Socio-economic impacts of GM crop technology: primary ‘first round’ impacts 1996-2007

Briefing note

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1. Introduction

This paper summarises the main 'first round' socio-economic global impacts of genetically modified (GM) crop technology since it was first adopted on a broad commercial scale in 1996. The material presented largely draws on the findings presented in the latest (4th) annual update report on the global socio-economic and environmental impacts of biotech crops by Brookes G & Barfoot P (2009)[1].

This report follows the same methodology used for the previous three annual reports, all of which have been published in the peer review scientific journal AgBioforum[2]. This latest report (4th edition) has also recently received acceptance for publication in the next edition of AgBioforum. Readers should also note that the Brookes & Barfoot analysis is based on an extensive review of existing farm level impact data for biotech crops (over 50 references on direct/first round socio-economic impacts, many of which are in peer reviewed journals). Whilst 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 was used as the basis for the analysis. Additional information about the methodology can be found in Appendix 1.

2 Socio-economic impacts: impact on yield & production

2.1 Insect resistant (IR) corn/maize

Two biotech insect resistant traits have been commercially used targeting the common corn boring pests (*Ostrinia nubilalis* (European corn borer or ECB) and *Sesamia nonagroides* (Mediteranean stem borer or MSB) and Corn Rootworm pests – *Diabrotica).* These are major pests of corn crops in many parts of the world and significantly reduce yield and crop quality, unless crop protection practices are employed.

The two biotech IR corn traits have delivered positive yield impacts in all user countries when compared to average yields derived from crops using conventional technology (mostly application of insecticides and seed treatments) for control of corn boring and rootworm pests.

The positive yield impact varies from an average of about +5% in North America to +24% in the Philippines (Figure 1). In terms of additional production, on an area basis, this is in a range of +0.25 tonnes/ha to +0.88 tonnes/ha.

Average positive yield and production impact across the total area planted to biotech IR corn traits over the cumulative time period of adoption (a maxium of twelve years) has been + 6.17%. This has added 62.4 million tonnes to total corn production in the countries using the technology. In 2007, the technology delivered an extra 15 million tonnes of corn production (Table 1).

[1] Available at www.pgeconomics.co.uk

[2] AgbioForum 8 (2&3) 187-196, 9 (3) 1-13 and 11 (1), 21-38. www.agbioforum.org

In the EU, in maize growing regions affected by corn boring pests, the primary impact of the adoption of GM IR maize has been higher yields compared to conventional maize. Average yield benefits have often been +10% and sometimes higher, although impacts vary by region and year according to pest pressure (Table 1).

Figure 1: Corn: yield and production impact of biotechnology 1996-2007 by country

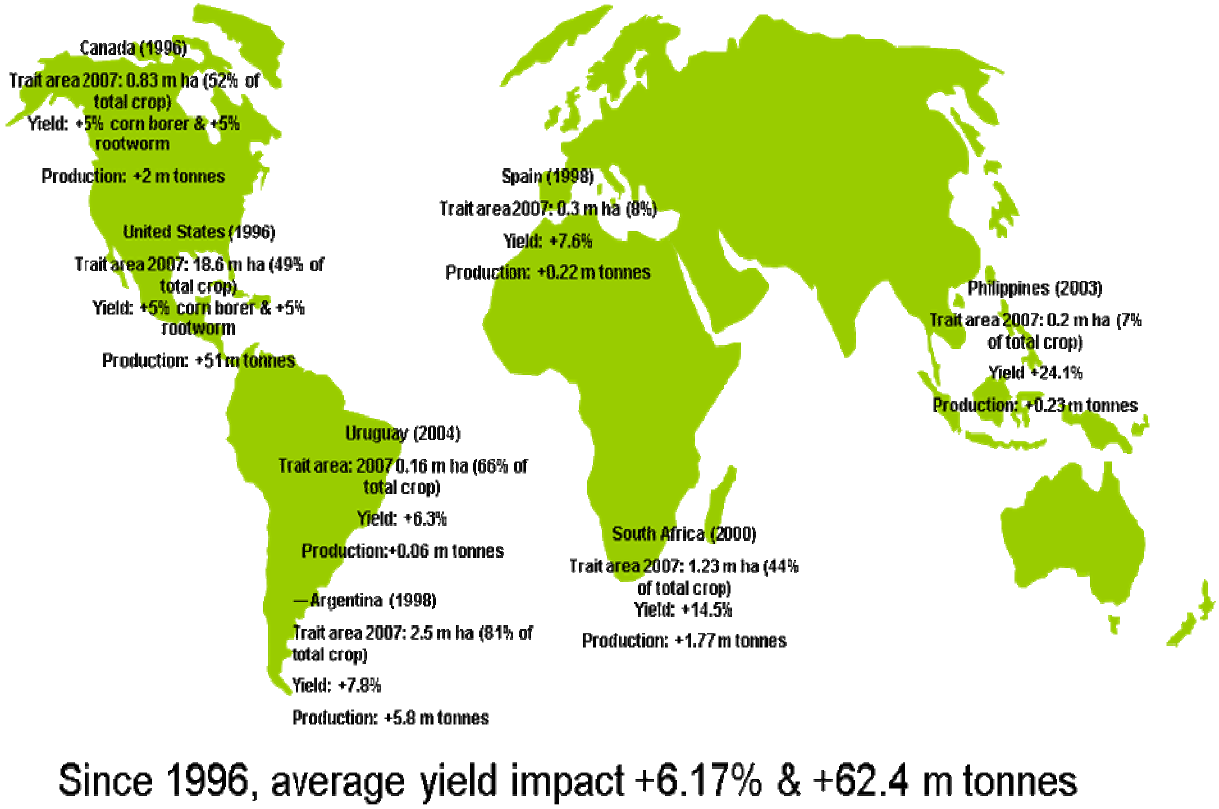


Table 1: Corn: yield and production impact of biotechnology 1996-2007

	Year of first adoption	GM trait area 2007	% of crop to trait[3]	Average trait impact on yield %[4]	Average yield impact (tonnes/ha)	Additional production from trait (tonnes): 2007	Additional production from trait (tonnes): cumulative
US Corn borer resistant	1996	18,560,907	49	5	0.43	8,584,419	44,662,867
US Corn Rootworm resistant	2003	8,417,645	22	5	0.43	3,893,161	7,023,290
Canada Corn borer resistant	1996	831,000	52	5	0.38	344,450	1,972,525
Canada Corn Rootworm	2004	39,255	2.5	5	0.38	16,271	30,591

[3] From year of first commercial planting to 2006

[4] Average of impact over years of use, as estimated by Brookes & Barfoot (2009)

resistant							
Argentina corn borer resistant	1997	2,509,000	81	7.8	0.48	938,366	5,801,153
Philippines corn borer resistant	2003	193,890	7	24.15	0.52	117,998	233,281
S Africa Corn borer resistant	2000	1,234,000	44	15.3	0.46	740,400	1,775,135
Uruguay Corn borer resistant	2004	105,000	62	6.3	0.32	32,398	62,957
Spain Corn borer resistant	1998	75,148	21	7.4	0.7	70,188	288,320
France Corn borer resistant	2005	22,135	1.5	10	0.88	20,807	25,540
Germany Corn borer resistant	2005	2,685	0.7	4	0.35	976	1,374
Portugal corn borer resistant	2005	4,263	3.6	12.5	0.65	2,936	4,203
Czech Republic Corn borer resistant	2005	5,000	4.7	10	0.66	2,875	3,939
Slovakia Corn borer resistant	2005	948	0.6	12.3	0.68	499	519
Poland Corn borer resistant	2006	327	0.1	12.5	0.59	216	231
Romania Corn borer resistant	2007	360	0.02	7.1	0.25	89	89
Cumulative totals		**32,001,563**				**14,766,049**	**61,886,014**

2.2 Insect resistant (IR) cotton

Insect resistant traits have been commercially used targeting various *Heliothis* pests (eg, budworm and bollworm). These are major pests of cotton crops in all cotton growing regions of the world and can devastate crops, causing substantial reductions in yield, unless crop protection practices are employed.

The biotech IR cotton traits used have delivered positive yield impacts in all user countries (except Australia[5]) when compared to average yields derived from crops using conventional technology (mainly the intensive use of insecticides) for control of *heliothis* pests.

The positive yield impact varies from an average of about +6% in South America to +54% in India (Figure 2). In terms of additional production, on an area basis, this is in a range of +0.05 tonnes/ha to +0.17 tonnes/ha (of cotton lint).

The average positive yield and production impact across the area planted to insect resistant cotton over the eleven year period has been + 13.3%. This has added 6.85 million tonnes to total cotton lint

[5] 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

production in the countries using the technology. In 2007, the technology delivered an extra 2.01 million tonnes of cotton lint production (Table 2).

Figure 2: Cotton: yield and production impact of biotechnology 1996-2007 by country

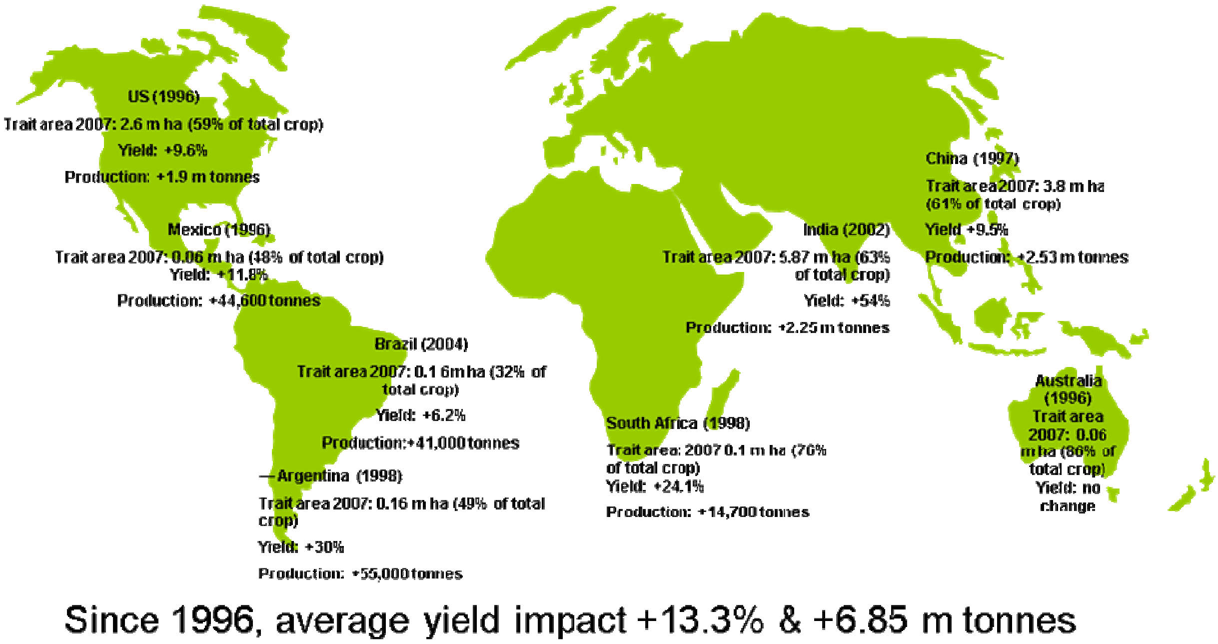


Table 2: Cotton: yield and production impact of biotechnology 1996-2007

	Year of first adoption	GM trait area 2007	% of crop to trait[6]	Average trait impact on yield %[7]	Average yield impact (tonnes/ha)	Additional production from trait (tonnes): 2007	Additional production from trait (tonnes): cumulative
US	1996	2,585,160	59	9.6	0.07	240,420	1,900,796
China	1997	3,800,000	61	9.5	0.1	449,920	2,533,336
South Africa	1998	9,900	76	24.3	0.11	1,644	14,734
Australia	1996	55,328	86	Nil	-	-	-
Mexico	1996	60,000	48	11.8	0.12	6,570	44,628
Argentina	1998	162,300	49	30	0.12	20,352	55,349
India	2002	5,868,000	63	54.8	0.17	1,261,620	2,255,826
Columbia	2002	20,000	43	8.1	0.06	1,763	5,360
Brazil	2006	358,000	32	6.2	0.08	29,440	40,627
Cumulative totals		**12,918,688**				**2,011,730**	**6,850,656**

[6] From year of first commercial planting to 2006

[7] Average of impact over years of use, as estimated by Brookes & Barfoot (2009)

2.3 Herbicide tolerant soybeans

Weeds have traditionally been a significant problem for soybean farmers, causing important yield losses (from weed competition for light, nutrients and water). Most weeds in soybean crops have been reasonably controlled, based on application of a mix of herbicides.

Although the primary impact of biotech herbicide tolerant (HT) technology has been to *provide more cost effective* (less expensive) and *easier* weed control versus improving yields from *better* weed control (relative to weed control obtained from conventional technology), improved weed control has, nevertheless occurred - delivering higher yields. Specifically, the main country in which HT soybeans has deliverd higher yields has been in Romania, where the average yield increased by over 30 per cent (Figure 3)[8].

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 67.6 million tonnes to soybean production in Argentina and Paraguay between 1996 and 2007. In 2007, the second crop soybean production in these countries was 14.5 million tonnes (Table 3).

Table 3: Second crop soybean production facilitated by biotech HT technology in South America 1996-2007 (million tonnes)

Country	Year first commercial use of HT soybean technology	Second crop soybean production 2007	Second crop soybean production cumulative
Argentina	1996	13,987,114	64,870,614
Paraguay	1999	472,358	2,689,280
Total		**14,459,472**	**67,559,894**

2.4 Herbicide tolerant canola

Weeds represent a significant problem for canola growers contributing to reduced yield and impairing quality by contamination (eg, with wild mustard seeds). Conventional canola weed control is based on a mix of herbicides which has provided reasonable levels of control although some resistant weeds have developed (eg, to the herbicide trifluralin). Canola is also sensitive to herbicide carryover from (herbicide) treatments in preceding crops which can affect yield.

The main impact of biotech HT canola technology, used widely by canola farmers in Canada and the US, has been to provide more cost effective (less expensive) and easier weed control, coupled with higher yields. The higher yields have arisen mainly from more effective levels of weed control than was previously possible using conventional technology. Some farmers have also obtained yield gains from biotech derived improvements in the yield potential of some HT canola seed.

[8] Weed infestation levels, particularly of difficult to control weeds such as Johnson grass have been very high in Romania. This is largely a legacy of the economic transition during the 1990s which resulted in very low levels of farm income, abandonment of land and very low levels of weed control. As a result, the weed bank developed substantially and has been subsequently very difficult to control, until the GM HT soybean system became available (glyphosate has been the key to controlling difficult weeds like Johnson grass)

The average annual yield gains (average over all years of adoption) have been about +3.5% in the US and +9% in Canada (Figure 3).

Over the 1996-2007 period, the additional North American canola production arising from the use of biotech HT technology was +4.44 million tonnes (Figure 3).

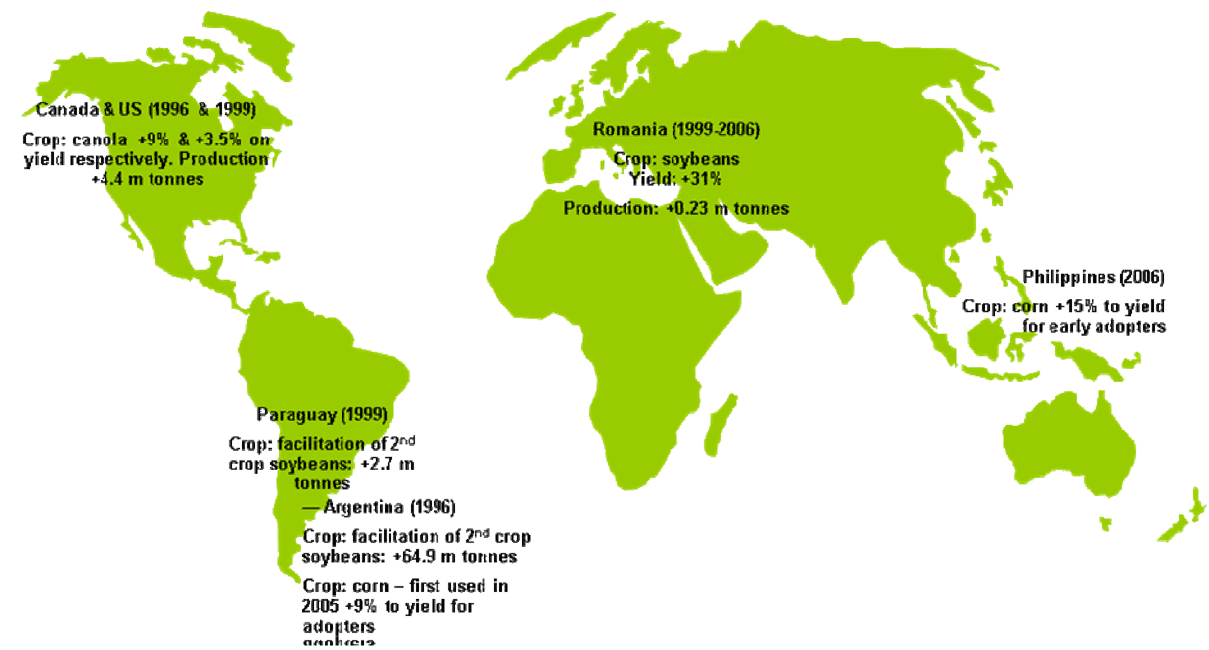
2.5 Herbicide tolerant corn & cotton

Weeds have also been a significant problem for corn and cotton farmers, causing important yield losses. Most weeds in these crops have been reasonably controlled based on application of a mix of herbicides.

The HT technology used in these crops has mainly provided more cost effective (less expensive) and easier weed control rather than improving yields from better weed control (relative to weed control levels obtained from conventional technology).

Improved weed control from use of the HT technology has, nevertheless, delivered higher yields in some regions and crops (Figure 3). For example, in Argentina, where HT corn was first used commercially in 2005, the average yield effect has been +9%, adding +0.45 million tonnes to national production (2005-2007). Similarly in the Philippines, (first used commercially in 2006), early adopters are finding an average of +15% to yields (this has delivered an extra 83,000 tonnes on the small area using the technology in the first two years of adoption).

Figure 3: Herbicide tolerant crops: yield and production impact of biotechnology 1996-2007 by country



2.6 Production impacts: summary

Drawing on the impacts presented above, in sections 2.1 to 2.5, Table 4 summaries the impact that adoption of biotech traits has had on production levels of the four main crops in which the technology has been used (soybeans, corn, cotton and canola) over the 1996-2007 period. Key points to note are:

- The biotech IR traits, used in the corn and cotton sectors, have accounted for 99% of the additional corn/maize production and all of the additional cotton production;
- In 2007, at the global level, world production levels of soybeans, corn, cotton lint and canola were respectively +6.5%, +1.9%, +7.7% and +1.1% higher than levels would have otherwise been if biotech traits had not been used by farmers;
- In area equivalent terms, if the biotech traits used by farmers in 2007 had not been available, maintaining global production levels at the 2007 levels would have required additional (conventional crop) plantings of 5.89 million ha of soybeans, 3 million ha of corn, 2.54 million ha of cotton and 0.32 million ha of canola. This total area requirement is equivalent to about 6% of the arable land in the US, or 23% of the arable land in Brazil.

Table 4: 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

3. Farm income and cost of production effects

3.1 Global level

Over the twelve year period 1996-2007, biotechnology has had a significant positive impact on global farm income derived from a combination of enhanced productivity and efficiency gains (Table 5):

- 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 herbicide tolerant (GM HT) soybeans in 2007 has been equivalent to adding 7.2% to the value of the crop in the 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 of the US, Brazil and Argentina increased by 58%. Of the total cumulative income gains from biotech HT soybeans ($21.81 billion 1996-2007), 78.5% has been due to cost savings and the balance due to yield increases (from improved weed control mainly in Romania and Mexico) and facilitation of 2nd crop soybeans in South America (by shortening the production cycle for soybeans, the technology has enabled many South American farmers to plant a crops of

soybeans immediately after a wheat crop 'in the same season'). The average farm income gain over the 1996-2007 period across the total biotech HT soybean area was $42/ha and for 2[nd] crop soybeans the average gain was $167/ha;

- Substantial gains have also arisen in the cotton sector through a combination of higher yields and lower costs associated with the use of GM IR technology. 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. Within this, 65% of the farm income gain has derived from yield gains (less pest damage) and the balance (35%) from reduced expenditure on crop protection (spraying of insecticides). 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. Biotech IR cotton has provided the largest gains per hectare, with an average farm income gain across the total biotech IR cotton area, over the 1996-2007 period, of $150/ha. Income gains have been largest in developing countries, notably China and India, where the average income gain has respectively been +$286/ha and +$275/ha;
- Significant increases to farm incomes have also resulted 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 $1.44 billion has been generated;
- Of the total cumulative farm income benefit, $20.5 billion (46.5%) has been due to yield gains (and second crop facilitation), with the balance arising from reductions in the cost of production. Within this yield gain component, 68% derives from the GM IR technology and the balance to GM HT crops.

Table 5: Global farm income benefits from growing biotech crops 1996-2007: million US $

Trait	Increase in farm income 2007	Increase in farm income 1996-2007	Farm income benefit in 2007 as % of total value of production of these crops in biotech adopting countries	Farm income benefit in 2007 as % of total value of global production of crop
GM herbicide tolerant soybeans	3,935	21,814	7.2	6.4
GM herbicide tolerant maize	442	1,508	0.7	0.4
GM herbicide tolerant cotton	25	848	0.1	0.1
GM herbicide tolerant canola	346	1,439	7.65	1.4
GM insect resistant maize	2,075	5,674	3.2	1.9
GM insect resistant cotton	3,204	12,576	16.5	10.2
Others	54	209	Not applicable	Not applicable
Totals	**10,081**	**44,068**	**6.9**	**4.4**

Notes: All values are nominal. Others = Virus resistant papaya and squash. Totals for the value shares exclude 'other crops' (ie, relate to the 4 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 (eg, payment of seed premia, impact on crop protection expenditure)

Table 6 summarises 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 US. It also illustrates the growing level of farm income benefits being obtained in South Africa, the Philippines and Mexico.

Table 6: GM crop farm income benefits 1996-2007 selected countries: million US $

	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	4,778.8	2,232.7	***19,789.6***
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	***3,181***
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	12.6	N/a	***12.6***
Columbia	N/a	N/a	N/a	N/a	N/a	10.4	***10.4***

Notes: 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 (eg, payment of seed premia, impact on crop protection expenditure). N/a = not applicable

In terms of the division of the economic benefits obtained by farmers in developing countries relative to farmers in developed countries. Table 7 shows that in 2007, 58% of the farm income benefits have been 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[9]. 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).

Table 7: GM crop farm income benefits 2007: developing versus developed countries: million US $

	Developed	Developing
GM HT soybeans	1,375	2,560
GM IR maize	1,773	302
GM HT maize	402	41
GM IR cotton	286	2,918
GM HT cotton	16	8

[9] 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 paper is consistent with the definition used by James (2007)

GM HT canola	346	0
GM virus resistant papaya and squash	54	0
Total	**4,252**	**5,829**

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

It is important to recognise that the analysis presented above is largely based on estimates of average impact in all years. Recognising that pest and weed pressure varies by region and year, additional sensitivity analysis is presented below 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 suggests a range of positive direct farm income gains in 2007 of +$8.5 billion to +$12.9 billion and over the 1996-2007 period, a range of +$38.2 billion to +$52.2 billion (Table 8). This range is broadly within 85% to 120% of the main estimates of farm income presented above.

Table 8: 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

3.2 EU focus

3.2.1 GM HT soybeans: Romania

After joining the EU at the beginning of 2007, Romania was no longer officially permitted to plant GM HT soybeans. The impact data presented below therefore covers the period 1999-2006.

The growing of GM HT soybeans in Romania had resulted in substantially greater net farm income gains per hectare than any of the other countries using the technology:

- Yield gains of an average of 31%[10] have been recorded (see section 2).
- The cost of the technology to farmers in Romania tended to be higher than other countries, with seed being sold in conjunction with the herbicide. For example, in the 2002-2006 period, the average cost of seed and herbicide per hectare was $120/ha to $130/ha. This relatively high cost

[10] Source: Brookes (2005)

however, did not deter adoption of the technology because of the major yield gains, improvements in the quality of soybeans produced (less weed material in the beans sold to crushers which resulted in price premia being obtained[11]) and cost savings derived;

- The average net increase in gross margin in 2006 was $220/ha (an average of $175/ha over the eight years of commercial use: Table 9);
- At the national level, the increase in farm income amounted to $28.6 million in 2006. Cumulatively in the period1999-2006 the increase in farm income was $92.7 million (in nominal terms);
- The yield gains in 2006 were equivalent to an 21% increase in national production[12] (the annual average increase in production over the eight years was equal to 14.9%);
- In added value terms, the combined effect of higher yields, improved quality of beans and reduced cost of production on farm income in 2006 was equivalent to an annual increase in production of 33% (124,000 tonnes).

Table 9: Farm level income impact of using herbicide tolerant soybeans in Romania 1999-2006

Year	Cost saving ($/ha)	Cost savings net of cost of technology ($/ha)	Net increase in gross margin ($/ha)	Impact on farm income at a national level ($ millions)	Increase in national farm income as % of farm level value of national production
1999	162.08	2.08	105.18	1.63	4.0
2000	140.30	-19.7	89.14	3.21	8.2
2001	147.33	-0.67	107.17	1.93	10.3
2002	167.80	32.8	157.41	5.19	14.6
2003	206.70	76.7	219.01	8.76	12.7
2004	260.25	130.25	285.57	19.99	27.4
2005	277.76	156.76	266.68	23.33	38.6
2006	239.07	113.6	220.55	28.67	33.2

Sources and notes:

1. Impact data (source: Brookes 2005). Average yield increase 31% applied to all years, average improvement in price premia from high quality 2% applied to years 1999-2004
2. All values for prices and costs denominated in Romanian Lei have been converted to US dollars at the annual average exchange rate in each year
3. Technology cost includes cost of herbicides
4. The technology was not permitted to be planted in 2007 – due to Romania joining the EU

3.2.2 GM IR maize: Spain

Spain has been commercially growing GM IR maize since 1998 and in 2007, 21% (75,150 ha) of the country's maize crop was planted to varieties containing a GM IR trait.

[11] Industry sources report that price premia for cleaner crops were no longer payable from 2005 by crushers and hence this element has been discontinued in the subsequent analysis

[12] Derived by calculating the yield gains made on the GM HT area and comparing this increase in production relative to total soybean production

As in the other countries planting GM IR maize, the main impact on farm profitability has been increased yields (an average increase in yield of 6.3% across farms using the technology in the early years of adoption). With the availability and widespread adoption of the Mon 810 trait from 2003, the reported average positive yield impact is about +10%[13]. There has also been a net annual average saving on cost of production (from lower insecticide use) of between $37/ha and $57/ha[14] (Table 10). At the national level, these yield gains and cost savings have resulted in farm income being boosted, in 2007 by $20.6 million and cumulatively since 1998 the increase in farm income (in nominal terms) has been $60 million.

Relative to national maize production, the yield increases derived from GM IR maize were equivalent to a 2% increase in national production (2007). The value of the additional income generated from Bt maize was also equivalent to an annual increase in production of 1.94%.

Table 10: Farm level income impact of using GM IR maize in Spain 1998-2007

Year	Cost savings ($/ha)	Net cost savings inclusive of cost of technology ($/ha)	Net increase in gross margin ($/ha)	Impact on farm income at a national level ($ millions)
1998	37.40	3.71	95.16	2.14
1999	44.81	12.80	102.20	2.56
2000	38.81	12.94	89.47	2.24
2001	37.63	21.05	95.63	1.10
2002	39.64	22.18	100.65	2.10
2003	47.50	26.58	121.68	3.93
2004	51.45	28.79	111.93	6.52
2005	52.33	8.72	144.74	7.70
2006	52.70	8.78	204.5	10.97
2007	57.30	9.55	274.59	20.63

Sources and notes:

1. Impact data (based on Brookes (2002 & Brookes (2008)). Yield impact +6.3% to 2004 and 10% used thereafter (originally Bt 176, latterly Mon 810). Cost of technology based on €18.5/ha to 2004 and €35/ha from 2005
2. All values for prices and costs denominated in Euros have been converted to US dollars at the annual average exchange rate in each year

3.2.3 GM IR maize: Other EU countries

A summary of the impact of GM IR technology in other countries of the EU is presented in Table 11. This shows that in 2007, the additional farm income derived from using GM IR technology in these seven countries was +$7.4 million. Cumulatively over the 2005-2007 period, the total income gain was $8.6 million.

Table 11: Farm level income impact of using GM IR maize in other EU countries 2005-2007

	Year first planted GM IR maize	Area 2007 (hectares)	Yield impact (%)	Cost of technology 2007 ($/ha)	Cost savings 2007 (before deduction	Net increase in gross margin 2007 ($/ha)	Impact on farm income at a national level 2007

[13] The cost of using this trait has been higher than the pre 2003 trait (Bt 176) – rising from about €20/ha to €35/ha

[14] Source: Brookes (2002) and Alcade (1999)

					of cost of technology: $/ha)		(million $)
France	2005	22,135	+10	54.57	68.21	254.73	5.64
Germany	2005	2,685	+4	54.57	68.21	117.32	0.32
Portugal	2005	4,263	+12.5	47.75	0	143.94	0.61
Czech Republic	2005	5,000	+10	47.75	24.56	146.25	0.73
Slovakia	2005	948	+12.3	47.75	0	102.35	0.09
Poland	2006	327	+12.5	47.75	0	123.33	0.04
Romania	2007	360	+7.1	43.66	0	34.66	0.01
Total other EU (excluding Spain)		**35,670**					**7.44**

Source and notes:

1. Source: based on Brookes (2008)
2. All values for prices and costs denominated in Euros have been converted to US dollars at the annual average exchange rate in each year

4. Other 'first round' impacts: non pecuniary benefits

As well as the quantifiable impacts on yield and farm profitability, there have been other important, more intangible impacts (of an economic nature), associated with the adoption of biotech traits. Most of these have been important influences for adoption of the technology and include:

Herbicide tolerant crops

- Increased management flexibility 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;
- Compared to conventional crops, where post-emergent herbicide application may result in 'knock-back' (some risk of crop damage from the herbicide), this problem is less likely to occur in GM HT crops;
- Facilitation of adoption of no/reduced tillage practices with resultant savings in time and equipment usage (see below for environmental benefits);
- Improved weed control has 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;
- Elimination of potential damage caused by soil-incorporated residual herbicides in follow-on crops.

Insect resistant crops

- Production risk management/insurance purposes – taking away the worry of significant pest damage occurring;
- A 'convenience' benefit (less time spent on crop walking and/or applying insecticides);
- Savings in energy use – mainly associated with less spraying;
- Savings in machinery use (for spraying and possibly reduced harvesting times);
- Improved quality (eg, lower levels of mycotoxins in GM IR maize);

- Improved health and safety for farmers and farm workers (from reduced handling and use of insecticides);
- Shorter growing season (eg, for some cotton growers in India) which allows some farmers to plant a second crop in the same season[15]. Also some Indian cotton growers have reported knock on benefits for bee keepers as fewer bees are now lost to insecticide spraying.

Since the early 2000s a number of farmer-survey based studies in the US have attempted to better quantify these non pecuniary benefits. These studies have usually employed contingent valuation techniques[16] to obtain farmers valuations of non pecuniary benefits. Drawing on this analysis, the estimated value for non pecuniary benefits derived from biotech crops in the US (1996-2007) is $5.11 billion. Relative to the value of the direct US farm income benefits, the non pecuniary benefits were equal to 26% 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 US, especially where the direct farm income benefits have been identified to be relatively small (eg, HT cotton).

It is also evident that biotech-using farmers in other countries also value the technology for a variety of non pecuniary/intangible reasons. However, it is not possible to quantify these benefits in other countries due to the lack of studies into non pecuniary benefits outside the US.

[15] Notably maize in India

[16] Survey based method of obtaining valuations of non market goods that aim to identify willingness to pay for specific goods (eg, environmental goods, peace of mind, etc) or willingness to pay to avoid something being lost

Appendix 1: Methodology Brookes G & Barfoot P annual global impact studies

The report is based largely on extensive analysis of existing farm level impact data for biotech crops. Whilst 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.

As 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 being the most common way in which the identified literature has reported impact. Where several pieces of relevant research (eg, 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 largely based on the average of these findings.

This approach may both, overstate, or 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, as impact data for every trait, crop, location and year data 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 of 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[17]. Hence, the analysis takes into account variation in the impact of the technology on yield according to its effectiveness in dealing 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 dynamic 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 (eg, 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;
- adjusts downwards 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.

[17] Examples where such data is available include the impact of GM IR cotton: in India (see Bennett R et al (2004), IMRB (2006) and IMRB (2007)), in Mexico (see Traxler et al (2001) and Monsanto Mexico (2005 & 2007)) and in the US (see Sankala & Blumenthal (2003 and 2006), Mullins & Hudson (2004))

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 analysed 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 labour[18]), crop quality (eg, 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 (eg, second crop soybeans in Argentina following wheat that would, in the absence of the GM herbicide tolerant (GM 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.

Appendix 2: Sensitivity analysis assumptions used by Brookes G & Barfoot P annual global impact study 2009

IR corn (resistant to corn boring pests)

Country	Average yield impact assumption used	Sensitivity analysis applied to yield assumptions
GM IR corn resistant to corn boring pests		
US & Canada	+5% all years	+3% to +9%
Argentina	+9% all years to 2004, +5.5% 2005 onwards	+5% all years to +9% all years
Philippines	+24.6% all years	+14% to +34% all years
South Africa	+11% 2000 & 2001 +32% 2002 +16% 2003 +5% 2004 +15% 2005 onwards	+5% to +32% all years
Spain	+6.3% 1998-2004 +10% 2005 onwards	+3% to +15% all years
Other EU	France +10%, Germany +4%, Portugal +12.5%, Czech Republic +10%, Slovakia +12.3%, Poland +12.5%,	Not applied in context of total study due to very small scale of production (ie, would produce an

[18] Inclusion of impact 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 analysis. Therefore in most cases the analysis relates to impact of crop protection and seed cost only

	Romania +7.1%	insignificant impact range in the context of the whole study)
Uruguay	As Argentina	As Argentina: +5% to +9%
GM IR corn (resistant to corn rootworm)	**Yield impact assumption used**	**Sensitivity analysis applied to yield assumptions**
US & Canada	+5% all years	+3% to +9%
IR cotton	**Yield impact assumption used**	**Sensitivity analysis applied to yield assumptions**
US	+9% 1996-2002 +11% 2003 & 2004 +10% 2005 onwards	+5% to +15%
China	+8% 1997-2001 +10% 2002 onwards	+6% to +12%
Australia	None	None applied
Argentina	+30% all years	+25% to +35%
South Africa	+24% all years	+15% to +40%
Mexico	+37% 1996 +3% 1997 +20% 1998 +27% 1999 +17% 2000 +9% 2001 +6.7% 2002 +6.4% 2003 +7.6% 2004 +9.25% 2005 +9% 2006 +9.28 2007	None applied as almost all years are crop-specific estimates
India	+45% 2002 +63% 2003 +54% 2004 +64% 2005 +50% 2006 & 2007	45% to 65% all years
Brazil	+6.23%	+4% to +8% all years
GM HT soybeans	**Yield impact assumption used**	**Sensitivity analysis applied to yield assumptions**
US	Nil	Not relevant
Canada	Nil	Not relevant
Argentina	Nil but second crop benefits	Not relevant
Brazil	Nil	Not relevant
Paraguay	Nil but second crop benefits	Not relevant
South Africa	Nil	Not relevant
Uruguay	Nil	Not relevant
Mexico	+9.1%	None applied – small scale plantings
Romania	+31%	+20% to +40%
GM HT corn	**Yield impact assumption used**	**Sensitivity analysis applied to yield assumptions**
US	Nil	Not relevant
Canada	Nil	Not relevant
Argentina	+3% corn belt +22% marginal areas	+1% to +5% corn belt, +15% to +30% marginal areas

South Africa	Nil	Not relevant
Philippines	+15%	+10% to +20% all years
GM HT Cotton	**Yield impact assumption used**	**Sensitivity analysis applied to yield assumptions**
US	Nil	Not relevant
Australia	Nil	Not relevant
South Africa	Nil	Not relevant
Argentina	Nil on area using farm saved seed, +17.4% on area using certified seed	+10% to +20% on certified seed area
Mexico	+3.6%	Zero to +5% all years
GM HT canola	**Yield impact assumption used**	**Sensitivity analysis applied to yield assumptions**
US	+6% all years to 2004. Post 2004 based on Canada – see below	+3% to +9% all years
Canada	+10.7% all years to 2004. After 2004 based on differences between average annual variety trial results for Clearfields (non GM herbicide tolerant 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% 2006 and 2007. For GM glufosinate tolerant varieties, the yield differences were +12% 2004, +19% 2005, +10% 2006 & 2007	+4% to +12% all years
GM VR crops US		
Papaya	between +15% and +50% 1999-2007 – relative to base yield of 22.86 t/ha	+15% all years to +50% all years
Squash	+100% on area planted	+50% all years

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