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Economic impact of transgenic crops in developing countries

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Transgenic crops are being adopted rapidly at the global level, but only a few developing countries are growing them in significant quantities. Why are these crops so successful in some countries but not in others? Farm level profitability ultimately determines whether farmers adopt and retain a new technology, but this depends on much more than technical performance. Recent economic studies in developing countries find positive, but highly variable, economic returns to adopting transgenic crops. These studies confirm that institutional factors such as national agricultural research capacity, environmental and food safety regulations, intellectual property rights and agricultural input markets matter at least as much as the technology itself in determining the level and distribution of economic benefits.

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Introduction

Transgenic crops are spreading more rapidly than any other agricultural technology in history, suggesting that farmers perceive important advantages in growing them. Developing countries now account for 38% of global transgenic crop area [1], despite continuing controversy surrounding them.

This review of recent peer-reviewed research on the *ex post* economic impacts of transgenic crops in developing countries confirms several other recent reviews [2^{••},3^{••},4] in finding positive, but highly variable, impacts over time and space. Most of the papers covered by this review were published within the past two years, although a few earlier ground-breaking papers are included because they are central to the economic debates on the subject.

The economic evidence available to date does not support the widely held perception that transgenic crops

benefit only large farms; on the contrary, the technology may be pro-poor [5^{••}]. Nor does the available evidence support the fear that multinational biotechnology firms are capturing all of the economic value created by transgenic crops. On the contrary, the benefits are shared by consumers, technology suppliers and adopting farmers, although non-adopting farmers are penalized as their competitors achieve efficiency gains they are denied [6].

This review attempts to identify the factors that influence the level and distribution of the economic value created by transgenic crops in developing countries. The availability of suitable transgenic crop cultivars in a country is the most basic requirement for successful adoption by farmers [7,8]. Institutional factors such as national research capacity [9–11], intellectual property rights (IPRs) [12[•]], environmental and food safety regulatory capacity [13[•],14[•],15], trade regulations [16,17] and the existence of functioning input markets [2^{••}] are crucially important determinants of the level and distribution of gains.

Although this survey clearly shows that farmers in developing countries can benefit from transgenic crops, it also illustrates the formidable institutional challenges that must be met.

Economic impacts in developing countries

The farm-level economic impact of transgenic crops depends on the costs of and returns to growing them compared with alternative varieties. Most studies use a partial accounting framework to compare production costs and returns for adopters versus non-adopters of transgenic crops.

The most extensive *ex post* studies of transgenic crop adoption in developing countries have been conducted for insect-resistant (IR) cotton in Argentina, China, India, Mexico and South Africa. Transgenic herbicide-tolerant (HT) soybeans are being grown in Argentina, Brazil, Paraguay and elsewhere, but Argentina is the only developing country for which peer-reviewed studies have been published. Some developing countries also produce HT and/or IR maize, but the only peer-reviewed *ex post* analyses of their impacts published so far are for Argentina and South Africa.

Table 1 summarizes the results from the most comprehensive economic studies of the farm-level impacts of IR cotton in developing countries. Each of the studies was based on data from two or three seasons of commercial farm production. The figures in Table 1 reflect the

Table 1**Performance advantage of IR over conventional cotton expressed as a percentage.**

	Argentina	China	India	Mexico	South Africa
Yield	33	19	34	11	65
Revenue	34	23	33	9	65
Pesticide costs	-47	-67	-41	-77	-58
Seed costs	530	95	17	165	89
Profit	31	340	69	12	299

Source: Author's calculations based on Argentina [23]; China [18]; India [36**]; Mexico [30]; and South Africa [25].

average percentage difference between IR and conventional cotton for all farmers over all seasons covered in the study.

Although the averages conceal a high degree of temporal and spatial variation, they clearly indicate positive overall results. Farmers who adopted the transgenic varieties experienced higher effective yields (owing to less pest damage), higher revenue and lower pesticide costs. These factors more than compensated for higher prices paid for IR seeds so that net profits increased for adopters.

China

China, where some 7.5 million small farmers are growing IR cotton, represents the most successful case so far in terms of productivity, farmer incomes, equity and sustainability [18]. Much of China's success rests on its highly developed public agricultural research system, which has independently produced two transgenic constructs that confer insect resistance. These have been incorporated into a large number of locally adapted cotton varieties and compete directly with Monsanto's IR cotton varieties. As a result, transgenic seed prices are much lower in China than elsewhere and farmers reap substantially higher returns. The role of the public sector in developing and distributing IR cotton varieties has been instrumental in reducing the price premium. Lower costs and marginally higher yields translate into large net profit gains in China.

Chinese farmers experience lower yield gains than in many other countries, because pest damage on conventional cotton is controlled by heavy pesticide use. China has been able to significantly reduce its use of chemical pesticides on cotton, with important environmental and farmer health benefits [19]. Field trials for IR rice in China suggest a similar pattern of significantly lower pesticide use and small yield gains [20*].

Pray and Huang [21] analysed the distribution of IR cotton benefits in China by farm size and found the innovation to be decidedly pro-poor. The smallest farms (less than 0.47 hectares [ha]) experienced the largest yield gains, and mid-size farmers (0.47–1.0 ha) had the largest reductions in total costs owing to less pesticide use. In

terms of net income, the gains for the two smaller farm-size categories were more than twice those for the largest farms (over 1.0 ha).

Argentina

The Argentine experience with IR cotton provides an interesting comparison with the Chinese case in terms of the effect of IPRs. Monsanto has strictly enforced its IPRs on IR cotton in Argentina and charges significantly higher prices than for conventional cotton seed [22]. As a result, IR cotton offers relatively small returns and thus has not been widely adopted. This is in contrast with HT soybeans, which have been enthusiastically embraced by Argentine farmers. The authors conclude that the crucial difference is that Monsanto failed to patent its soybean innovation in Argentina and thus has been unable to strictly enforce its IPRs.

HT soybeans are estimated to have increased total factor productivity in Argentina by 10% on average, with the cost savings being slightly greater for smaller farms (less than 100 ha) than for larger farms, owing mainly to lower seed prices among small farmers who are more likely to use uncertified seed than larger farms [23]. Aggregate global welfare benefits from HT soybeans are estimated at more than US \$1.2 billion, with the largest share going to consumers (53%), followed by seed and biotechnology firms (34%) and farmers (13%). Owing to comparatively weak intellectual property protection, Argentine soybean growers receive 90% of the benefits in that country.

The only published study to look comprehensively at transgenic crop adoption in Argentina [24] credits them with major responsibility for transforming the farming sector, although transgenic maize and cotton have been of less value to farmers than soybeans.

South Africa

South Africa provides another important lesson about the role of institutions. South Africa has a dualistic farm sector with large commercial farms served by a modern input supply system operating along side smallholder semisubsistence farms. IR cotton and yellow IR maize were introduced in 1998/99. White IR maize varieties (preferred for food) were introduced in 2001/02, and free seed was distributed by Monsanto to smallholders on a trial basis.

For IR cotton, several studies [25,26] have found positive economic impacts for smallholder farmers in the Makhathini Flats of KwaZulu Natal province, where a local cooperative provided seed on credit along with technical advice. Within the smallholder category, in the first year IR adopters were more likely to be older males with larger farms who were specially targeted by the cooperative, by the second year both genders and all age groups and farm sizes were equally likely to adopt.

Table 2

Performance advantage of IR over non-IR cotton in India, listed by state, expressed as a percentage.

	Yield		Revenue		Chemical costs		Total costs		Profits	
Maharashtra	32	***	29	***	-44	***	15	**	56	***
Karnataka	73	***	67	***	-49	***	19	**	172	***
Tamil Nadu	43	***	44	***	-73	***	5		229	***
Andhra Pradesh	-3		-3		-19		13	*	-40	
National average	34	***	33	***	-41	***	17	***	69	***

Values were calculated for the year 2002/03. Source: [36**]. Statistically different from zero at the 10% (*), 5% (**) and 1% (***) significance levels.

The benefits were widely shared by all farm types, and both studies found significant pro-poor benefits. Pesticide use also declined significantly, having both environmental and health benefits. In a study comparing results for smallholders versus large farms, the smallholders were found to benefit more than large dryland farms, but less so than large irrigated farms [27].

The Makhathini Flats IR cotton success story was not sustained, however [28**]. The local cooperative also ran the only cotton gin in the area, thereby assuring a high rate of debt recovery. When another cotton gin opened in the region, the cooperative was no longer assured repayment of its debts and ceased providing IR cotton seed on credit in 2002/03 and cotton production in the region has fallen drastically.

A comparison of IR maize varieties and their non-IR counterparts in South Africa in 2001/02 found that large commercial farmers experienced yield, pesticide and income advantages, while smallholders experienced higher yields [29*]. The authors argue that the main constraint to smallholder IR maize adoption will be the ability of seed companies to provide seed at affordable prices.

Mexico

The Mexican case provides a clear example of the importance of introducing effective innovations [30]. The IR cotton varieties available in Mexico (as with most varieties available elsewhere) incorporate a gene from the soil bacterium *Bacillus thuringiensis* (Bt), which confers resistance against a narrow range of pests. Comarca Lagunera is the only state in Mexico where these pests constitute the major threat to cotton production; hence, it is the only state where IR cotton has been widely adopted. The major pests in other states require continued chemical pesticide use, making the IR varieties of less value. The authors estimate that farmers gained 83% of the total economic value created by the crop on average for the two years in the study.

India

Despite the rapid expansion of IR cotton in India, its economic impact continues to be hotly contested with some critics charging that IR adopters are worse off than conventional growers [31]. The first economic studies

were based on farm-level field trial data, and as such did not reflect the actual farm experience with commercial cultivation [32,33]. These studies estimated potential yield benefits of 80%. Later farm-level research found smaller, but significant, yield advantages [34] even for unofficial varieties [35*].

A subsequent study, summarized in Table 1 and shown in detail in Table 2, was based on farm-level data from four different states in India [36**]. This study found large net gains from IR cotton adoption at the national level, although significant variation was observed across states and one state, Andhra Pradesh, experienced negative results. The authors speculated that the lack of locally adapted cultivars was the main reason for poor performance in this state. At the time of the study, the Indian biosafety authorities had approved only four IR cotton varieties for use throughout the country. By 2005, that number had increased to 20, and the area of the country planted with IR cotton almost tripled from the previous year [1].

Conclusions

The evidence reviewed in this paper suggests that farmers in developing countries can benefit from transgenic crops, but a fairly high level of national institutional capacity is required to ensure that farmers have access to suitable innovations on competitive terms. A certain level of national research and regulatory capacity are prerequisites, along with effective IPR management and input supply systems, especially for seeds. The economic results so far suggest that farmers in developing countries can benefit from transgenic crops, but for the poorest farmers in the poorest countries, where institutional conditions are weak, ensuring access will remain a formidable challenge.

Acknowledgements

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References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- of special interest
- of outstanding interest

1. James C: **Preview: global status of commercialized biotech/ GM crops: 2005**. ISAAA 2005. *ISAAA Briefs* No. 34.

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2. Food and Agriculture Organization: **Agricultural biotechnology: meeting the needs of the poor?** *The State of Food and Agriculture 2003-04*. Food and Agriculture Organization; 2004:3-106.

This report provides a comprehensive survey of agricultural biotechnology – especially transgenic crops – in developing countries and explores its potential for alleviating poverty and hunger. The report analyzes the socio-economic impacts of technological change and reviews the economic impacts of transgenic crops in developing countries thus far. The report also reviews the environmental and food safety hazards associated with transgenic crops and evaluates the scientific evidence to date. Recommendations to enhance delivery of appropriate innovations to farmers in poor countries are made.

3. Qaim M, Matuschke I: **Impacts of genetically modified crops in developing countries: a survey.** *Q J Int Agric* 2005, **44**:207-227. This article reviews the evolving academic literature on the economic and environmental impacts of transgenic crops in developing countries. The authors conclude that farmers in developing countries can benefit substantially from proprietary, private-sector innovations, but that more public sector involvement in research, product development and dissemination are required to reach marginalized farmers and consumers.

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5. Ruttan VW: **Controversy about agricultural technology – lessons from the green revolution.** *Int J Biotechnol* 2004, **6**:43-54.

Reviews the productivity and equity effects of technological change in agriculture on the basis of the green revolution experience and draws lessons for the likely impact of biotechnology.

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12. Zilberman D, Graaf G: **IPR innovation and the evolution of biotechnology in developing countries.** *Q J Int Agric* 2005, **44**:247-266 Special Issue.

The authors examine the impact of IPR regimes on agricultural biotechnology research and argue that, although the current system of patents and proprietary information effectively generates innovations for large commercial markets, it neglects niche markets, including those aimed at the poor.

13. Evenson R, Santaniello V (Eds): *The Regulation of Agricultural Biotechnology*. CABI Publishing; 2004.

This book of selected papers from the International Consortium for Agricultural Biotechnology Research (ICABR) provides a good introduction to, and overview of, the economics of regulation for agricultural biotechnology. The annual ICABR meetings are often the first place where academic research on the economics of agricultural biotechnology is presented, and several volumes of selected papers on various themes have been published.

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This paper investigates the economics of biosafety regulations in developing countries and finds that, although the direct costs of compliance can be high, they are often dwarfed by the indirect costs of profits foregone by the technology developer when approval is delayed or denied. These costs act as a disincentive to R&D by private firms.

15. Wesseler J (Ed): *Environmental Costs and Benefits of Transgenic Crops*. Springer; 2005.

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18. Pray C, Huang J, Hu R, Rozelle S: **Five years of Bt cotton in China – the benefits continue.** *Plant J* 2002, **31**:423-430.

19. Huang J, Hu R, Pray C, Qiao F, Rozelle S: **Biotechnology as an alternative to chemical pesticides: a case study of Bt cotton in China.** *Agric Econ* 2003, **29**:55-67.

20. Huang J, Hu R, Rozelle S, Pray C: **Insect-resistant GM rice in farmers' fields: assessing productivity and health effects.** *Science* 2005, **308**:688-690.

This work studies two of the four GM rice varieties that are being considered for commercialization in China on the basis of farm-level pre-production trials. Farm surveys of randomly selected farm households that are cultivating the IR rice varieties, without the aid of experimental station technicians, demonstrate that small and poor households benefit through both higher yields and reduced use of pesticides, which in addition to lower costs also contribute to improved health. Yield advantages were also apparent, but comparisons with non-GM varieties suggest that the available IR varieties might not have the best available background germplasm.

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27. Gouse M, Pray C, Schimmelpfennig D: **The distribution of benefits from Bt cotton adoption in South Africa.** *AgBioForum* 2004, **7**:187-194.

28. Gouse M, Kirsten J, Shankar B, Thirtle C: **Bt cotton in KwaZulu Natal: technological triumph but institutional failure.** *AgBiotechNet* 2005, **7**:1-7.

This study reviews the experience of poor small-scale farmers in South Africa with Bt cotton adoption and examines the institutional arrangements underpinning the initial success and ultimate failure of the technology. The study concludes that Bt cotton could be an excellent technology for other African countries, but warns that institutional failure is the norm rather than the exception in Africa.

29. Gouse M, Pray C, Kirsten J, Schimmelpfennig D: **A GM subsistence crop in Africa: the case of Bt white maize in South Africa.** *Int J Biotechnol* 2005, **7**:84-94.

This paper examines the economic impact of the first transgenic staple food crop to be adopted anywhere in the world. IR varieties of yellow maize have been grown by large commercial farmers in South Africa since 1998, but it is used primarily in animal feed. White maize is the preferred food crop, and IR varieties were first made available to farmers in 2001. The study evaluates the economic impacts of IR maize by farm size and concludes with policy recommendations to make IR maize more accessible to small farmers.

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The study evaluated the relative merits of two official and two unofficial Bt cultivars with a popular non-Bt counterpart in Gujarat. Unofficial varieties

have not received government authorization, which has several implications: they are less costly because no royalties are paid, they may be newer varieties because they have not undergone a lengthy approval process, but they might be less reliable than the official varieties. The study confirmed that both of the official Bt varieties outperformed the unofficial and non-Bt varieties in terms of yields and net profits. However, the unofficial locally produced Bt hybrid also performed significantly better than the non-Bt hybrids.

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This paper evaluates the farm-level economic impacts of Bt cotton in four states in India in 2003 controlling for existing variability in pest pressure, pesticide use and germplasm. The average results for India show a significant positive impact on farm returns, but they mask considerable regional variations.