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Global Impact of Biotech Crops: Income and Production Effects, 1996-2007

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This article updates the assessment of the impact of commercialized agricultural biotechnology on global agriculture from an economic perspective. It examines specific global economic impacts on farm income, indirect (non-pecuniary) farm-level income effects and impacts on the production base of the four main crops—soybeans, corn, cotton, and canola. The analysis shows that there have been substantial net economic benefits at the farm level, amounting to $10.1 billion in 2007 and $44.1 billion for the 12-year period (in nominal terms). The non-pecuniary benefits associated with the use of the technology have also had a positive impact on adoption (in the US accounting for the equivalent of 25% of the total direct farm income benefit). Biotech crops have also made important contributions to increasing global production levels of the four main crops—adding, for example, 68 million tonnes and 62 million tonnes respectively to global production of soybeans and corn.

Key words: yield, cost, income, non-pecuniary benefit, production, biotech crops.

Introduction

This article presents the findings of research on the global economic impact of GM crops since their commercial introduction in 1996. It updates part of the findings of earlier analysis presented by the authors in *AgBioForum 8*(2&3), *9*(3), and *11*(1).[1]

The analysis concentrates on farm income effects because this is a primary driver of adoption amongst farmers (both large commercial and small-scale subsistence). It also considers more indirect farm income or non-pecuniary benefits, and quantifies the (net) production impact of the technology.

Methodology

The report is based largely on extensive analysis of existing farm-level impact data for biotech crops. While primary data for impacts of commercial cultivation were not available for every crop, in every year, and for each country, a substantial body of representative research and analysis is available, and this has been used as the basis for the analysis presented.

Since the economic performance and impact of this technology at the farm level varies widely—both between, and within regions/countries (as applies to any technology used in agriculture)—the measurement of performance and impact is considered on a case-by-case basis in terms of crop and trait combinations. The analysis presented is based on the average performance and impact recorded in different crops by the studies reviewed; the average performance is the most common way in which the identified literature has reported impact. Where several pieces of relevant research (e.g., on the impact of using a GM trait on the yield of a crop in one country in a particular year) have been identified, the findings used have been based largely on the average of these findings.

This approach may both overstate and understate the real impact of GM technology for some trait, crop, and country combinations, especially in cases where the technology has provided yield enhancements. However, since impact data for every trait, crop, location, and year is not available, the authors have had to extrapolate available impact data from identified studies to years for which no data are available. Therefore, the authors acknowledge that this represents a weakness in the research. To reduce the possibilities of over/understating impact, the analysis:

- directly applies impacts identified from the literature to the years that have been studied. As a result, the impacts used vary in many cases according to the findings of literature covering different years.[2] Hence, the analysis takes into account variation in the impact of the technology on yield according to its effectiveness in dealing

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[1] *Readers should note that some data presented in this article are not directly comparable with data presented in the previous three articles because the current articles takes into account the availability of new data and analysis (including revisions to data for earlier years).*

with (annual) fluctuations in pest and weed infestation levels as identified by research;
- uses current farm-level crop prices and bases any yield impacts on (adjusted—see below) current average yields. In this way some degree of dynamics has been introduced into the analysis that would otherwise be missing if constant prices and average yields indentified in year-specific studies had been used;
- includes some changes and updates to the impact assumptions identified in the literature based on consultation with local sources (analysts, industry representatives) so as to better reflect prevailing/changing conditions (e.g., pest and weed pressure, cost of technology);
- includes some sensitivity analysis in which the impacts based on average performance are supplemented by a range incorporating 'below average' and 'above average' performance assumptions (see Appendix 2 for details); and
- adjusts downward the average base yield (in cases where GM technology has been identified as having delivered yield improvements) on which the yield enhancement has been applied. In this way, the impact on total production is not overstated.

Detailed examples of how the methodology has been applied to the calculation of the 2007 year results are presented in Appendix 1. Appendix 2 also provides details of the impacts and assumptions applied and their sources.

Other aspects of the methodology used to estimate the impact on direct farm income are as follows.

- Impact is quantified at the trait and crop level, including where stacked traits are available to farmers. Where stacked traits have been used, the individual trait components were analyzed separately to ensure estimates of all traits were calculated.
- All values presented are nominal for the year shown and the base currency used is the US dollar. All financial impacts in other currencies have been converted to US dollars at prevailing annual average exchange rates for each year.
- The analysis focuses on changes in farm income in each year arising from impact of GM technology on yields, key costs of production (notably seed cost and crop protection expenditure, but also impact on costs such as fuel and labor),[3] crop quality (e.g., improvements in quality arising from less pest damage or lower levels of weed impurities, which result in price premia being obtained from buyers), and the scope for facilitating the planting of a second crop in a season (e.g., second crop soybeans in Argentina following wheat that would, in the absence of the GM herbicide-tolerant [HT] seed, probably not have been planted). Thus, the farm income effect measured is essentially a gross margin impact (impact on gross revenue less variable costs of production) rather than a full net cost of production assessment. Through the inclusion of yield impacts and the application of actual (average) farm prices for each year, the analysis also indirectly takes into account the possible impact of biotech crop adoption on global crop supply and world prices.

The article also examines some of the more intangible (more difficult to quantify) economic impacts of GM technology. The literature in this area is much more limited and, in terms of aiming to quantify these impacts, largely restricted to the US-specific studies. The findings of this research are summarized[4] and extrapolated to the cumulative biotech crop planted areas in the United States in the 1996-2007 period.

Lastly, the article includes estimates of the production impacts of GM technology at the crop level. These have been aggregated to provide the reader with a global perspective of the broader production impact of the technology. These impacts derive from the yield impacts (where identified), but also from the facilitation of addi-

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2. *Examples where such data is available include the impact of GM insect-resistant cotton: in India, see Bennett, Ismael, Kambhampati, and Morse (2004) and IMRB (2006, 2007); in Mexico, see Traxler, Godoy-Avilla, Falck-Zepeda, and Espinoza-Arellano (2001) and Monsanto Mexico (2005, 2007); and in the US, see Sankula and Blumenthal (2003, 2006) and Mullins and Hudson (2004).*

3. *Impacts on these categories of cost are, however, more limited than the impacts on seed and crop protection costs because only a few of the papers reviewed have included consideration of such costs in their analyses. Therefore, in most cases the analysis relates to impact of crop protection and seed cost only.*

4. *Notably relating to the US—Marra and Piggott (2006).*

Table 1. Global farm income benefits from growing biotech crops, 1996-2007 (US $ million).

Trait	2007 increase in farm income	1996-2007 increase in farm income	2007 farm income benefit as % of total value of production of these crops in biotech adopting countries	2007 farm income benefit as % of total value of global production of crop
GM HT soybeans	3,935.5	21,814.1	7.2	6.4
GM HT maize	442.3	1,507.6	0.7	0.4
GM HT cotton	24.5	848.2	0.1	0.1
GM HT canola	345.6	1,438.6	7.65	1.4
GM IR maize	2,075.3	5,673.6	3.2	1.9
GM IR cotton	3,204.0	12,576.2	16.5	10.2
Others	54.4	208.8	n/a	n/a
Totals	**10,081.6**	**44,067.1**	**6.9**	**4.4**

Note. All values are nominal. Others = Virus-resistant papaya and squash. Totals for the value shares exclude "other crops" (i.e., relate to the four main crops of soybeans, maize, canola, and cotton). Farm income calculations are net farm income changes after inclusion of impacts on yield, crop quality, and key variable costs of production (e.g., payment of seed premia, impact on crop protection expenditure).

tional cropping within a season (notably in relation to soybeans in South America). Details of how these values were calculated (for 2007) are shown in Appendix 1.

Results

GM technology has had a significant positive impact on farm income derived from a combination of enhanced productivity and efficiency gains (Table 1). In 2007, the direct global farm income benefit from biotech crops was $10.1 billion. This is equivalent to having added 4.4% to the value of global production of the four main crops of soybeans, maize, canola, and cotton. Since 1996, farm incomes have increased by $44.1 billion.

The largest gains in farm income have arisen in the soybean sector, largely from cost savings. The $3.9 billion additional income generated by GM HT soybeans in 2007 has been equivalent to adding 7.2% to the value of the crop in biotech-growing countries, or adding the equivalent of 6.4% to the $60 billion value of the global soybean crop in 2007. These economic benefits should, however be placed within the context of a significant increase in the level of soybean production in the main biotech-adopting countries. Since 1996, the soybean area in the leading soybean-producing countries—United States, Brazil, and Argentina—increased by 58%.

Substantial gains also have arisen in the cotton sector through a combination of higher yields and lower costs. In 2007, cotton farm income levels in the biotech-adopting countries increased by $3.2 billion, and since 1996, the sector has benefited from an additional $12.6 billion. The 2007 income gains are equivalent to adding 16.5% to the value of the cotton crop in these countries, or 10.2% to the $27.5 billion value of total global cotton production. This is a substantial increase in value-added terms for two new cotton seed technologies.

Significant increases to farm incomes have also occurred in the maize and canola sectors. The combination of GM insect-resistant (GM IR) and GM HT technology in maize has boosted farm incomes by $7.2 billion since 1996. In the North American canola sector, an additional $1.4 billion has been generated.

Table 2 summarizes farm income impacts in key biotech-adopting countries. This highlights the important farm income benefit arising from GM HT soybeans in South America (Argentina, Brazil, Paraguay, and Uruguay), GM IR cotton in China and India, and a range of GM cultivars in the United States. It also illustrates the growing level of farm income benefits being obtained in South Africa, the Philippines, and Mexico.

In terms of the division of the economic benefits obtained by farmers in developing countries relative to farmers in developed countries, Table 3 shows that in 2007, 58% of the farm income benefits were earned by developing-country farmers. The vast majority of these income gains for developing-country farmers have been from GM IR cotton and GM HT soybeans.[5] Over the twelve years—1996-2007—the cumulative farm income gain derived by developing country farmers was $22.1 billion (50.1% of the total).

Examining the cost farmers pay for accessing GM technology, Table 4 shows that across the four main bio-

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5. *The authors acknowledge that the classification of different countries into developing or developed country status affects the distribution of benefits between these two categories of country. The definition used in this article is consistent with the definition used by James (2007).*

Table 2. GM crop farm income benefits in selected countries, 1996-2007 ($ million).

	GM HT soybeans	GM HT maize	GM HT cotton	GM HT canola	GM IR maize	GM IR cotton	Total
US	10,422	1,402.9	804	149.2	4,778.9	2,232.7	19,789.7
Argentina	7,815	46	28.6	n/a	226.8	67.9	8,184.3
Brazil	2,868	n/a	n/a	n/a	n/a	65.5	2,933.5
Paraguay	459	n/a	n/a	n/a	n/a	n/a	459
Canada	103.5	42	n/a	1,289	208.5	n/a	1,643
South Africa	3.8	5.2	0.2	n/a	354.9	19.3	383.4
China	n/a	n/a	n/a	n/a	n/a	6,740.8	6,740.8
India	n/a	n/a	n/a	n/a	n/a	3,181.0	3,181.0
Australia	n/a	n/a	5.2	n/a	n/a	190.6	195.8
Mexico	8.8	n/a	10.3	n/a	n/a	65.9	85
Philippines	n/a	11.4	n/a	n/a	33.2	n/a	44.6
Romania	92.7	n/a	n/a	n/a	n/a	n/a	92.7
Uruguay	42.4	n/a	n/a	n/a	2.7	n/a	45.1
Spain	n/a	n/a	n/a	n/a	60.0	n/a	60
Other EU	n/a	n/a	n/a	n/a	8.6	n/a	8.6
Colombia	n/a	n/a	n/a	n/a	n/a	12.6	12.6

Note. All values are nominal. Farm income calculations are net farm income changes after inclusion of impacts on yield, crop quality, and key variable costs of production (e.g., payment of seed premia, impact on crop protection expenditure). n/a = not applicable. US figures exclude benefits from virus-resistant crops.

Table 3. GM crop farm income benefits in developing versus developed countries, 2007 ($ million).

	Developed	Developing
GM HT soybeans	1,375.1	2,560.5
GM IR maize	1,773.4	301.9
GM HT maize	401.6	40.8
GM IR cotton	285.8	2,918.1
GM HT cotton	16.3	8.2
GM HT canola	345.6	0
GM virus-resistant papaya and squash	54.4	0
Total	**4,252.2**	**5,829.5**

Note. Developing countries = all countries in South America, Mexico, India, China, the Philippines, and South Africa.

tech crops, the total cost in 2007 was equal to 24% of the total technology gains (inclusive of farm income gains plus the cost of the technology payable to the seed supply chain).[6]

For farmers in developing countries the total cost was equal to 14% of total technology gains, while for farmers in developed countries the cost was 34% of the total technology gains. While circumstances vary between countries, the higher share of total technology gains accounted for by farm income gains in developing countries relative to the farm income share in developed countries reflects factors such as weaker provision and enforcement of intellectual property rights in developing countries and the higher average level of farm income gain on a per-hectare basis derived by developing country farmers relative to developed country farmers.

As indicated in the methodology section, the analysis presented above is largely based on estimates of average impact in all years. Recognizing that pest and weed pressure varies by region and year, additional sensitivity analysis was conducted for the crop/trait combinations where yield impacts were identified in the literature. This sensitivity analysis (see Appendix 2 for details) was undertaken for two levels of impact assumption: one in which all yield effects in all years were assumed to be ‘lower than average’ (levels of impact that reflected yield impacts in years of low pest/weed pressure), and one in which all yield effects in all years were assumed to be ‘higher than average’ (levels of impact that reflected yield impacts in years of high pest/weed pressure). The results of this analysis suggest a range of positive direct farm income gains in 2007 of +$8.5 to +$12.9 billion and, over the 1996-2007 period, a range of +$38.2 to +$52.2 billion (Table 5). This range

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[6] *The cost of the technology accrues to the seed supply chain, including sellers of seed to farmers, seed multipliers, plant breeders, distributors, and the GM technology providers.*

Table 4. Cost of accessing GM technology relative to the total farm income benefits, 2007 ($ million).

	Cost of technology: All farmers	Farm income gain: All farmers	Total benefit of technology to farmers and seed supply chain	Cost of technology: Developing countries	Farm income gain: Developing countries	Total benefit of technology to farmers and seed supply chain: Developing countries
GM HT soybeans	930.8	3,935.5	4,866.3	326	2,560.5	2,886.5
GM IR maize	714.3	2,075.3	2,789.6	79.1	301.9	381
GM HT maize	530.8	442.3	973.1	20.2	40.8	61
GM IR cotton	670.4	3,204.0	3,874.4	535.1	2,918.1	3,453.2
GM HT cotton	226.4	24.5	250.9	8.5	8.2	16.7
GM HT canola	102.2	345.6	447.8	n/a	n/a	n/a
Total	**3,174.9**	**10,027.2**	**13,202.1**	**968.9**	**5,829.5**	**6,798.4**

Note. n/a = not applicable. Cost of accessing technology based on the seed premia paid by farmers for using GM technology relative to its conventional equivalents. Total farm income gain excludes $54.4 million associated with virus-resistant crops in the United States.

Table 5. Direct farm income benefits 1996-2007 under different impact assumptions ($ million).

Crop	Consistent below average pest/weed pressure	Average pest/weed pressure (main study analysis)	Consistent above average pest/weed pressure
Soybeans	21.796.0	21,814.1	21,829.0
Corn	4,571.0	7,181.2	12,152.0
Cotton	10,920	13,424.4	15,962.0
Canola	818.7	1,438.6	2.013.0
Others	101.4	208.8	224.3
Total	**38,207.1**	**44,067.1**	**52,180.3**

Note. No significant change to soybean production under all three scenarios as almost all gains due to cost savings and second crop facilitation.

is broadly within 85% to 120% of the main estimates of farm income presented above.

Indirect (Non-Pecuniary) Farm-Level Impacts

In addition to the tangible and quantifiable impacts on farm profitability presented above, there are other important, more intangible (difficult to quantify) impacts of an economic nature.

Many of the studies[7] of the impact of biotech crops have identified the following reasons as being important influences for adoption of the technology.

Herbicide Tolerant Crops

- HT crops allow for increased management flexibility and convenience that comes from a combination of the ease of use associated with broad-spectrum, post-emergent herbicides like glyphosate and the increased/longer time window for spraying. This not only frees up management time for other farming activities but also allows additional scope for undertaking off-farm, income-earning activities.
- In a conventional crop, post-emergent weed control relies on herbicide applications before the weeds and crop are well established. As a result, the crop may suffer ‘knock-back’ to its growth from the effects of the herbicide. In the GM HT crop, this problem is avoided because the crop is both tolerant to the herbicide and spraying can occur at a later stage when the crop is better able to withstand any possible “knock-back” effects.
- These crops facilitate the adoption of conservation or no-tillage systems. This provides for additional cost savings such as reduced labor and fuel costs associated with plowing, additional moisture retention, and reductions in soil erosion levels.
- Improved weed control has contributed to reduced harvesting costs—cleaner crops have resulted in reduced times for harvesting. It has also improved harvest quality and led to higher levels of quality price bonuses in some regions and years (e.g., HT soybeans and HT canola in the early years of adoption, respectively, in Romania and Canada).
- Elimination of potential damage caused by soil-incorporated residual herbicides in follow-on

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[7] *For example, relating to HT soybeans, USDA (1999), Gianessi and Carpenter (1999), and Qaim and Traxler (2002); relating to IR maize, Rice (2004) and Brookes (2008); relating to IR cotton, Ismael, Bennett, Morse, and Buthelezi (2002) and Pray et al. (2002).*

crops and less need to apply herbicides in a follow-on crop because of the improved levels of weed control;

- HT crops also contribute to a general improvement in human safety (as manifest in greater peace of mind about own and worker safety) from reduced exposure to herbicides and a switch to more environmentally benign products.

Insect Resistant Crops

- IR crops offer benefits in the areas of production risk management and insurance. The technology takes away much of the worry of significant pest damage occurring and is, therefore, highly valued. Although not applicable in 2007 (piloted in 2008 and likely to be more widely operational from 2009), US farmers using stacked corn traits (containing IR and HT traits) are being offered discounts on crop insurance premiums equal to $7.41/hectare.
- These crops have a 'convenience' benefit derived from having to devote less time to crop walking and/or applying insecticides.
- IR crops offer savings in energy use—mainly associated with less use of aerial spraying and less tillage.
- Planting IR crops can produce savings in machinery use (for spraying and possibly reduced harvesting times).
- IR crops produce a higher quality of crop. There is a growing body of research evidence relating to the superior quality of GM IR corn relative to conventional and organic corn from the perspective of having lower levels of mycotoxins. Evidence from Europe (as summarized in Brookes [2008]) has shown a consistent pattern in which GM IR corn exhibits significantly reduced levels of mycotoxins compared to conventional and organic alternatives. In terms of revenue from sales of corn, however, no premia for delivering product with lower levels of mycotoxins have been reported to date; however, where the adoption of the technology has resulted in reduced frequency of crops failing to meet maximum permissible fumonisin levels in grain maize (e.g., in Spain), this delivers an important economic gain to farmers selling their grain to the food-using sector. In one study (Yorobe, 2004), GM IR corn farmers in the Philippines have also been reported to have obtained price premia of 10% relative to conventional corn because of better quality, less damage to cobs, and lower levels of impurities.
- They also offer improved health and safety for farmers and farm workers—from reduced handling and use of pesticides, especially in developing countries where many apply pesticides with little or no use of protective clothing and equipment.
- Shorter growing seasons (e.g., for some cotton growers in India) allow some farmers to plant a second crop in the same season.[8] Also, some Indian cotton growers have reported benefits for bee keepers, as fewer bees are now lost to insecticide spraying.

Some of the economic impact studies have attempted to quantify some of these benefits. For example, Qaim and Traxler (2002) quantified some of these in Argentina—a $3.65/hectare saving (-7.8%) in labor costs and a $6.82/ha (-28%) saving in machinery/fuel costs associated with the adoption of GM HT soybeans. Where identified, these cost savings have been included in the analysis presented above. Nevertheless, it is important to recognize that these largely intangible benefits are considered by many farmers as a primary reason for adoption of GM technology, and in some cases farmers have been willing to adopt for these reasons alone, even when the measurable impacts on yield and direct costs of production suggest marginal or no direct economic gain.

Since the early 2000s, a number of farmer-survey-based studies in the United States have also attempted to better quantify these non-pecuniary benefits. These studies have usually employed contingent valuation techniques[9] to obtain farmer valuations of non-pecuniary benefits.

- A 2002 survey of 600 US corn farmers explored opinions and valuations of the then new IR corn trait resistant to corn rootworm, which was introduced in the following year (2003). Respondents were asked to value any potential time and equipment savings, additional farmer and worker

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[8] *Notably maize in India.*

[9] *Survey-based method of obtaining valuations of non-market goods that aim to identify willingness to pay for specific goods (e.g., environmental goods, peace of mind, etc.) or willingness to pay to avoid something being lost.*

safety, additional environmental benefits, and production risk management benefits (from more consistent control of rootworm) that they thought might arise from use of the technology relative to existing corn rootworm control methods. The production risk management benefit was mostly highly valued by farmers, followed by operator/worker safety and environmental gains. The average value of all the non-pecuniary benefits was $17.89/hectare for likely adopters, $9.54/hectare for unlikely adopters, and an overall average of $16.33/hectare across all farmers surveyed.

- A 2002 survey of 610 US soybean farmers sought farmers' views on the benefits associated with their use (since 1996) of GM HT soybeans. Respondents were asked to value additional farmer and worker safety, the environmental impact of the technology and the additional convenience and flexibility the technology provided for weed control relative to the conventional alternatives. All of these benefits were valued by the soybean farmers, with convenience given the highest value. Overall, the average benefit attributed to these three categories of non-pecuniary benefits was $27/hectare (58% of which came from the convenience benefit).
- A 2003 survey of nearly 300 farmers of GM HT crops (soybeans, corn, and cotton) asked respondents to value additional farmer and worker safety, the environmental impact of the technology, and the additional convenience and flexibility the technology provided for weed control relative to the conventional alternatives. Results obtained were similar to those in the 2002 soybean farmer survey referred to above. In terms of valuations, the average benefit attributed to these three categories of non-pecuniary benefits were, respectively, $32/hectare for HT corn farmers, $35.70/hectare for HT soybean farmers, and $39.40/hectare for HT cotton farmers.

The values for non-pecuniary benefits identified in these surveys are, however, usually subject to bias due to factors such as the hypothetical nature of the contingent valuation technique, the framing of questions, and what is referred to as part-whole bias.[10] Marra and Piggott (2006) examined bias (notably part-whole bias) in the three surveys referred to above and found most respondents tended to overstate the value of parts by more than 60% compared with the separately stated total values for all non-pecuniary benefits. They subsequently rescaled[11] the sum of the values given by respondents to each separate non-pecuniary benefit and identified revised average (median) values for the non-pecuniary benefits in each survey (Table 6). This suggests that US farmers who make widespread use of biotech HT traits value the non-pecuniary benefits of the technology at between $12.35/hectare and $24.71/hectare, with cotton farmers valuing the non-pecuniary aspects highest and corn farmers having the lowest valuation. In terms of attributes most valued, convenience is perceived to provide between 50% and 66% of the total non-pecuniary benefit of the HT technology. It is also interesting to note that the most recent survey of cotton farmers using HT (flex) technology have valued this technology as delivering an additional $12/hectare in tterms of benefit from extra convenience relative to the first generation of biotech HT cotton technology. Corn producers value the non-pecuniary benefits of the IR ((rootworm resistance) technology at about $7.40/hectare, of which the risk reduction component accounted for the largest single share (about a third).

Table 6. Re-scaled values of non-pecuniary benefits.

Survey	Median value ($/hectare)
2002 IR (to rootworm) corn growers survey	7.41
2002 soybean (HT) farmers survey	12.35
2003 HT cropping survey (corn, cotton & soybeans)—North Carolina	24.71
2006 HT (flex) cotton survey	12.35 (relative to first generation HT cotton)

Source: Marra and Piggot (2006, 2007).

Aggregating the Impact to US Crops 1996-2007

The approach used to estimate the non-pecuniary benefits derived by US farmers from biotech crops over the period 1996-2007 has been to draw on the re-scaled values identifed by Marra and Piggot (2006, 2007, Table 6) and to apply these to the biotech-crop planted areas during this 12-year period. Figure 1 summarizes the values for non-pecuniary benefits derived from biotech crops

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10. In the case of non-pecuniary benefits, the sum of values given by farmers to individual categories of benefit is greater than their stated total value of all non-pecuniary benefits (farmers being asked to value each type of benefit separately in addition to separately valuing total non-pecuniary benefits).

11. See Marra and Piggott (2006).

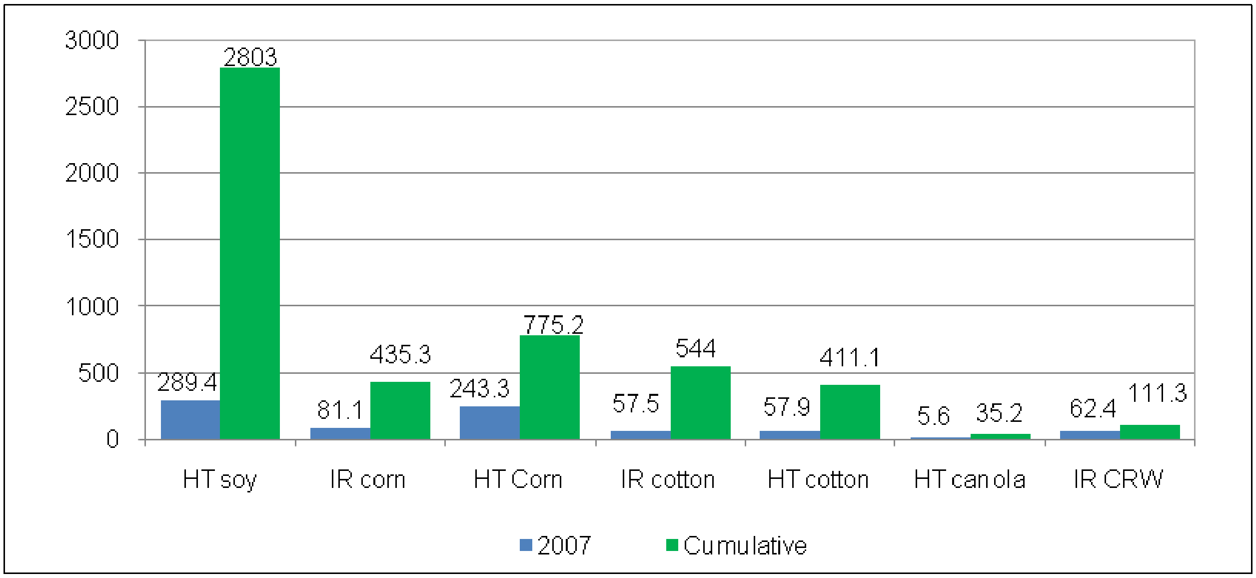

Figure 1. Non-pecuniary benefits derived by US farmers by trait, 1996-2007 ($ million).

in the United States (1996-2007) and shows an estimated (nominal value) benefit of $792 million in 2007 and a cumulative total benefit (1996-2007) of $5.11 billion. Relative to the value of direct farm income benefits presented above, the non-pecuniary benefits were equal to 21% of the total direct income benefits in 2007 and 25% of the total cumulative (1996-2007) direct farm income. This highlights the important contribution this category of benefit has had on biotech trait adoption levels in the United States, especially where the direct farm income benefits have been identfied to be relatively small (e.g., HT cotton).

Estimating the Impact in Other Countries

It is evident from the literature review that GM technology-using farmers in other countries also value the technology for a variety of non-pecuniary/intangible reasons. The most appropriate methodology for identifying these non-pecuniary benefit valuations in other countries would be to repeat the type of US farmer surveys in other countries. Unfortunately, the authors are not aware of any such studies undertaken to date.

Production Effects of the Technology

Based on the yield assumptions used in the direct farm income benefit calculations presented above (see Appendix 1) and taking into account the second soybean crop facilitation in South America, biotech crops have added important volumes to global production of corn, cotton, canola, and soybeans since 1996 (Table 7).

Table 7. Additional crop production arising from positive yield effects of biotech crops.

	1996-2007 additional production (million tonnes)	2007 additional production (million tonnes)
Soybeans	67.80	14.46
Corn	62.42	15.08
Cotton	6.85	2.01
Canola	4.44	0.54

The biotech IR traits—used in the corn and cotton sectors—have accounted for 99% of the additional corn production and almost all of the additional cotton proddduction. Positive yield impacts from the use of this technology have occurred in all user countries (except GM IR cotton in Australia)[12] when compared to average yields derived from crops using conventional technology (such as application of insecticides and seed treatments). Since, 1996 the average yield impact across the total area planted to these traits over the 12 year period has been +6.1% for corn traits and +13.4% for cotton traits (Figure 2).

Although the primary impact of biotech HT technology has been to provide more cost-effective (less expensive) and easier weed control—versus improving yields

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[12] *This reflects the levels of Heliothis pest control previously obtained with intensive insecticide use. The main benefit and reason for adoption of this technology in Australia has arisen from significant cost savings (on insecticides) and the associated environmental gains from reduced insecticide use.*

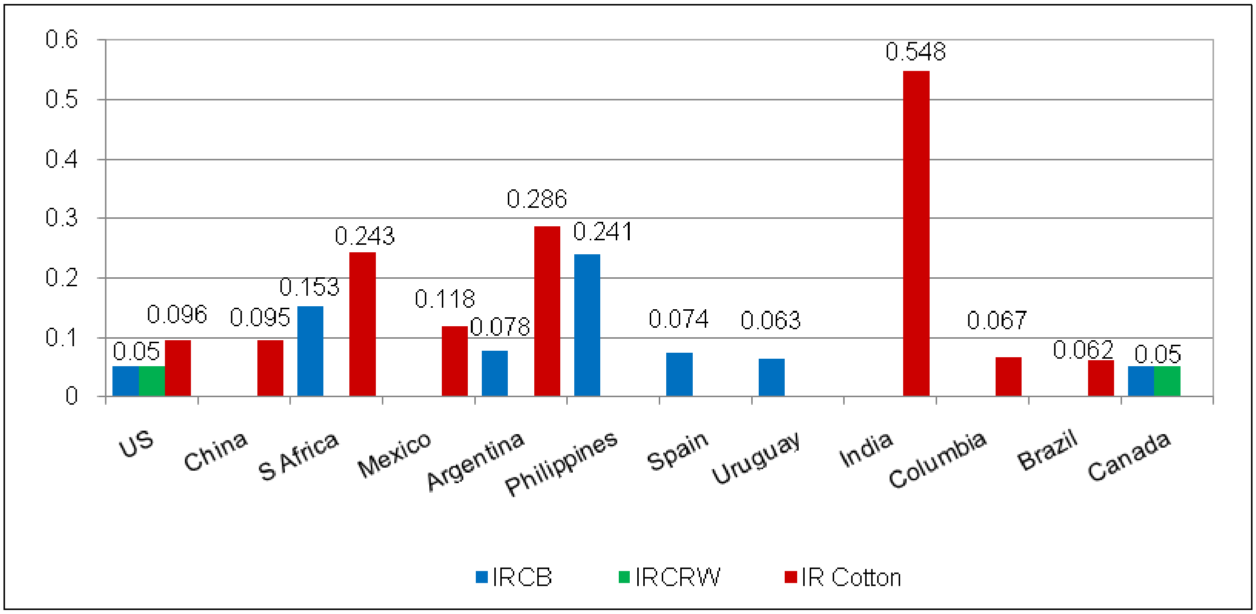

Figure 2. Average yield impact of biotech IR traits by country and trait, 1996-2007.
Note. IRCB = resistant to corn-boring pests. IRCRW = resistant to corn rootworm.

Table 8. Additional crop production arising from positive yield effects of biotech crops under different pest/weed pressure assumptions and impacts of the technology, 1996-2007 (million tonnes).

Crop	Consistent below average pest/weed pressure	Average pest/ weed pressure (main study analysis)	Consistent above average pest/weed pressure
Corn	46.0	62.42	109.5
Cotton	4.61	6.86	9.03
Canola	2.09	4.44	6.26

Note. No significant change to soybean production under all three scenarios as 99% of production gain due to second cropping facilitation of the technology.

from better weed control (relative to weed control obtained from conventional technology)—improved weed control has, nevertheless occurred, delivering higher yields in some countries. Specifically, HT soybeans in Romania improved the average yield by more than 30%, and biotech HT corn in Argentina and the Philippines delivered yield improvements of +9% and +15%, respectively.

Biotech HT soybeans have also facilitated the adoption of no-tillage production systems, shortening the production cycle. This advantage enables many farmers in South America to plant a crop of soybeans immediately after a wheat crop in the same growing season. This second crop, additional to traditional soybean production, has added 67.5 million tonnes to soybean production in Argentina and Paraguay between 1996 and 2006—accounting for 99% of the total biotech-related additional soybean production.

Using the same sensitivity analysis as applied to the farm income estimates presented above to the production impacts (one scenario of consistent lower-than-average pest/weed pressure and one of consistent higher-than-average pest/weed pressure), Table 8.

Concluding Comments

This study quantified the cumulative global impact of GM technology between 1996 and 2007 on farm income and production. The analysis shows that there have been substantial direct economic benefits at the farm level, amounting to a cumulative total of $44.1 billion; half of this has been derived by farmers in developing countries. Important non-pecuniary benefits have also been derived by many farmers, which in the case of US farmers added a further $5.1 billion to the farm income benefits derived from the technology. GM technology has also resulted in additional production of important crops, equal to an extra 68 million tonnes of soybeans and 62 million tonnes of corn (1996-2007).

The impacts identified are based on estimates of average impact, reflecting the limitations of the methodologies used and the limited availability of relevant data.

Applying alternative assumptions that reflect the extremes of low weed and pest pressure in all years and high weed and pest pressure in all years suggests that the impact on farm income probably falls within a range of -15% to +20% around the cumulative estimate of $44.1 billion referred to above. Subsequent research at the trait- and country-level might usefully extend this analysis to incorporate more sophisticated consideration of dynamic economic impacts and broader (outside the United States) examination of the less tangible (non-pecuniary) economic impacts.

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Appendix 1: Details of Methodology as Applied to 2007 Farm Income Calculations

Table A1. GM IR corn (targeting corn boring pests), 2007.

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ ha)	Farm level price ($/ tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
United States	18,561	+5	9.25	135.4	-17.3	-1.42	61.22	+1,136,212	+8,584.4
Canada	831	+5	8.29	165.44	-19.3	+1.68	+70.26	+58,382	+344.4
Argentina	2,509	+5.5	6.8	113.0	-19.9	-19.9	+22.41	+56,220	+938.4
Philippines	194	+24.15	2.52	215.12	-36.2	-22.14	+108.78	+21,091	+118
South Africa	1,234	+15	4.0	304.47	-16.19	-2.29	+180.39	+222,601	+740.4
Spain	75.1	+10	9.34	283.77	-47.75	+9.55	+274.59	+20,634	+70.2
Uruguay	105	+5.5	5.61	125	-19.9	-19.9	+18.63	+1,956.6	+32.4
France	22.1	+10	9.4	256.48	-54.57	+13.64	+254.73	+5,638.5	+20.8
Germany	2.7	+4	9.09	285.13	-54.57	+13.64	+117.32	+315	+1
Portugal	4.3	+12.5	5.51	278.31	-47.75	-47.75	+143.95	+613.6	+2.9
Czech Republic	5	+10	5.75	294.68	-47.75	-23.19	+146.25	+713.2	+2.9
Slovakia	0.9	+12.3	4.28	285.13	-47.75	-47.75	+102.35	+97.1	+0.5
Poland	0.3	+12.5	5.28	259.21	-47.75	-47.75	+123.33	+40	+0.2
Romania	0.3	+7.1	3.50	315.14	-43.66	-43.66	+34.66	+12	+0.1

Note. Impact on costs net of cost of technology = cost savings from reductions in pesticide costs, labor use, fuel use, etc., from which the additional cost (premium) of the technology has been deducted. For example (above), US cost savings from reduced expenditure on insecticides, etc. = +$15.88/ha, from which cost of technology (-$17.3/ha) is deducted to leave a net impact of costs of -$1.42.

There are no Canadian-specific studies available, so we have applied US study findings to the Canadian context (since it is the nearest country for which relevant data is available).

Table A2. GM IR corn (targeting corn rootworm), 2007.

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ha)	Farm level price ($/tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US	8,417.6	+5	9.25	135.4	-35	+2.47	+65.10	+547,991	+3,893.2
Canada	39.3	+5	8.29	165.44	-35	+2.47	+71.04	+2,788.7	+16.3

Note. There are no Canadian-specific studies available, hence application of US study findings to the Canadian context (since it is the nearest country for which relevant data is available).

Table A3. GM IR cotton, 2007.

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ha)	Farm level price ($/ tonnes)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US	2,585.2	+10	0.93	1,202	-46.95	-5.77	+106.02	+274,078	+240.4
China	3,800	+10	1.18	807.4	-48.07	+152.48	+248.08	+942,695	+449.9
South Africa	9.9	+24	0.692	1,172.0	-49.43	-31.23	+163.42	+1,617.8	+1.6
Australia	55.3	0	1.91	1,458	-251.3	+212.0	+212.09	+11,734.3	0
Mexico	60.0	+9.28	1.18	1088.7	-70.41	+20.49	+139.71	+8,382.1	+6.6
Argentina	162.3	+30	0.418	1,455	-37.85	-21.17	+161.31	+26,180.8	+20.3
India	5,868	+50	0.43	1,536.9	-55.29	-8.86	+321.57	+1,886,986	+1,261.6
Colombia	20.0	+9.28	0.95	1,900	-70.41	+20.49	+187.99	+3,749.8	+1.8
Brazil	358	+6.23	1.32	1,316.6	-43.94	+71.21	+135.54	+48,524	+29.4

Table A4. GM HT soybeans, 2007 (excluding second crop soybeans—see separate table).

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ ha)	Farm level price ($/tonnes)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US	23,433.5	0	2.77	331	-24.71	+57.96	+57.96	+1,358,206.4	0
Canada	688	0	2.3	395	-37.47	+24.52	+24.52	+16,871.2	0
Argentina	16,419.5	0	2.83	221.7	-2.5	+26.11	+29.23	+480,012.1	0
Brazil	13,562.5	0	2.85	282.4	-18.77	+57.2	+61.2	+830,022.6	0
Paraguay	2,600	0	2.41	261.3	-9.64	+18.97	+22.11	+57,476.6	0
South Africa	144	0	1.12	356.6	-27.94	+5.01	+5.01	+722.1	0
Uruguay	443.5	0	2.19	256.1	-2.5	+26.11	+28.9	+12,819.2	0
Mexico	5	+9.1	1.48	360	-34.5	+120	+168.48	+842	+0.7
Romania	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Note. Quality premium for cleaner crops assumed at 0.5% of base price (price shown is inclusive of premium) in South American countries.

Romania—n/a = not applicable, as no longer permitted to plant GM HT soybeans on entry into the EU.

Table A5. GM HT corn, 2007.

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ha)	Farm level price ($/tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US	19,697.3	0%	9.48	135	-24.71	+19.89	+19.89	+391,779.1	0
Canada	751	0%	8.51	165.44	-31.8	+13.01	+13.01	+9,771.3	0
Argentina	369	+3% corn belt +22% marginal regions	7.68 corn belt 4.31 marginal areas	113	-19.9	0	+26.1 corn belt +107.43 marginal regions	+27,637.1	+244.1
South Africa	453	0%	4.29	304.47	-17.19	+6.02	+6.02	+2,725.8	0
Philippines	191.3	+15	2.52	215.12	-26.69	-26.69	+54.47	+10,419.2	+72.2

Note. Where no positive yield effect due to this technology is applied, the base yields shown are the indicative average yields for the crops and differ (are higher) than those used for the GM IR base yield analysis, which have been adjusted downwards to reflect the impact of the yield enhancing technology (see below).

Argentina: corn belt assumed to account for 70% of trait plantings and marginal regions to the balance.

Table A6. GM HT cotton, 2007.

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ha)	Farm level price ($/tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US	3,067.1	0	0.985	1,202	-70.35	+5.2	+5.2	+15,949	0
South Africa	9.7	0	0.8	1,172	-23.6	-22.9	-0.72	-7	0
Australia	50.5	0	1.91	1,458	-42.71	+7.54	+7.54	+380.4	0
Argentina	124	Farm saved seed area 0% Certified seed area +17.4%	0.453	1,455	-39.86 certified seed -8 farm saved seed	-17.67 certified seed +14.19 farm saved seed	+99.57 certified seed +14.19 farm saved seed	-3,876.5	+2.0
Mexico	50	+3.6	1.208	1,089	-66.4	+39.67	+87.02	+4,350.8	+2.2

Note. Where no positive yield effect due to this technology is applied, the base yields shown are the indicative average yields for the crops and differ (are higher) than those used for the GM IR base yield analysis, which have been adjusted downwards to reflect the impact of the yield enhancing technology (see below).

Argentina: 20% of area assumed to use certified seed with 80% farm-saved seed.

Table A7. GM HT canola, 2007.

Country	Area of trait ('000 ha)	Yield assumption % change	Base yield (tonnes/ ha)	Farm level price ($/tonnes)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US glyphosate tolerant	271.9	+4	1.65	359.36	-12.36	+27.73	+51.45	+13,990.1	+5.2
US glufosinate tolerant	182.9	+10	1.65	359.36	-12.36	+22.28	+81.57	+14,918.4	+8.7
Canada glyphosate tolerant	2,840.9	+4	1.41	508.27	-34.01	+6.82	+35.49	+100,823.3	+160.2
Canada glufosinate tolerant	2,588.4	+10	1.41	508.27	0	+11.72	+83.38	+215,830.1	+365.0

Note. Baseline (conventional) comparison in Canada with HT (non GM) 'Clearfield' varieties.

Table A8. GM virus-resistant crops.

Country	Area of trait (ha)	Yield assumption % change	Base yield (tonnes/ ha)	Farm level price ($/tonne)	Cost of technology ($/ha)	Impact on costs, net of cost of technology ($/ha)	Change in farm income ($/ha)	Change in farm income at national level ('000 $)	Production impact ('000 tonnes)
US papaya	778	+15	22.86	864.36	-148	-148	+2,816.1	+2,190	+2.7
US squash	3002	+100	31.4	566.90	-398	-398	+17,402.9	+52,252.3	+94.3

Second Soybean Crop Benefits: Argentina

An additional farm income benefit that many Argentine soybean growers have derived comes from the additional scope for second cropping of soybeans. This has arisen because of the simplicity, ease, and weed management flexibility provided by the (GM) technology which has been an important factor facilitating the use of no- and reduced-tillage production systems. In turn, the adoption of low/no-tillage production systems has reduced the time required for harvesting and drilling subsequent crops and, hence, has enabled many Argentine farmers to cultivate two crops (wheat followed by soybeans) in one season. As such, the proportion of soybean production in Argentina using no- or low-tillage methods has increased from 34% in 1996 to 90% by 2005. Also, 30% of the total Argentine soybean crop was second crop in 2007, compared to 8% in 1996. Based on the additional gross margin income derived from second crop soybeans (see below), this has contributed a further boost to national soybean farm income of $1.1 billion in 2007 and $4.4 billion cumulatively since 1996.

Base Yields Used Where GM Technology Delivers a Positive Yield Gain

In order to avoid over-stating the positive yield effect of GM technology (where studies have identified such an impact) when applied at a national level, average (national level) yields used have been adjusted downwards (see example in Table A10). Production levels based on these adjusted levels were then cross checked with total production values based on reported average yields across the total crop.

Table A9. Farm-level income impact of using GM HT soybeans in Argentina, 1996-2007 (2): Second crop soybeans.

Year	Second crop area (million ha)	Average gross margin/ha for second crop soybeans ($/ha)	Increase in income linked to GM HT system (million $)
1996	0.45	128.78	Negligible
1997	0.65	127.20	25.4
1998	0.8	125.24	43.8
1999	1.4	122.76	116.6
2000	1.6	125.38	144.2
2001	2.4	124.00	272.8
2002	2.7	143.32	372.6
2003	2.8	151.33	416.1
2004	3.0	226.04	678.1
2005	2.3	228.99	526.7
2006	3.2	218.40	698.9
2007	4.94	229.36	1,133.6

Note. Crop areas and gross margin data based on data supplied by Grupo CEO (no data available before 2000, hence 2001 data applied to earlier years but adjusted, based on GDP deflator rates).

The second cropping benefits are based on the gross margin derived from second crop soybeans multiplied by the total area of second crop soybeans (less an assumed area of second crop soybeans that equals the second crop area in 1996—this was discontinued from 2004 because of the importance farmers attach to the GM HT system in facilitating them remaining in no-tillage production systems).

Table A10. Example: GM IR cotton (2007).

Country	Average yield across all forms of production (t/ha)	Total cotton area (‘000 ha)	Total production (‘000 tonnes)	GM IR area (‘000 ha)	Conventional area (‘000 ha)	Assumed yield effect of GM IR technology	Adjusted base yield for conventional cotton (t/ha)	GM IR production (‘000 tonnes)	Conventional production (‘000 tonnes)
United States	0.985	4,381.6	4,315.9	2,585.2	1,796.5	+10%	0.93	2,644.7	1,670.7
China	1.257	6,200.0	7,793,4	3,800.0	2,400.0	+10%	1.184	4,949.1	2.841.6

Note. Figures subject to rounding.

Appendix 2: Impacts, Assumptions, Rationale, and Sources for All Trait/Country Combinations

Table 1. IR corn (resistant to corn-boring pests).

Country	Yield impact assump. used	Rationale	Yield references	Sensitivity analysis applied to yield assump.	Cost of technology data/ assump.	Cost savings (excluding impact of seed premium) assump.	Cost references
GM IR corn resistant to corn boring pests							
US & Canada	+5% all years	Broad average of impact identified from several studies/ papers	Carpenter and Gianessi (2002) found yield impacts of +9.4% in 1997, +3% in 1998, +2.5% in 1999 Marra et al. (2002) average impact of +5.04% 1997-2000 based a review of five studies, James (2003) average impact of +5.2% 1996-2002, Sankula and Blumenthal (2003, 2006) range of +3.1% to +9.9% Canada—no studies identified —as US—impacts qualitatively confirmed by industry sources (personal communication, 2005, 2007).	+3% to +9%	1996 & 1997: $25 1998 & 1999: $20 2000-2004: $22 2005 & onwards: $17	All years to 2004: $15.50 2005 onwards: $15.90	The same reference sources as yield were used. Industry sources also confirmed costs of technology and estimated cost-saving values for Canada.
Argentina	+9% all years to 2004 +5.5% 2005 onwards	Average of reported impacts in first seven years, later revised downwards for more recent years to reflect professional opinion	James (2003) cites two unpublished industry survey reports; one for 1996-1999 showing an average yield gain of +10% and one for 2000-2003 showing a yield gain of +8%. Trigo, Chudnovsky, Cap, and Lopez (2002), Trigo and Cap (2006) +10%, Trigo (personal communication, 2007, 2008) estimates average yield impact since 2005 to be lower at between +5% and +6%.	+5% all years to +9% all years	Same as US to 2005 then 60 Pesos 2006 onwards	None, as maize crops not traditionally treated with insecticides for corn boring pest damage	Cost of technology drawn from Trigo et al. (2002) and Trigo and Cap (2006), i.e., costed/priced at same level as US (Trigo, personal communication, 2007, 2008).
Philippines	+24.6% all years	Average of three studies used all years	Gonsalves (2005) found average yield impact of +23% dry season crops and +20% wet season crops; Yorobe (2004) +38% dry season crops and +35% wet season crops; Ramon (2005) found +15.3% dry season crops and +13.3% wet season crops.	All years +14% to +34%	All years: 1,673 Pesos	All years: 651 Pesos	Based on Gonsalves (2005)—the only source to break down these costs. For 2006 and 2007, this level of cost and average cost savings were confirmed by industry sources.
South Africa	2000-2001: +11% 2002: +32% 2003: +16% 2004: +5% 2005 onwards: +15%	Reported average impacts used for years available (2000-2004), 2005 onwards based on average of other years.	Gouse, Pray, Kirsten, and Schimmelpfenning (2005), Gouse, Piesse, and Thirtle (2006), and Gouse, Pray, Schimmelpfenning, and Kirsten (2006) reported yield impacts as shown (range of +11% to +32%).	+5% to +32% all years	(In Rand) 2000 & 2001: 84 2002: 90 2004 & 2005: 94 2006 and onwards: 113	All years 97 Rand	Based on the same papers as used for yield, plus confirmation in 2006 and 2007 that these are representative values from industry sources.

Spain	1998-2004: +6.3% 2005 onwards: +10%	Impact based on author's own detailed, representative analysis for period 1998-2002 then updated to reflect improved technology based on industry analysis.	Brookes (2003) identified an average of +6.3% using the Bt 176 trait mainly used in the period 1998-2004 (range +1% to +40% for the period 1998-2002). From 2005, 10% used based on Brookes (2008), which derived from industry (unpublish-ed sources) commercial-scale trials and monitoring of impact of the newer, dominant trait Mon 810 in the period 2003-2007. Gomez-Barbero and Rodriguez-Cerezo (2006) reported an average impact of +5% for Bt 176 used in 2002-2004.	+3% to +15% all years	(In Euros) 1998 & 1999: 30 2000: 28 2001-2005: 18.5 2006 and onwards: 35	42 Euros all years	Based on Brookes (2003), the only source to break down these costs. The more recent cost of technology costs derive from industry sources (reflecting the use of Mon 810 technology). Industry sources also confirm value for insecticide cost savings as being representative.
Other EU	France: +10% Germany: +4% Portugal: +12.5% Czech Rep.: +10% Slovakia: +12.3% Poland: +12.5% Romania: +7.1%	Impacts based on average of available impact data in each country.	Based on Brookes (2008), which drew on a number of sources. For France, four sources with average yield impacts of +5% to +17%; for Germany the sole source had average annual impacts of +3.5% and +9.5% over a two year period; for Czech Republic, three studies identified average impacts in 2005 of an average of 10% and a range of +5% to +20%; for Portugal, commercial trial and plot monitoring reported +12% in 2005 and between +8% and +17% in 2006; in Slovakia based on trials for 2003-2007 and 2006/07 plantings with yield gains averaging between +10% and +14.7%; in Poland based on variety trial tests 2005 and commercial trials 2006 which had a range of +2% to +26%; Romania based on estimated impact by industry sources for the 2007 year.	Not applied in context of total study due to very small scale of production (i.e., would produce an insignificant impact range in the context of the whole study).	France and Germany, 40 Euros Portugal, Czech and Slovak Republics, and Poland, 35 Euros Romania, 32 Euros	France and Germany, 50 Euros; Portugal, Slovakia, Poland and Romania, 0; Czech Republic, 18 Euros	Data derived from the same sources referred to for yield.
Uruguay	Same as Argentina	Same as Argentina	No country-specific studies identified, so impact analysis from nearest country of relevance (Argentina) applied.	Same as Argentina: +5% to +9%	Same as Argentina	Same as Argentina	Same as Argentina

			GM IR corn (resistant to corn rootworm)				
US & Canada	+5% all years	Based on the impact used by the references cited.	Sankula and Blumenthal (2003, 2006) used +5% in analysis, citing this as conservative, themselves having cited impacts of +12%-+19% in 2005 in Iowa, +26% in Illinois in 2005, and +4%-+8% in Illinois in 2004. Johnson and Strom (2007) used the same basis as Sankula and Blumenthal. Rice (2004) range of +1.4% to +4.5% (based on trials) Canada—no studies identified—as US—impacts qualitatively confirmed by industry sources (personal communication, 2005, 2007).	+3% to +9%	2003 & 2004: $42 2005 onwards: $35	2003: $33 2004 onwards: $37	Data derived from Sankula and Blumenthal (2006) and Johnson and Strom (2007). Canada—no studies identified —as US—impacts qualitatively confirmed by industry sources (personal communication, 2005, 2007).

			GM HT cotton				
US	0%	Not relevant	Not relevant	Not relevant	$12.85 1996-2000 $21.32 2001-2003 $34.55 2004 $68.22 2005 $70.35 2006 onwards	$34.12 1996-2000 $66.59 2001-2003 $83.35 2004 $71.12 2005 $75.55 2006 onwards	Carpenter and Gianessi (2002) Sankula and Blumenthal (2003, 2006) Johnson and Strom (2007)—these are the only available studies breaking down impact into disaggregated parts.
Australia	0%	Not relevant	Not relevant	Not relevant	Aus $50 all years	Aus $60 all years	Doyle et al. (2003) Monsanto Australia (personal communication, 2005, 2007, 2008)
South Africa	0%	Not relevant	Not relevant	Not relevant	133 Rand 2001-2004 101 Rand 2005 165 Rand 2006 onwards	160 Rand all years	No studies identified—based on Monsanto South Africa (personal communication, 2005, 2007, 2008)
Argentina	0% on area using farm saved seed, +17.4% on area using certified seed	Based on only available data—company monitoring of commercial plots.	No studies identified—based on personal communic-ations with Grupo CEO & Monsanto Argentina (2007, 2008).	+10% to +20% on certified seed area	122 Pesos all years	68 Pesos all years	No studies identified—based on personal communications with Grupo CEO and Monsanto Argentina (2007, 2008).
Mexico	+3.6%	Based on only available data—company monitoring of commercial plots.	Same as source for cost data	0% to +5% all years	All years: 720 Pesos	All years: 1,150 Pesos	No studies identified—based on personal communications with Monsanto Mexico (2007).

			IR cotton				
US	1996-2002: +9% 2003 & 2004: +11% 2005 onwards: +10%	Based on the (conservative) impact used by the references cited	Sankula and Blumenthal (2003, 2006) drew on earlier work from Carpenter and Gianessi (2002) in which they estimated the average yield benefit in the 1996-2000 period was +9%. Marra et al. (2002) examined the findings of over 40 state-specific studies covering the period 1996 up to 2000, the approximate average yield impact was +11%. The lower of these two values was used for the period to 2002. The higher values applied from 2003 reflect values used by Sankula and Blumenthal (2006) and Johnson and Strom (2007) that take into account the increasing use of Bollgard II technology, and draws on work by Mullins and Hudson (2004) that identified a yield gain of +12% relative to conventional cotton. The values applied 2005 onwards were adjusted downwards to reflect the fact that some of the GM IR cotton area has still been planted to Bollgard I.	+5% to +15%	1996-2002: $58.27 2003 & 2004: $68.32 2005 onwards: $49.60	1996-2002: $63.26 2003-2005: $74.10 2006 onwards: $41.18	Data derived from the same sources referred to for yield.
China	1997-2001: +8% 2002 onwards: +10%	Average of studies used to 2001. Increase to 10% on basis of industry assessments of impact and reporting of unpublished work by Schuchan.	Pray, Huang, Hu, and Rozelle (2002) surveyed farm level impact for the years 1999-2001 and identified yield impacts of +5.8% in 1999, +8% in 2000, and +10.9% in 2001 Monsanto China (personal communication, 2007, 2008)	+6% to +12%	All years to 2005: $46.30 2006 onwards: 366 Yuan	2000: $261 2001: $438 average of these used all other years to 2004 2005 onwards: 1,530 Yuan	Data derived from the same sources referred to for yield.
Australia	None	Studies have usually identified no significant average yield gain.	Fitt (2001) Doyle (2005) James (2002) Commonwealth Scientific and Industrial Research Organisation (CSIRO, 2005)	None applied	(In Australian dollars) 1996 & 1997: $245 1998: $155 1999: $138 2000-2001: $155 2002: $167 2003: $190 2004: $250 2005 onwards: $300	1996: $151 1997: $157 1998: $188 1999: $172 2000-2002: $267 2003: $598 2004: $509 2005 onwards: $553	Data derived from the same sources referred to for yield (Fitt, 2001) covering earlier years of adoption, then CSIRO for later years. For 2006 and 2007 cost of technology values confirmed by personal communication from Monsanto Australia.

Argentina	+30% all years	More conservative of the two pieces of research used	Qaim and De Janvry (2002, 2005) analysis based on farm level analysis in 1999/00 and 2000/01 +35% yield gain, Trigo and Cap (2006) used an average gain of +30% based on work by Elena (2001).	+25% to +35%	All years to 2004: $86 2005 onwards: 116 Pesos	51 Pesos all years	Data derived from the same sources referred to for yield. Cost of technology in 2006 and 2007 also confirmed from industry sources.
South Africa	+24% all years	Lower end of estimates applied	Ismael et al. (2002) identified yield gain of +24% for the years 1998/99 & 1999/2000. Kirsten, Gouse, and Jenkins (2002) for 2000/01 season found a range of +14% (dry crops/large farms) to +49% (small farmers). James (2002) also cited a range of impact between +27% and +48% during the years 1999-2001.	+15% to +40%	All years to 2005: 149 Rand 2006 onwards: 345 Rand	127 Rand all years	Data derived from the same sources referred to for yield. Values for cost of technology and cost of insecticide cost savings also provided/ confirmed from industry sources.
Mexico	1996: +37% 1997: +3% 1998: +20% 1999: +27% 2000: +17% 2001: +9% 2002: +6.7% 2003: +6.4% 2004: +7.6% 2005: +9.25% 2006: +9% 2007: +9.28	Recorded yield impact data used as available for almost all years	The yield impact data for 1997 and 1998 is drawn from the findings of farm level survey work by Traxler et al. (2001). For all other years the data is based on the commercial crop monitoring reports required to be submitted to the Mexican government (Monsanto Mexico, 2005, 2007). As data from this source was not available for 2007, the yield applied in 2007 is the average for the period 2000-2006.	None applied as almost all years are crop-specific estimates	All years to 2005: 540 Pesos 2006 onwards: 760 Pesos	1996 & 1999 onwards: 985 Pesos 1997: $121 1998: $94	Data derived from the same sources referred to for yield
India	2002: +45% 2003: +63% 2004: +54% 2005: +64% 2006 & 2007: +50%	Recorded yield impact used for almost all years	Yield impact data 2002 and 2003 is drawn from Bennett et al. (2004), for 2004 the average of 2002 and 2003 was used. 2005 and 2006 are derived from IMRB (2006, 2007). 2007 impact data based on lower end of range of impacts identified in previous three years (2007 being a year of similar pest pressure to 2006—lower than average).	All years 45% to 65%	(in Rupees) 2002: 2,636 2003: 2,512 2004: 2,521 2005: $2,307 2006 & 2007: 2,211	(in Rupees) 2002: 2,032 2003: 1,767 2004: 1,900 2005: 1,362 2006: 2,308 2007: 1,857	Data derived from the same sources referred to for yield. 2007 cost of technology confirmed from industry sources and cost savings for 2007 taken as average of past three years
Brazil	+6.23%		The only data source identified (unpublished farm survey data—Monsanto Brazil, 2008) has been used covering the 2006 season. This has also been used for 2007.	All years: +4% to +8%	2006 onwards: $40	141 Real	Data derived from the same source referred to for yield.

			GM HT soybeans				
US	0%	Not relevant	Not relevant	Not relevant	1996-2002: $14.82 2003: $17.30 2004: $19.77 2005 onwards: $24.71	1996-97: $25.20 1998-2002: $33.90 2003: $78.50 2004: $60.10 2005: $69.40 2006 onwards: $81.70	Marra, Pardey, and Alston (2002) Gianessi and Carpenter (1999) Carpenter and Gianessi (2002) Sankula and Blumenthal (2003, 2006) Johnson and Strom (2007)
Canada	0%	Not relevant	Not relevant	Not relevant	(Canadian $) 1997-2002: $32 2003: $48 2004 & 2005: $45 2006 onwards: $41	Range of Can $66-89 1997-2007 converted to US $ at prevailing exchange rate	George Morris Centre (2004)
Argentina	0% but second crop benefits	Not relevant except 2nd crop—see separate table	Not relevant	Not relevant	$3-$4 all years to 2001 $1.20 2002-2005 (reflecting all use of farm saved seed) $2.50 2006 onwards (Monsanto royalty rate)	$24-$30: varies each year according to exchange rate	Qaim and Traxler (2002, 2005), Trigo and Cap (2006).
Brazil	0%	Not relevant	Not relevant	Not relevant	Same as Argentina to 2002 (illegal plantings) 2003: $9 2004: $15 2005: $16 2006: $19.80 2007: $18.80	$88 in 2004 applied to all other years at prevailing exchange rate	Data from the Parana Department of Agriculture (2004). Also agreed royalty rates from 2004.
Paraguay	0% but second crop benefits	Not relevant except 2nd crop	Not relevant	Not relevant	Same as Argentina to 2004 2005: $4.86 2006: $3.09 2007: $9.64	Same as Argentina	Same as Argentina: no country-specific analysis identified. Impacts confirmed from industry sources (personal communication, 2006, 2008).
South Africa	0%	Not relevant	Not relevant	Not relevant	All years to 2005: 170 Rand 2006 onwards: 195 Rand	230 Rand each year converted to US $ at prevailing exchange rate	No studies identified—based on Monsanto South Africa (personal communication, 2005, 2007, 2008).
Uruguay	0%	Not relevant	Not relevant	Not relevant	Same as Argentina	Same as Argentina	Same as Argentina: no country-specific analysis identified. Impacts confirmed from industry sources (personal communication, 2006, 2008).

Mexico	+9.1%	Recorded yield impact from studies	From Monsanto (2007) unpublished study—the only identified data	None applied—small scale plantings	$34.50 all years	$154.50	No studies identified based on Monsanto (2007) and updated by personal communication (2008).
Romania	+31%	Based on only available study covering 1999-2003 (note not grown in 2007).	For previous year—based on Brookes (2005)—the only published source identified	+20% to +40%	1999-2000: $160 2001: $148 2002: $135 2003 & 2004: $130 2005: $121 2006: $100 Not permitted for use in EU 2007 All years includes 4 liters of herbicide	1999-2006: $150-$192 depending on Euro to $ exchange rate 2007 not applicable—trait not permitted for growing in EU	Brookes (2005)

GM VR crops US							
Papaya	Between +15% and +50% 1999-2007—relative to base yield of 22.86 t/ha	Based on average yield in three years before first use.	Draws on only published source disaggregating to this aspect of impact.	+15% all years to +50% all years	$0 1999 to 2003 $42 2004 $148 2005 onwards	None—no effective conventional method of protection.	Sankula and Blumenthal (2003, 2006) Johnson and Strom (2007)
Squash	+100% on area planted	Assumes virus otherwise destroys crop on planted area.	Draws on only published source disaggregating to this aspect of impact.	+50% all years	$398 all years	None—no effective conventional method of treatment.	Sankula and Blumenthal (2003, 2006) Johnson and Strom (2007)

GM HT corn							
US	0%	Not relevant	Not relevant	Not relevant	$14.80 all years to 2004 $17.30 2005 $24.71 2006 onwards	$39.90 all years to 2003 $40.55 2004 $40.75 2005 $44.60 2006 onwards	Carpenter and Gianessi (2002) Sankula and Blumenthal (2003, 2006) Johnson and Strom (2007)—these are the only available studies breaking down impact into disaggregated parts.
Canada	0%	Not relevant	Not relevant	Not relevant	Can $27 1999-2005 Can $35 2006 onwards	Can $48.75 all years	No studies identified—based on personal communications with industry sources, including Monsanto Canada.
Argentina	+3% corn belt +22% marginal areas	Based on only available analysis—Corn Belt = 70% of plantings, marginal areas 30%—industry analysis (note no significant plantings until 2006)	No studies identified—based on personal communications with industry sources in 2007 and 2008 Monsanto Argentina and Grupo CEO (personal communication, 2007, 2008).	+1% to +5% corn belt, +15% to +30% marginal areas	61 Pesos all years	61 Pesos all years	No studies identified—based on Monsanto Argentina and Grupo CEO (personal communication, 2007, 2008).
South Africa	0%	Not relevant	Not relevant	Not relevant	80 Rand 2003-2005 120 Rand 2006 onwards	162 Rand all years	No studies identified—based on Monsanto South Africa (personal communication, 2005, 2007, 2008).
Philippines	+15%	Based on only available analysis—industry analysis		+10% to +20% all years	1,232 Pesos all years	Not known so conservative assumption of zero used	No studies identified—based on Monsanto Philippines (personal communication, 2007, 2008).

GM HT canola							
US	+6% all years to 2004. Post 2004, based on Canada—see below	Based on the only identified impact analysis—post 2004 based on Canadian impacts as same alternative (conventional HT) technology to Canada available.	Same as source for cost data	All years: +3% to +9%	**Glyphosate tolerant** 1999-2001: $29.50 2002-2004: $33 2005 onwards: $12 **Glufosinate tolerant** All years for to 2004: $17.30 From 2005: $12	**Glyphosate tolerant** 1999-2001: $60.75 2002 & 2003: $67 2004: $69 2005: $49 2006 onwards: $40 **Glufosinate tolerant** All years to 2003: $44.89 2004: $44 2005: $40 2006 onwards: $435	Sankula and Blumenthal (2003, 2006) Johnson and Strom (2007) These are the only studies identified that examine GM HT canola in the US.
Canada	+10.7% all years to 2004. After 2004, based on differences between average annual variety trial results for Clearfields (non-GM HT varieties) and GM alternatives. GM alternatives differentiated into glyphosate tolerant and glufosinate tolerant. This resulted in—for GM glyphosate tolerant varieties—no yield difference for 2004 and 2005 and +4% for 2006 and 2007. For GM glufosinate tolerant varieties, the yield differences were +12% in 2004, +19% in 2005, and +10% for 2006 and 2007.		Same as source for cost data	+4% to +12% all years	Can $44.63 all years to 2003 2004 onwards based on difference seed premium and technology fee relative to Clearfields HT canola; $0 for GM glufosinate tolerance and Can $37 for glyphosate tolerance	(In Canadian $) **Glyphosate tolerant** $39 all years to 2003 2004 onwards: $40 **Glufosinate tolerant** All years to 2003: $39 2004 onwards: $10	Based on Canola Council of Canada (2001) to 2003, then adjusted to reflect main current non GM (HT) alternative of 'Clearfields'—data derived from personal communications with the Canola Council of Canada (2008) and Gusta et al. (2008).

Readers should note that the assumptions are drawn from the references cited, supplemented and updated by industry sources (where the authors have not been able to identify specific studies). This has been particularly of relevance for some of the HT traits more recently adopted in several developing countries. Accordingly, the authors are grateful to industry sources who have provided information on impact, notably on cost of the technology and impact on costs of crop protection. While this information is not derived from detailed studies, the authors are confident that it is reasonably representative of average impacts; in fact, in a number of cases, information provided from industry sources via personal communications has suggested levels of average impact that are lower than those identified in independent studies. Where this has occurred, the more conservative (industry source) data has been used.