The socio-economic impacts of currently commercialised genetically engineered crops

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Abstract: A substantial and growing body of literature now exists on the socio-economic impacts of genetically engineered (GE) crops. While the bulk of literature has focused on the primary impacts of commercialised GE technology, in terms of changes in yields, costs and profitability, researchers have increasingly addressed a range of additional questions such as the distribution of impacts across groups, as well as secondary impacts on labour markets, non-pecuniary factors and social welfare. This review summarises the results of the literature on this broader set of socio-economic impacts. The primary findings include: adopters receive a substantial share of the benefits; consumers are also shown to benefit from increased production leading to lower prices; small farmers in developing countries are benefiting from GE crop technology; adopters report improvements in health, education, debt repayment, maternal care services and food security.

Keywords: agricultural biotechnology; genetically engineered crops; GM crops; socio-economic considerations; social welfare; biosafety protocol.

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1 Introduction

A substantial and growing body of literature now exists on the socio-economic impacts of genetically engineered (GE) crops. While the bulk of literature has focused on the primary impacts of commercialised GE technology, in terms of changes in yields, costs and profitability, researchers have increasingly addressed a range of additional questions such as the distribution of impacts across groups, as well as secondary impacts on labour markets, non-pecuniary factors and social welfare. Here, we provide a brief summary of the literature on the direct farm level impacts of currently commercialised GE crops to provide the backdrop for the review of these other threads in the literature on the broader socio-economic impacts of currently commercialised GE crops around the world.

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2 Primary farm level impacts

GE crops were commercially grown on 160 million hectares in 29 countries in 2011 (James, 2011). The most widely adopted GE crops, and therefore the most widely studied, are herbicide tolerant soybeans, insect resistant corn and insect resistant cotton. In 2011, 82% of the global cotton area, 75% of the global soybean area and 32% of the global maize area were planted to GE varieties (James, 2011). The rapid rate of adoption implies that farmers are realising benefits from growing GE crops. Indeed, a starting point for many other socio-economic impacts is the impact that GE crops have on yields, costs and profitability at the farm level. Since their commercial introduction in the mid 1990s, an extensive literature has developed addressing the impacts of current technology on primary economic indicators: yields, costs and profitability.

The literature on global primary farm level impacts has been recently reviewed in two separate analyses. Looking at peer-reviewed publications reporting the results of farmer surveys, Carpenter (2010) compared yields and other indicators of economic performance for adopters and non-adopters of currently commercialised GE crops. Results from 12 countries indicated that GE crops have benefited farmers, with few exceptions. The mostly small farmers in developing countries have benefited most, especially in terms of increased yields. Of 168 results comparing yields of GE and conventional crops, 124 show positive results for adopters compared to non-adopters, 32 indicate no difference and 13 are negative. The average yield increases for developing countries range from 16% for insect resistant corn to 30% for insect resistant cotton, with an 85% yield increase observed in a single study on herbicide tolerant corn. On average, developed country farmers report yield increases that range from no change for herbicide tolerant cotton to a 7% increase for herbicide tolerant soybean and insect resistant cotton (see Table 1). The impacts on profitability, most commonly measured in terms of gross margins, were also overwhelmingly positive. Of 98 results comparing profitability of GE crops to their conventional counterparts, 71 indicated a positive impact, 11 results were neutral and 16 negative. The profitability results were driven by yield improvement as well as reduced costs, which were found in all but 12 cases Carpenter (2010). Impacts vary across years and locations due to differences in weather, pest pressure and the efficacy of conventional practices, which may explain some of the negative findings.

Kaphengst et al. (2011) conducted a statistical analysis of the results of both peer-reviewed and non-peer reviewed publications reporting results comparing the performance of GE varieties to conventional varieties from both field trials and farmer surveys. They found a similar pattern in the literature, namely that compared to conventional crops, GE crops can lead to yield increases mostly through reduced yield losses from insect infestation and weeds. Also, GE crops can reduce pesticide costs. The findings showed heterogeneity across countries and regions (Kaphengst et al., 2011).

In an analysis of the global impacts of GE crops, Brookes and Barfoot (2011) quantify the impacts of currently commercialised GE crops on farm income and production, using existing farm level impact data and extrapolating to traits, crops and locations where no data were available. Globally, the direct farm income benefit of currently commercialised GE crops resulting from increased yields and decreased costs was estimated to be \$10.8 billion in 2009, equal to 5.8% of the value of global production of soybeans, maize, canola and cotton.

Table 1 Average percentage changes in yield by technology for developed and developing countries [(GE-conventional)/conventional)][a]

Technology	*Change in yield*	*# of results*	*Min.*	*Max.*	*Std. err.*
Developed countries	6%	59	–12%	26%	1.0%
HT cotton	0%	6	–12%	17%	3.8%
HT soybean	7%	14	0%	20%	1.7%
HT/IR cotton	3%	2	–3%	9%	5.8%
IR corn	4%	13	–3%	13%	1.6%
IR cotton	7%	24	–8%	26%	1.9%
Developing countries	29%	107	–25%	150%	2.9%
HT corn	85%	1			
HT soybean	21%	3	0%	35%	11%
IR corn	16%	12	0%	38%	4%
IR corn (white)	22%	9	0%	62%	6.9%
IR cotton	30%	82	–25%	150%	3.5%

Notes: [a]Averages calculated across surveys, geographies, years and methodologies. A two-tailed t-test shows a significant difference between the average yields of developed and developing countries ($t = 7.48$, df = 134, $P < 0.0005$)

Source: Carpenter (2010)

3 Distribution of impacts

Researchers have extended the farm level analysis to look at how these benefits are distributed across different groups, breaking down the analysis between market actors, as well as by farm size, income groups and gender.

3.1 Market actors

Estimates of the distribution of impacts between producers, technology providers[1] and consumers have been calculated for technology introductions in eight countries and globally (Tables 2 and 3). In the seven studies that assume no price impacts,[2] and therefore no consumer impacts are estimated, farmers are estimated to have captured a large share of the benefits, between 40 and 90% of total on-farm benefits. The results illustrate the variability of benefits to farmers from year to year, particularly for insect resistant crops, where the benefits are correlated to pest pressure (Traxler and Godoy-Avila, 2004).

Table 2 Distribution of farm-level benefits between farmers and technology providers with no price effects*

Country	*Year(s)*	*Technology*	*Sector*	*Proportion of total gain*	*Reference*
Argentina	1996–2005	HT soybean	Producers	77%	Trigo and Cap (2006)
			Tech. providers	4%	
			Herbicide providers	5%	
			National govt.	13%	
Argentina	1998–2005	IR maize	Producers	43%	Trigo and Cap (2006)
			Tech. providers	41%	
			National govt.	16%	
Argentina	1996–2005	IR cotton	Producers	86%	Trigo and Cap (2006)
			Tech. providers	9%	
			National govt.	5%	
China	1999	Bt cotton-CAAS varieties	Producers	83%	Pray et al. (2001)
			Tech. providers	17%	
China	1999	Bt cotton-Monsanto varieties	Producers	40%	(Pray et al., 2001)
			Tech. providers	60%	
Mexico	1997	Bt cotton	Producers	39%	Traxler and Godoy-Avila (2004)
			Tech. providers	61%	
Mexico	1998	Bt cotton	Producers	90%	Traxler and Godoy-Avila (2004)
			Tech. providers	10%	
Philippines	2003/2004	Bt corn	Producers	52%	Yorobe and Quicoy (2006)
			Tech. providers	48%	

Notes: *All studies calculate benefits to technology providers as gross revenues, which do not include the costs of research, marketing or administrative costs, with the exception of Traxler and Godoy-Avila (2004), which includes estimated costs of seed production, but no costs for field research, technical assistance to farmers, monitoring for contract compliance or compensation to local seed distributor agents.
**Results presented are within group distributions and do not include losses to pesticide companies.

Table 2 Distribution of farm-level benefits between farmers and technology providers with no price effects* (continued)

Country	*Year(s)*	*Technology*	*Sector*	*Proportion of total gain*	*Reference*
South Africa**	1999/2000	Bt cotton-smallholders	Producers	76%	Gouse et al. (2004)
			Tech. providers	24%	
		Bt cotton-large dryland	Producers	49%	
			Tech. providers	51%	
		Bt cotton-large irrigated	Producers	76%	
			Tech. providers	24%	
Spain	1998	Bt corn	Producers	64.5%	Demont and Tollens (2004)
			Tech. providers	35.5%	
Spain	1999	Bt corn	Producers	64%	Demont and Tollens (2004)
			Tech. providers	36%	
Spain	2000	Bt corn	Producers	63.5%	Demont and Tollens (2004)
			Tech. providers	36.5%	
Spain	2001	Bt corn	Producers	63%	Demont and Tollens (2004)
			Tech. providers	37%	
Spain	2002	Bt corn	Producers	62%	Demont and Tollens (2004)
			Tech. providers	38%	
Spain	2003	Bt corn	Producers	60%	Demont and Tollens (2004)
			Tech. providers	40%	
Global	2007	HT soybean, corn, cotton, canola; IR corn and cotton	Producers	76%	Brookes and Barfoot (2009)
			Tech. providers	24%	
Global-developing countries	2007	HT soybean, corn, cotton, canola; IR corn and cotton	Producers	86%	Brookes and Barfoot (2009)
			Tech. providers	14%	

Notes: *All studies calculate benefits to technology providers as gross revenues, which do not include the costs of research, marketing or administrative costs, with the exception of Traxler and Godoy-Avila (2004), which includes estimated costs of seed production, but no costs for field research, technical assistance to farmers, monitoring for contract compliance or compensation to local seed distributor agents.

**Results presented are within group distributions and do not include losses to pesticide companies.

Table 3 Distribution of farm-level benefits between farmers and technology providers with price and trade effects*

Country	*Year(s)*	*Technology*	*Sector*	*Proportion of total world surplus gain*	*Reference*
USA**	1996	Bt cotton	US producers	43to 59%	Falck-Zepeda et al. (1999)
			ROW producers	–6 to +9%	
			Tech. providers	26 to 47%	
			Consumers	16 to 24%	
USA	1997	Bt cotton	US producers	42%	Falck-Zepeda et al. (1999)
			ROW producers	–6%	
			Tech. providers	44%	
			Consumers	19%	
US	1997	Bt cotton	US producers	29 to 39%	Price et al. (2005)
			Tech. providers	25 to 35%	
			ROW producers	–63 to –78%	
			Consumers	99 to 114%	
US	1997	HT cotton	US producers	4%	Price et al. (2005)
			ROW producers	–316%	
			Tech. providers	7%	
			Consumers	406%	
USA	1997	HT soybean	US producers	20%	Price et al. (2005)
			ROW producers	–11%	
			Tech. providers	68%	
			Consumers	23%	
			ROW net benefit	7%	
USA***	1997	HT soybeans	US producers	29 to 76%	Falck-Zepeda et al. (2000)
			ROW producers	2 to 3%	
			Tech. providers	10 to 25%	
			Consumers	10 to 44%	

Notes: *All studies calculate benefits to technology providers as gross revenues, which do not include the costs of research, marketing or administrative costs.
‘Consumers’ includes adopting and non-adopting regions. Rest of World (ROW).
**Range reflects estimates calculated using two separate datasets for on-farm impacts.
***Range reflects estimates calculated using different assumptions for the elasticity of US supply.

Table 3 Distribution of farm-level benefits between farmers and technology providers with price and trade effects* (continued)

Country	*Year(s)*	*Technology*	*Sector*	*Proportion of total world surplus gain*	*Reference*
USA	1998	Bt cotton	US producers	46%	Falck-Zepeda et al. (1999)
			ROW producers	–7%	
			Tech. providers	43%	
			Consumers	18%	
USA, Argentina and Brazil	1999/2000	HT soybean	US producers	19%	Moschini et al. (2000)
			ROW producers	–7%	
			Tech. providers	45%	
			Consumers	40%	
USA and Argentina	1996	HT soybeans	US producers	40%	Qaim and Traxler (2005)
			Argentina producers	–5%	
			ROW producers	–20%	
			Tech. providers	37%	
			Consumers	47%	
USA and Argentina	1997	HT soybeans	US producers	34%	Qaim and Traxler (2005)
			Argentina producers	5%	
			ROW producers	–23%	
			Tech. providers	35%	
			Consumers	49%	
USA and Argentina	1998	HT soybeans	US producers	27%	Qaim and Traxler (2005)
			Argentina producers	11%	
			ROW producers	–23%	
			Tech. providers	36%	
			Consumers	49%	

Notes: *All studies calculate benefits to technology providers as gross revenues, which do not include the costs of research, marketing or administrative costs. 'Consumers' includes adopting and non-adopting regions. Rest of World (ROW).
**Range reflects estimates calculated using two separate datasets for on-farm impacts.
***Range reflects estimates calculated using different assumptions for the elasticity of US supply.

Table 3 Distribution of farm-level benefits between farmers and technology providers with price and trade effects* (continued)

Country	*Year(s)*	*Technology*	*Sector*	*Proportion of total world surplus gain*	*Reference*
USA and Argentina	1999	HT soybeans	US producers	16%	Qaim and Traxler (2005)
			Argentina producers	17%	
			ROW producers	–22%	
			Tech. providers	34%	
			Consumers	54%	
USA and Argentina	2000	HT soybeans	US producers	12%	Qaim and Traxler (2005)
			Argentina producers	21%	
			ROW producers	–23%	
			Tech. providers	35%	
			Consumers	54%	
USA and Argentina	2001	HT soybeans	US producers	12%	Qaim and Traxler (2005)
			Argentina producers	25%	
			ROW producers	–24%	
			Tech. providers	34%	
			Consumers	53%	
USA and China	2001	Bt cotton	US producers	21%	Frisvold et al. (2006)
			China producers	51%	
			ROW producers	–42%	
			Consumers	76%	

Notes: *All studies calculate benefits to technology providers as gross revenues, which do not include the costs of research, marketing or administrative costs. ‘Consumers’ includes adopting and non-adopting regions. Rest of World (ROW).
**Range reflects estimates calculated using two separate datasets for on-farm impacts.
***Range reflects estimates calculated using different assumptions for the elasticity of US supply.

In models where prices are assumed to change with associated trade impacts, farmers who are adopting the technology also receive a substantial share of the estimated benefits, and consumers worldwide may also capture a large share of the benefits due to lower prices.[3] Farmers in regions where the technology has not been commercialised realise losses due to lower prices. In a study of the evolution of impacts from adoption of herbicide tolerant soybeans in the USA and Argentina, the share of total benefits accruing to farmers in Argentina grew from a small loss in 1996 as US farmers began to plant HT soybeans, to 25% by 2001 (Qaim and Traxler, 2005). The net impact in non-adopting regions is positive, with producer losses being outweighed by consumer gains due to lower prices.

It should be noted that in nearly all studies on the distribution of benefits across market actors, the benefits to technology providers are calculated as gross revenues, and are therefore overestimated because there is no accounting for the costs of technology research, marketing or administration.

While non-adopters may suffer losses due to the introduction of the technology through global market impacts, more localised effects of the technology may be beneficial to non-adopters. Several studies have shown evidence of regional suppression of the target pests of GE insect resistant corn and cotton. Area-wide pest suppression not only reduced losses to adopters of the technology, but may also benefit non-adopters and growers of other crops by reducing crop losses and/or the need to use pest control measures such as insecticides. A study of the impacts of insect resistant corn in the USA Midwest showed that the majority of benefits of Bt corn accrued to non-adopters due to area-wide pest suppression of European Corn Borer (Hutchison et al., 2010).

Table 4 Farm level impact in relation to farm size

Country	*Year*	*Technology*	*Result*	*Reference*
Argentina	1996/1997–2000/2001	HT soybean	Farm size not related to adoption, with small farmers accounting for > 90% of farmers using HT soybean; gross margins 4.48–6.76% higher for adopters	Penna and Lema (2003)
Canada	2000	Bt corn and HT soybean	The smallest operations (< 490 acres) accounted for the highest level of use, large farms appear to be slower to adopt GM crops than smaller farms; IR corn –2.6 to +12.8% change in yields for adopters, HT soybean 2.6 to 9.9% increase in yields for adopters	Hategekimana (2002a, 2002b) and Hategekimana and Trant (2002)
China	1999	Bt cotton	Adopters planted Bt cotton on 0.42 ha on average; farms with smallest holdings (< 1 ha) gained almost twice as much income per unit of land compared to larger farms	Pray et al. (2001)

Table 4 Farm level impact in relation to farm size (continued)

Country	*Year*	*Technology*	*Result*	*Reference*
India	2001/2002–2002/2003	Bt cotton	Average cotton area planted 1.56 acres in 2001/2002 and 2.37 acres in 2002/2003 for Bt cotton and 2.4 acres in 2001/2002 and 2.76 acres in 2002/2003 for non-Bt; yield increase 45–63% on average and 33% by production function for adopters; gross margins 50% greater for adopters on average	Bennett et al. (2006a)
India	2002/2003	Bt cotton	Average cotton area 4.9 acres for adopters and 4.5 acres for non-adopters; yield increase 34% on average and 27% by production function for adopters, profits 2161 rupees higher for adopters	Qaim et al. (2006)
India	2003/2004	Bt cotton	Average plot area under 5 acres and not significantly different between adopters and non-adopters; yield increase 14–37% for adopters, gross margins 37–132% higher for adopters, depending on variety grown	Bennett et al. (2005)
India	2004/2005	Bt cotton	Small farmers (< 5 acres) had 10% increase in yields, medium (5–10 acres) had 21% increase and large (> 10 acres) had 83% increase for adopters	Dev and Rao (2007)
India	2003/2004	Bt cotton	Returns to management time saved and reemployed in alternative activities are higher for large than for small farmers	Subramanian and Qaim (2009)
India	2002–2008	Bt cotton	24% yield increase and 50% increase in profit on average for smallholder adopters	Kathage and Qaim (2012)

Table 4 Farm level impact in relation to farm size (continued)

Country	*Year*	*Technology*	*Result*	*Reference*
Mexico	1997–1998	Bt cotton	Average holding of adopting farmers was 14 ha; yield increase 2.6–20.4% for adopters	Traxler and Godoy-Avila (2004)
Philippines	2003–2004	Bt corn	Average corn area 2.64 ha for Bt and 1.64 ha for non-Bt corn; yield increase of 34–37.5% on average, and 22.5 based on production function for adopters, increase in net income of PhP10,132 per ha on average for adopters	Yorobe and Quicoy (2006)
Romania	1999–2003	HT soybean	No correlation between farm size and adoption	Brookes (2005)
South Africa	2001/2002–2003/2004	Bt white corn	Smallholders achieve 0–32% higher yield per kg of seed with Bt corn	Gouse et al. (2006)
South Africa	1999/2000	Bt cotton	Smallholders had 45.8% yield increase compared to large scale farmers who had 13.8% or 18.5% yield increase for dryland and irrigated	Gouse et al. (2004)
Spain	2002–2004	Bt corn	Adoption is not significantly related to farm size; yield increase of 0–12% on average for adopters	Gomez-Barbero et al. (2008)
USA/ Delaware	2000	HT soybean	Duration analysis reveals that earlier-adopting farmers had larger farms; 10% yield increase for adopters based on production function	Bernard et al. (2004)
USA	1998	HT soybean	No relationship between farm size and adoption	Fernandez-Cornejo and McBride (2002)
USA	1998	HT corn	Positive relationship between farm size and adoption	Fernandez-Cornejo and McBride (2002)
USA	1998	Bt corn	Positive relationship between farm size and adoption	Fernandez-Cornejo and McBride, (2002)

3.2 Farm size

The impact of GE crops on smallholder farmers has been a key question for researchers and policymakers interested in whether the technology has increased the gap between rich and poor farmers, particularly as large farmers are better able to afford the more expensive GE seed and other inputs such as fertiliser and irrigation (Morse et al., 2007). The presumption by many is that large firms are the first to adopt new technologies, and therefore benefit from improved productivity and efficiency. While this may be true of innovations that require capital investment in new machinery and equipment, the adoption of GE crops is relatively inexpensive.

The literature on the impacts of GE crops in relation to size of farm clearly shows that small farmers in many countries (China, India, Mexico, Philippines and South Africa) are benefiting from the adoption of GE crops (Table 4). In China and South Africa, researchers have found the benefits to small farmers to be greater than for large farmers (Pray et al., 2001; Bennett et al., 2004b; Gouse et al., 2004), which in South Africa is attributed to better conventional pest management by large farms (Gouse, 2009). In addition to the observed benefits for small farmers, an analysis of Bt cotton in Argentina estimated that small farmers (with less than 90 hectares) would achieve 42% higher yields if they adopted Bt cotton, due to low insecticide use and consequent reduced yields due to insect damage (Qaim and De Janvry, 2005). Researchers have noted that the relationship between adoption and farm size is more important at the innovator stage, and diminishes over time (Fernandez-Cornejo and McBride, 2002).

3.3 Income groups

Fewer studies have examined the distribution of impacts across income groups, as distinct from size of farm, to address the question of whether GE crops contribute to a widening of income disparities between rich and poor farmers due to the ability of richer farmers to afford more expensive seed. In China, Bt cotton farmers in the lower income groups, as measured by either household income or per capita income, achieved greater increases in net income during the 1999 study season than their counterparts in higher income groups (Pray et al., 2001). In South Africa, the distribution of gross margins from cotton growing increased across adopters and non-adopters from 1998/1999 to 2000/2001, though inequality decreased among Bt cotton adopters (Bennett et al., 2004a). Survey results from India for 2003 showed that Bt cotton adopting households had higher cotton income than non-adopters, but also that inequality in cotton income was greater among non-adopters than for adopters. The difference was attributed to the consistent performance of Bt cotton over conventional varieties, but also the better performance of the non-Bt cotton variety favoured by Bt cotton adopters (Morse et al., 2007).

3.4 Gender

Women play important roles in agriculture, especially in developing countries, planting, weeding, harvesting among other tasks. Women comprise about 20% of the agricultural labour force in Latin America to almost 50% in Sub-Saharan Africa and eastern and Southeastern Asia (Meinzen-Dick et al., 2011). Despite their importance in agriculture, women face unique challenges, such as limited access to inputs, technological resources, equipment and land, as well as non-tangible assets such as human capital, and decision making power. Understanding any gender differences that might exist in the access and use of GE crop technology contributes to the discussion of the role of GE crops in furthering development and addressing poverty.

Little research has been done to examine the role of gender in the adoption and use of GE crops. However, two recent studies have explored gender issues related to Bt cotton. In India, the adoption of Bt cotton was found to increase aggregate returns to labour by 42% while the returns for hired female agricultural workers increased by 55%, largely due to additional labour employed for picking cotton, which is primarily a female activity in India. Further, the use of Bt cotton was associated with improved female working conditions, as the reduction in the amount of family male labour involved in pest management was reallocated to other household economic activities. Researchers noted that women's income has a particularly positive effect for child nutrition and welfare (Subramanian et al., 2010).

In a recent in-depth exploration of gender differences in the production of Bt cotton in Colombia, researchers found that female farmers preferred Bt varieties over conventional because of the reduced need for hired labour to spray insecticides. A lack of adequate and timely information about the technology was important for both men and women, but affected females more than males (Zambrano et al., 2011).

4 Secondary impacts

Looking beyond the direct farm level impacts of GE crops, several studies have examined a range of 'secondary' impacts, including impacts on the labour market, non-pecuniary factors, and various aspects of social welfare.

4.1 Labour market

Researchers have been interested in the impacts of GE crops on labour markets, particularly related to poverty implications of reduced managerial requirements and changes in wage-earning opportunities. For the HT soybeans, studies in Argentina and the USA find that labour requirements were lower due to fewer tillage operations for weed control (Table 5). In the USA, adoption of HT soybeans was associated with increases in off-farm income due to reduced managerial time requirements (Fernandez-Cornejo, 2007). For Bt cotton, labour impacts have been mixed. In both India and China, labour required for spraying insecticides is reduced. However, in India this is outweighed by the increase in labour needs for harvesting increased yields so that the net effect on labour is an increase. China, the yield increase is smaller than in India and the net labour impact is a decrease.

In a meta-analysis of global results of the impacts of GE crops on various parameters, labour costs were found to be generally lower for HT soybeans and generally higher for Bt cotton (Kaphengst et al., 2011).

Two studies go beyond the direct labour impacts, to look at impacts in related industries. In China, although on farm labour was lower for Bt cotton adopters, overall labour impacts were positive due to an increased demand for labour in the textile industry (Huang et al., 2004). In India, not only were returns to on farm labour increased by an expansion of Bt cotton, but returns to non-agricultural labour were also increased in related sectors such as transportation, trade and other services (Subramanian et al., 2010).

Table 5 Results on the impact of technology adoption on labour

Country	*Year*	*Technology*	*Relevant results*	*Reference*
Argentina	2001	HT soybean	Hired labour and custom operations $42.33/ha for HT and $46.82/ha for conventional.	Qaim and Traxler (2005)
China	1999–2001	Bt cotton	Total labour costs lower in two of three years in Bt cotton compared to conventional.	Huang et al. (2002)
China	1999–2001	Bt cotton	In welfare model of Bt cotton adoption, although on farm labour decreases, aggregate demand for labour increases, due to additional labour demand from the textiles sector.	Huang et al. (2004)
India	2002/2003–2003/2004	Bt cotton	Picking costs higher in Bt cotton 27% on average across years.	Ramasundaram et al. (2007)
India	2003/2004	Bt cotton	While more labour is employed for harvesting, labour requirements for pest control decrease. However, saved family labour can be reemployed efficiently in alternative activities so that overall returns to labour increase.	Subramanian and Qaim (2009)
India	2004/2005	Bt cotton	Labor costs increased by 20.58%. Bt farmers on average hired human labour more than non-Bt farmers and utilised family labour more intensively.	Dev and Rao (2007)
South Africa	1998/1999, 1999/2000 and 2000/2001	Bt cotton	Spray labour significantly lower for all three years, weeding labour significantly higher for adopters in one of two years where data were available, and harvest labour significantly higher all three years. Total labour in two of three years where data were available was the same.	Bennett et al. (2006b)
Spain	2002–2004	Bt corn	No impact on amount of farm labour employed	Gomez-Barbero et al. (2008)
USA	2001–2003	HT soybeans	14.55% savings in household labour	Gardner et al. (2009)
USA	2001–2003	HT corn	No difference	Gardner et al. (2009)
USA	2001–2003	HT cotton	No difference	Gardner et al. (2009)
USA	2004	HT soybean	16% increase in off-farm income is associated with a 10% increase in the probability of adopting HT soybean.	Fernandez-Cornejo (2007)

The complexity of labour markets, which differ in terms of excess or lack of supply and where impacts in one sector may be offset by impacts in another related sector, must be carefully examined in a consideration of desirable outcomes.

4.2 Non-pecuniary factors

Several studies have identified important factors that influence farmer adoption decisions, but are not direct contributors to increased profits. These factors include the simplicity and flexibility of weed management programmes with herbicide tolerant crops, lower production risk associated with insect resistant crops, and human and environmental safety benefits related to changes in insecticide and herbicide use (Brookes and Barfoot, 2009). Because these factors are not priced in the marketplace, as farmers do not pay for them, they are inherently difficult to measure. Beyond a traditional accounting of the impacts of GE crops, studies have estimated the value of the 'non-pecuniary' benefits, or intangible benefits that are not paid for out of pocket. In a study of glyphosate-tolerant soybean in the USA, non-market valuation techniques were used to estimate non-pecuniary convenience benefits, such as management-time savings and flexibility, at $12/ha (Marra and Piggott, 2006). Similarly, a survey of US corn farmers found that non-pecuniary benefits (handling and labour-time savings, human and environmental safety, reduced yield risk, equipment cost savings and better standability)[4] of GM insect-resistant corn were valued at $10.32/ha (Alston et al., 2002). Based on existing estimates of per hectare non-pecuniary benefits, Brookes and Barfoot (2009) estimate a total value of $921 million in non-pecuniary benefits for GE crops the USA in 2009.

4.3 Social welfare

Various aspects of social welfare have been addressed in the literature,[5] including human health, food security and other measures of standard of living.

Studies in China, South Africa and India have extended consideration of the impacts of reduced pesticide use related to adoption of Bt cotton to human health impacts. In China, Bt cotton has been credited with reducing the number of farmers who are poisoned annually from applying pesticides. In a comparison of the proportion of full adopters, partial adopters and non-adopters reporting pesticide poisoning after applying pesticides,[6] between 5 to 8% of adopters reported pesticide poisoning, whereas 10 to 19% of partial adopters and 12 to 29% of non-adopters reported pesticide poisoning for the same time period (Huang et al., 2002). In South Africa, a clear but not proven causal relationship has been shown between a reduced number of recorded cases of accidental pesticide poisoning from local hospital records and increasing adoption rates of Bt cotton over time. There is a suggestion that these benefits accrue more to women who do most of the farm work and children who would play in a field soon after a pesticide application (Bennett et al., 2006b). An analysis of pesticide poisoning related to application of pesticides from 2002 to 2008 in India estimated a reduction of at least 2.4 million and possibly as many as 9 million cases. Resulting savings to the Indian healthcare system were estimated to be in the range of $14 to 51 million (Kouser and Qaim, 2011).

Additional indirect health benefits may be achieved through reduced mycotoxin contamination in Bt corn. Insect damage predisposes corn to mycotoxin contamination as insects create openings through which fungal spores enter the kernels. Mycotoxins that contaminate corn are associated with various types of cancer, neural tube defects and other disorders in humans as well as various health problems in livestock. Reduced mycotoxin contamination resulting from the planting of Bt corn has been documented through field studies in several countries where Bt corn is grown, including the USA, Europe, Canada, Argentina, the Philippines and South Africa (Wu, 2008; Barros et al., 2009; Abbas et al., 2008; Pray et al., 2009).

Food security impacts have been estimated for adopters in South Africa, where a 16% yield increase in a season with good rainfall could result in a substantial increase in food security because of a higher base yield. The increased yield is estimated to mean 36 more days of maize meal for a household of seven in 2002/2003 (Gouse et al., 2006).

In the Philippines, researchers calculated the subsistence carrying capacity of farms growing Bt corn compared to conventional corn, estimating an advantage of 26 to 83% for farms growing Bt corn. They conclude that farmers growing Bt corn are more likely to meet the poverty threshold than conventional corn growers (Gonzales, 2005).

With respect to broader social impacts at the community level, studies from South Africa and India have quantified impacts on various indicators. In South Africa, 88% of interviewed resource-poor farmers growing Bt cotton, regardless of gender or farm size, reported that their increased income from cotton seasons 2003/2004 and 2004/2005 was used primarily for greater education of their children (76%), more investment in growing cotton (46%), repaying debt (28%), investment in other crops (20%) and spending money on themselves. Some 89% had increased their asset base due to Bt cotton, primarily by increasing their cultivable land (Morse and Bennett, 2008).

In a survey of over 3000 farmers in India, the benefits of using Bt cotton were: spending less time in the field (51%), peace of mind (49%), less tension from cotton cultivation (48%), planning for child's education (42%), ability to buy gifts for family (40%), paying off debt (39%), ability to buy more land (23%), ability to get daughter married (20%), ability to buy tractor (14%) (Anonymous, 2005).

Also in India, a survey of more than 9000 farmers across 467 villages in eight cotton growing states found that households growing Bt cotton had higher incomes, which translated into higher access to maternal care services, child education and immunisation. At the village level, villages with higher adoption rates had higher levels of accessibility to services such as telephone systems, electricity, drinking water, internet connectivity, banking services and markets (Anonymous, 2007).

A survey on gender differences in Bt cotton production in Colombia found that the additional resources from adoption was spent differently by male and female farmers. Men generally preferred to spend their profits on leisure activities, while women spent their additional income on food, education and health for their families (Zambrano et al., 2011). In China, surveyed farmers in Hebei province in 2002/2003 reported using the increased income from Bt cotton to invest in education, leisure and healthcare (Wan et al., 2008).

5 Conclusions

The analysis of socioeconomic impacts of GE crops has broadened to include a wider range of issues than those considered in the early years of commercialisation. The results of the available literature show that the impacts of the technology are multi-faceted and ripple through local and national economies. Specifically, the key results of this review are:

- With respect to the distribution of benefits across market actors, while proportions vary, the results show farmers who adopt the technology receiving a substantial share of benefits. Where prices are assumed to change, consumers capture a large share of benefits due to increased production leading to lower prices.
- The literature on results in relation to farm size shows that small farmers in many countries are benefiting from the adoption of GE crops, and in some cases the benefits appear to be greater than for large farmers. Studies of income inequality among adopters and non-adopters have shown a decrease in inequality for adopters, likely resulting from more consistent yields.
- The few studies that have looked at impacts in relation to household or per capita income have found lower income farmers achieving greater increases in income than their richer counterparts.
- In a single study that investigated impacts by gender, women were found to have greater returns to labour from adoption of Bt cotton.
- Labour impacts have been mixed, with some studies showing increased labour requirements, particularly from increased labour for harvesting increased yields, and some studies showing reductions from reduced spraying and tillage, while other studies show no impacts. On this question, context would seem to be extremely important to determining what a desirable outcome would be.
- In studies that explore the impacts of the technology on various indicators of social welfare, adopters report improvements in health, education, debt repayment, maternal care services and food security.

For several of the parameters investigated in the studies reviewed here, the results represent the experience of farmers in a single region for one or few years, and may not be representative of the broader experience of adopters of the technology. However, the results of farmer surveys on the primary benefits of GE crops globally show a remarkable consistency (Carpenter, 2010). To the extent that secondary benefits such as those illustrated in the available literature follow readily from the primary on farm impacts, the expectation is that many farmers around the world are achieving a broad range of socio-economic benefits as the result of adopting GE crops.

References

Abbas, H.K., Accinelli, C., Zablotowicz, R.M., Abel, C.A., Bruns, H.A., Dong, Y. and Shier, W.T. (2008) 'Dynamics of mycotoxin and aspergillus flavus levels in aging Bt and non-Bt corn residues under Mississippi no-till conditions', *Journal of Agricultural and Food Chemistry*, Vol. 56, No. 16, pp.7578–7585.

Alston, J.M., Hyde, J., Marra, M.C. and Mitchell, P.D. (2002) 'An ex ante analysis of the benefits from the adoption of corn rootworm resistant transgenic corn technology', *AgBioForum*, Vol. 5, No. 3, pp.71–84.

Anonymous (2005) *Socio Economic Benefits of Bollgard and Product Satisfaction (in India)*, IMRB International, Mumbai, India.

Anonymous (2007) *The Socio-Economic Appraisal of Bt Cotton Cultivation in India*, Indicus Analytics, New Delhi, India.

Barros, G., Magnoli, C., Reynoso, M., Ramirez, M., Farnochi, M., Torres, A., Dalcero, M., Sequeira, J., Rubinstein, C. and Chulze, S. (2009) 'Fungal and mycotoxin contamination in Bt maize and non-Bt maize grown in Argentina', *World Mycotoxin Journal*, Vol. 2, No. 1, pp.53–60.

Bennett, R., Ismael, Y., Morse, S. and Shankar, B. (2004a) 'Reductions in insecticide use from adoption of Bt cotton in South Africa: impacts on economic performance and toxic load to the environment', *J. Agr. Sci.*, Vol. 142, No. 6, pp.665–674.

Bennett, R.M., Ismael, Y., Kambhampati, U. and Morse, S. (2004b) 'Economic impact of genetically modified cotton in India', *AgBioForum*, Vol. 7, No. 3, pp.96–100.

Bennett, R., Kambhampati, U., Morse, S. and Ismael, Y. (2006a) 'Farm-level economic performance of genetically modified cotton in Maharashtra, India', *Review of Agricultural Economics*, Vol. 28, No. 1, pp.59–71.

Bennett, R., Morse, S. and Ismael, Y. (2006b) 'The economic impact of genetically modified cotton on South African smallholders: yield, profit and health effects', *Journal of Development Studies*, Vol. 42, No. 4, pp.662–677.

Bernard, J.C., Pesek, J.D., Jr., et al. (2004) 'Performance results and characteristics of adopters of genetically engineered soybeans in Delaware', *Agricultural and Resource Economics Review*, Vol. 33, No. 2, pp.282–292.

Brookes, G. (2005) 'The farm-level impact of herbicide-tolerant soybeans in Romania', *AgBioForum*, Vol. 8, No. 4, pp.235–241.

Brookes, G. and Barfoot, P. (2009) 'Global impact of biotech crops: income and production effects, 1996–2007', *AgBioForum*, Vol. 12, No. 2, pp.184–208.

Brookes, G., Yu, T.H., Tokgoz, S. and Elobeid, A. (2010) 'The production and price impact of biotech corn, canola, and soybean crops', *AgBioForum*, Vol. 13, No. 1, pp.25–52.

Carpenter, J.E. (2010) 'Peer-reviewed surveys indicate positive impact of commercialized GM crops', *Nat. Biotech*., Vol. 28, No. 4, pp.319–321.

Demont, M. and Tollens, E. (2004) 'First impact of biotechnology in the EU: Bt maize adoption in Spain', *Annals of Applied Biology*, Vol. 145, No. 2, pp.197–207.

Dev, S.M. and Rao, N.C. (2007) 'Socioeconomic impact of Bt cotton', Centre for Economic and Social Studies, Hyderabad, India.

Falck-Zepeda, J.B., Traxler, G. and Nelson, R.G. (1999) *Rent Creation and Distribution from the First Three Years of Planting Bt Cotton*, International Service for the Acquisition of Agri-Biotech Applications, Ithaca, New York.

Falck-Zepeda, J.B., Traxler, G. and Nelson, R.G. (2000) 'Rent creation and distribution from biotechnology innovations: the case of Bt cotton and herbicide-tolerant soybeans in 1997', *Agribusiness*, Vol. 16, No. 1, pp.21–32.

Fernandez-Cornejo, J. (2007) *Off-Farm Income, Technology Adoption, and Farm Economic Performance*, US Department of Agriculture Economic Research Service, Washington, DC.

Fernandez-Cornejo, J. and Mcbride, W.D. (2002) *Adoption of Bioengineered Crops*, US Department of Agriculture Economic Research Service, Washington, DC.

Frisvold, G.B., Reeves, J.M. and Tronstad, R. (2006) 'Bt cotton adoption in the United States and China: international trade and welfare effects', *AgBioForum*, Vol. 9, No. 2, pp.69–78.

Gardner, J.G., Nehring, R.F. and Nelson, C.H. (2009) 'Genetically modified crops and household labor savings in US crop production', *AgBioForum*, Vol. 12, Nos. 3–4, pp.303–312.

Gomez-Barbero, M., Berbel, J. and Rodriguez-Cerezo, E. (2008) 'Bt corn in Spain – the performance of the EU's first GM crop', *Nat. Biotech.*, Vol. 26, No. 4, pp.384–386.

Gonzales, L.A. (2005) *Harnessing the Benefits of Biotechnology: The Case of Bt Corn in the Philippines*, STRIVE Foundation.

Gouse, M. (2009) 'Ten years of Bt cotton in South Africa: putting the smallholder experience into context', in Tripp, R. (Ed.): *Biotechnology and Agricultural Development: Transgenic Cotton, Rural Institutions and Resource-Poor Farmers*, Routledge, Abingdon, Oxon, UK.

Gouse, M., Pray, C. and Schimmelpfennig, D. (2004) 'The distribution of benefits from Bt cotton adoption in South Africa', *AgBioForum*, Vol. 7, No. 4, pp.187–194.

Gouse, M., Pray, C., Schimmelpfennig, D. and Kirsten, J. (2006) 'Three seasons of subsistence insect-resistant maize in South Africa: have smallholders benefited?', *AgBioForum*, Vol. 9, No. 1, pp.15–22.

Hategekimana, B. (2002a) *Genetically Modified Grain Corn and Soybeans in Quebec and Ontario in 2000 and 2001*, edited by A. Division, Statistics Canada, Ottawa, Ontario.

Hategekimana, B. (2002b) *Growers of Genetically Modified Grain Corn and Soybeans in Quebec and Ontario: A Profile*, edited by A. Division, Ottawa, Canada.

Hategekimana, B. and Trant, M. (2002) 'Adoption and diffusion of new technology in agriculture: genetically modified corn and soybeans', *Canadian Journal of Agricultural Economics*, No. 4, Vol. 50, pp.357–371.

Huang, J., Hu, R., Fan, C., Pray, C.E. and Rozelle, S. (2002) 'Bt cotton benefits, costs, and impacts in China', *AgBioForum*, Vol. 5, No. 4, pp.153–166.

Huang, J., Hu, R., Van Meijl, H. and Van Tongeren, F. (2004) 'Biotechnology boosts to crop productivity in China: trade and welfare implications', *Journal of Development Economics*, Vol. 75, No. 1, pp.27–54.

Hutchison, W.D., Burkness, E.C., Mitchell, P.D., Moon, R.D., Leslie, T.W., Fleischer, S.J., Abrahamson, M., Hamilton, K.L., Steffey, K.L., Gray, M.E., Hellmich, R.L., Kaster, L.V., Hunt, T.E., Wright, R.J., Pecinovsky, K., Rabaey, T.L., Flood, B.R. and Raun, E.S. (2010) 'Areawide suppression of european corn borer with Bt maize reaps savings to non-Bt maize growers', *Science*, Vol. 330, No. 6001, pp.222–225.

James, C. (2011) *Global Status of Commercialized Biotech/GM Crops: 2011*, ISAAA, Ithaca, NY.

Kaphengst, T., Benni, N.E., Evans, C., Finger, R., Herbert, S., Morse, S. and Stupak, N. (2011) 'Assessment of the economic performance of GM crops worldwide', Report to the European Commission.

Kathage, J. and Qaim, M. (2012) 'Economic impacts and impact dynamics of Bt (Bacillus thuringiensis) cotton in India', *Proceedings of the National Academy of Sciences*, Vol. 109, pp.11652–11656.

Kouser, S. and Qaim, M. (2011) 'Impact of Bt cotton on pesticide poisoning in smallholder agriculture: a panel data analysis', *Ecological Economics*, Vol. 70, No. 11, pp.2105–2113.

Marra, M.C. and Piggott, N.E. (2006) 'The value of non-pecuniary characteristics of crop biotechnologies: a new look at the evidence', in Just, R.E., Alston, J.M. and Zilberman, D. (Eds.): *Regulating Agricultural Biotechnology: Economics and Policy*, Springer Science and Business Media, New York, New York.

Meinzen-Dick, R., Quisumbing, A., Behrman, J., Biermayr-Jenzano, P., Wilde, V., Noordeloos, M., Ragasa, C. and A.N.B. (2011) *Engendering Agricultural Research, Development, and Extension*, International Food Policy Research Institute, Washington, DC.

Morse, S. and Bennett, R. (2008) 'Impact of Bt cotton on farmer livelihoods in South Africa', *International Journal of Biotechnology*, Vol. 10, Nos. 2/3, pp.224–239.

Morse, S., Bennett, R. and Ismael, Y. (2007) 'Inequality and GM crops: a case-study of Bt cotton in India', *AgBioForum*, Vol. 10, No. 1, pp.44–50.

Moschini, G., Lapan, H. and Sobolevsky, A. (2000) 'Roundup ready® soybeans and welfare effects in the soybean complex', *Agribusiness*, Vol. 16, No. 1, pp.33–55.

Penna, J.A. and Lema, D. (2003) 'Adoption of herbicide tolerant soybeans in Argentina: an economic analysis', in Kalaitzandonakes, N. (Ed.): *The Economic and Environmental Impacts of Agbiotech: A Global Perspective*, Kluwer Academic/Plenum Publishers, New York, NY.

Pray, C., Ma, D., Huang, J. and Qiao, F. (2001) 'Impact of Bt cotton in China', *World Development*, Vol. 29, No. 5, pp.813–825.

Pray, C., Rheeder, J., Gouse, M., Volkwyn, Y., Westhuizen, L.V.D. and Shephard, G.S. (2009) 'Can Bt maize reduce exposure to the mycotoxin fumonisin in South Africa?', *International Association of Agricultural Economists, 2009 Conference*. Beijing, China.

Price, G.K., Lin, W., Falck-Zepeda, J. and Fernandez-Cornejo, J. (2005) *Size and Distribution of Market Benefits from Adopting Biotech Crops*, edited by U.E.R. Service, Washington, DC.

Qaim, M. and De Janvry, A. (2005) 'Bt cotton and pesticide use in Argentina: economic and environmental effects', *Environ. Dev. Econ.*, Vol. 10, No. 2, pp.179–200.

Qaim, M. and Traxler, G. (2005) 'Roundup ready soybeans in Argentina: farm level and aggregate welfare effects', *Agr. Econ.*, Vol. 32, No. 1, pp.73–86.

Qaim, M., Subramanian, A., Naik, G. and Zilberman, D. (2006) 'Adoption of Bt cotton and impact variability: insights from India', *Review of Agricultural Economics*, Vol. 28, No. 1, pp.48–58.

Ramasundaram, P., Vennila, S. and Ingle, R.K. (2007) 'Bt cotton performance and constraints in central India', *Outlook on Agriculture*, Vol. 36, No. 3, pp.175–180.

Subramanian, A. and Qaim, M. (2009) 'Village-wide effects of agricultural biotechnology: the case of Bt cotton in India', *World Development*, Vol. 37, No. 1, pp.256–267.

Subramanian, A., Kirwan, K., Pink, D. and Qaim, M. (2010) 'GM crops and gender issues', *Nat. Biotech.*, Vol. 28, No. 5, pp.404–406.

Traxler, G. and Godoy-Avila, S. (2004) 'Transgenic cotton in Mexico', *AgBioForum*, Vol. 7, Nos. 1–2, pp.57–62.

Trigo, E.J. and Cap, E.J. (2006) *Ten Years of Genetically Modified Crops in Argentine Agriculture*, ArgenBio, Buenos Aires, Argentina.

Wan, G., Wu, Y., Gao, W., Fok, M. and Liang, W. (2008) 'Impact of Bt cotton on farmer's livelihood system in China', *ISSCRI International Conference Rationales and Evolutions of Cotton Policies*, Montpellier, France.

Wu, F. (2008) 'Field evidence: Bt corn and mycotoxin reduction', in Biotechnology, I.S.F. (Ed.): *ISB News Report*, Virginia Tech., Blacksburg, VA.

Yorobe, J.M.J. and Quicoy, C.B. (2006) 'Economic impact of Bt corn in the Philippines', *The Philippine Agricultural Scientist*, Vol. 89, No. 3, pp.258–267.

Zambrano, P., Maldonado, J.H., Mendoza, S.L., Ruiz, L., Fonseca, L.A. and Cardona, I. (2011) *Women Cotton Farmers: Their Perceptions and Experiences with Transgenic Varieties: A Case Study for Colombia*, International Food Policy Research Institute, Washington, DC.

Notes

1 Technology provider includes the supply chain that delivers seed and technology to the farmer.

2 Studies assuming no price impacts are either reflecting real market conditions where there would realistically be no change in prices due to the introduction of GE crops because domestic production is not large enough to affect world prices, or use simplified modelling techniques.

3 In an examination of the global production, trade and price impacts of GE corn, soybean and canola, it was estimated that world prices would be 5.8%, 9.6% and 3.8% higher on average than baseline 2007 levels if the technology were no longer available (Brookes et al., 2010)

4 Standability refers to the mechanical stability of the plant, especially to remain upright through heavy wind and rain events.

5 For the purposes of this discussion, social welfare is defined as the well-being of the entire society. Social welfare is not the same as standard of living but is more concerned with the quality of life that includes factors such as the quality of environment (air, soil, and water), level of crime, extent of drug abuse, availability of essential social services, as well as religious and spiritual aspects of life (http://www.businessdictionary.com).

6 Pesticide poisoning included farmer reported headaches, nausea, skin pain or digestive problems after applying pesticides.