to benefit from the introduction of transgenic crops, but data are still scarce and detailed or comparative studies are not yet available for every nation. On the other hand, economic gain cannot be the only parameter to be taken into consideration when planning environmental releases or commercialization of GM products. Cultural and ethical issues and citizens' choices should also find a way to fit into the debate that leads to the adoption of this technology.

However, what is really important in my point of view is that technology should not be judged on the basis of prejudices or fear, nor on the basis of the excitement generated by new discoveries, but because it is *appropriate* to the situation we are considering: appropriate, meaning accessible, affordable, easy-to-use and maintain, effective, and most importantly *able to serve a real need*.

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