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Final Report

Assessment of the economic performance of GM crops worldwide

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Timo Kaphengst, Nadja El Benni, Clive Evans, Robert Finger, Sophie Herbert, Stephen Morse, Nataliya Stupak

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Ecologic Institute, Berlin
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Executive Summary

1. Overview

The global area planted with GM crops has been increasing each year since they were first commercially cultivated in 1996, when just about 2.8 million hectares were cropped with GM crops. This number increased to 90 million hectares in 2005 and to 134 million hectares in 2009. The countries with major areas relying on GM crops in 2009 were the USA (64 million hectares), Brazil (21.4), Argentina (21.3), India (8.4), Canada (8.2), China (3.7), Paraguay (2.2), and South Africa (2.1 million hectares) (James, 2009).

There are only four major GM crops that dominate the market: soybean, cotton, maize and canola. In terms of area cultivated, soybean is far more successful than any other GM crop. In 2009, more than three-quarters (77%) of the 90 million hectares of soybean grown globally were GM crops, while for cotton, almost half (49%) of the 33 million hectares were GM. Over a quarter (26%) of the 158 million hectares of globally grown maize were GM crops and 21% of globally grown canola (with a total area of 31 million hectares) (James, 2009).

The two dominant agronomic traits currently available are herbicide tolerance (HT) and insect resistance (mostly in the form of Bt crops). Herbicide tolerance is the prevailing trait that is deployed in all four dominant crops, while maize and cotton are the only two insect resistant GM crops currently commercially available (Sanvido, Romeis and Bigler, 2007).

In the EU, seven countries (Spain, Czech Republic, Romania, Portugal, Germany, Poland and Slovakia) planted MON 810, a genetically modified Maize variety from Monsanto, on a commercial basis in 2008 (James, 2008). The total acreage for the seven countries increased from 88,673 hectares in 2007 to 107,719 hectares in 2008 (James, 2008), with Spain being by far the most important adopting country in Europe (Gomez-Barbero et al., 2008a,b). However, in 2009, the EU acreage decreased by 9% compared to 2008 (due to the German ban of MON 810).

Reviews of the economic performance of GM crops have been conducted, both at the global level and for specific regions. The most recent overview study (Carpenter, 2010), which was based on 49 peer-reviewed publications reporting on farmer surveys in 12 countries worldwide, came to the conclusion that benefits from growing GM crops mainly derive from increased yields, which are greatest for small farmers in developing countries. Apart from higher yields, the adoption of GM-crops can reduce production costs by reducing pesticide use, labour and fuel costs. Barfoot and Brookes (2007) estimated that even with seed costs of GM crops being higher than for their conventional counterpart, total farm benefits are higher for GM crop adopters, amounting to about $7 billion (5.23 billion €) globally per year.

2. Purpose of the study and methodology applied

The objectives of this study are, firstly, to provide an overview of the current state of knowledge on the economic performance of GM crops worldwide based on data from a wide range of available literature and secondly, to evaluate the results in terms of their conclusiveness and consistency. The study thereby focuses on the direct monetary and other effects of growing GM crops that influence farmers' income, as represented by the following economic parameters: crop yields, seed costs, pesticides and herbicides costs, labour costs, and gross margins.

In order to consider most of the available data and to obtain an overall understanding of the issues, comparative analyses are conducted between different levels, including field trials, farm level surveys and general reviews at the national and even regional level. The analysis focuses on ex-post studies of the most dominant GM crops - cotton, maize, soy and canola - and on the two most dominant traits: GM crops modified to express the *Bacillus thuringiensis* (Bt) toxin, a natural insecticide, and crops modified to be herbicide tolerant (HT). Although potentially important in the future, stacked crops could not be considered due to lack of available data.

In addition to a current and comprehensive assessment of the economic performance of GM crops, another main outcome of this study is a better understanding of data availability and data quality regarding global assessments of the economic performance that have been conducted.

The methodology applied in this study encompasses different packages that partly built on each other:

- Design of a relational database
- Comprehensive literature review
- Statistical analyses
- Expert interviews
- Assessment of data availability and conclusiveness of results

The database functions as the core element of the analysis undertaken in the study, facilitating data queries and statistical comparisons across various parameters. As many publications on GM crops use data from several case studies (e.g. a field trial at a particular site for a specific year) for comparative assessments, publications were "divided" into different studies containing their own data set. Thus, it was not the results of publications (e.g. articles or reports) that were compared in the statistical analysis, but the raw data that could be derived from the publications. This also means that only publications that contained quantitative data on at least one of the investigated economic parameters, rather than mere qualitative statements, were considered in the data base.

The literature review included peer-reviewed scientific articles, as well as non-peer-reviewed sources from grey literature. Such non-peer-reviewed sources were mainly official reports from governmental organisations or agencies/institutes funded by governments, official international and national statistics as well as conference proceedings in which scientists presented results from their research that were not published elsewhere. For the comprehensive literature overview, results from peer-reviewed and non-peer-reviewed sources were briefly analysed and described in separate sections.

In all, the database contains 196 publication entries which have provided 721 single study entries for the statistical analysis. Of the 196 publications, 109 were designated as peer-reviewed, while 87 are non-peer-reviewed sources. Asia and Europe are the most well represented continents, with a significant amount of studies in India (220) and China (70) for the former and in Spain (65) for the latter. South Africa accounts for 58 studies. The largest shares of North and South American studies included in the database were taken from the USA (120) and Argentina (55).

Drawing from the data gathered and processed in the database, a number of different statistical tests were conducted for the assessment of the economic performance of GM crops compared to conventional crops, both worldwide and for different geographic regions. The general approach started with an illustration of the distribution of data for the parameter of interest, followed by regression analysis leading to country specific comparisons. Results from the analyses were compared with and underpinned by some key references from the literature that came to similar or contrasting conclusions. By analysing raw data from studies found in different publications, instead of merely comparing the results from these publications, this approach is an attempt to obtain statistically viable results across current literature.

Subsequently, the knowledge and results gained from the data analysis were discussed with regard to the conclusiveness of the results themselves and of other studies which used other approaches to assess the performance of GM crops on a global scale. This critical analysis of data sources elaborates on the strengths and weaknesses of the different methods which are currently available for such assessments.

The results from the statistical analyses gave quantitative indications of variations and trends across parameters. In order look behind the mere figures, however, the question of what is meant by "yield increases" reported in the literature was discussed in more detail, i.e. the variation arising from natural conditions and differences in the baseline interpretations. These issues were considered in light of scientific literature and underpinned by expert knowledge obtained through interviews.

3. Results from the literature review

Bt cotton

There is substantial evidence that the adoption of Bt cotton provides economic benefits for farmers in a number of countries. These benefits arise mostly from increased yields due to limited damage incurred via insect pests (most notably the bollworm complex) while reducing costs through lower use levels of insecticide (South Africa, India, USA, China, Argentina, and Mexico).

There is evidence that other factors such as more efficient production methods used by farmers adopting Bt cotton have an impact on the outcome, resulting in a self-selection bias. Moreover, research shows that the education level of the farmers has a significant positive effect on the technical and cost efficiencies of the farm. Similarly, the field size has a positive impact on the performance of the Bt cotton.

However, the choice of the variety of cotton used as 'background' in the comparison has a significant impact on the relative performance of the Bt cotton. Results from India show, that not all Bt cotton varieties are equally suitable for all climatic conditions, which can lead to Bt yields below the yields of conventional varieties grown by farmers.

Additionally, many farmers, particularly those in India and China, keep using the same amount of pesticides and thus do not benefit from lower pest control costs, mostly due to lack of information and training.

Bt cotton is effective overall in reducing the risks of production, although there was some evidence that the technology increases output risks, mostly due to the lack of an Integrated Pest Management System. Moreover, the additional seed costs mean that significant economic benefits are only achieved when pest pressure is high.

The availability of a diverse range of Bt cotton varieties has supported successful adoption in countries such as China and Mexico, where institutional support has also played a significant role.

Bt cotton adoption is still relatively new, so it is difficult to extrapolate current and past results into the future. In particular, uncertainty about future pest pressure contributes to a high level of uncertainty about economic benefits. Climate change predictions suggest a general increase of pest pressure in many regions.

HT cotton

Although there was only limited literature to support findings regarding the benefits of HT cotton, the available data suggest adoption of this crop technology results in economic benefits to farmers. That being said, other factors than the HT characteristics contributed to the increase in yield and income as well, such as greater crop flexibility. HT cotton was the most rapidly adopted trait in the USA.

Bt maize

In South Africa, evidence was inconclusive as to whether gross margins of Bt maize were significantly higher than for conventional maize. It was shown that using Bt maize was an effective strategy for lowering yield risks associated with pest pressure. However, the high seed costs resulted in an overall financial risk for Bt adopters. When looking at the yield per kg sown, instead of looking at the yield per hectare, there was no real difference between conventional and Bt maize, indicating again that results from comparison-based studies should be handled with care.

Limited data lead to concerns regarding temporal and spatial transferability of findings in a number of studies.

In Spain, Bt maize led to increases in average yield, although this was only statistically significant for one region. The higher yield led to increases in gross margin. Other studies show savings made through lower insecticide use. The economic benefits of Bt maize compared to conventional maize depended ultimately on level of pest pressure.

HT maize

Literature on HT maize was limited, possibly due to low adoption rates, especially in the USA.

The fast growing canopy of maize renders weed management much simpler than for other crops and thus reduces the comparative benefits of the HT trait.

In South Africa, a study indicated considerable increases in yield and gross margin for HT maize compared to conventional maize. Still, the benefits varied between regions.

HT soybean

In the USA, there were limited economic benefits from growing HT soybean, although it led to statistically significant but small increases in yield and reduced herbicide costs. Evidence was inconclusive as to whether or not farm size was a contributing factor. Similarly, in Romania HT soybean use led to economic benefits due to increased yield.

The parallel introduction of no-till practices and HT soybean reduced weed management costs significantly while increasing yields and resulted in positive side effects of reduced erosion and associated nutrient loss.

Non-peer-reviewed literature

The literature review focused on peer-reviewed literature. However, as peer-reviewed sources cite non-peer-reviewed literature and refer to their findings, there is inevitably some overlap between the two categories. Conclusions reached in non-reviewed sources often match those within the peer-reviewed literature.

4. Results of statistical analysis on major GM crops

Bt cotton

On average, Bt cotton shows an economic advantage over conventional cotton. However, the effects on economic performance indicators show a high degree of heterogeneity across countries, which is mainly a result of differences in pest management practices. Countries lacking well-established pest management, and consequently featuring low yield levels, benefit most from growing Bt cotton because yield losses could be reduced. For instance, in India yield increases of up to 50% could be observed. In contrast, countries with rather high yield levels and well-established pest management, such as Australia or the USA, benefited most from reduced pesticide costs (16%-70%) rather than increases in yields.

In most cases, reduced pesticide costs and/or higher yields of Bt cotton outweigh higher seed costs (mark-ups of between 30% to 230% for Bt cotton seed compared to conventional seed were observed) resulting in gross margins that range between -10 to 32% compared to gross margins of conventional cotton. In countries where crops are well adapted to local conditions and pesticide control is efficient (e.g. Australia), Bt cotton shows the lowest net-benefit.

Bt maize

Across all countries considered, Bt maize shows differences in overall economic performance between 10 and 17% compared to conventional maize. While the seed costs of Bt maize are higher (10%-36%) and the pesticide costs are lower (25-60%) than for conventional maize, yield levels of GM exceed those of conventional maize by 5%-25%. In Spain, gross margin increases in the range of 10% could be found. However, the results indicate significant heterogeneity of the effect of using Bt maize across seasons and regions where the crop is grown. This also means that yield advantages within a country vary over time and space. In general, the effect of using Bt maize on economic performance indicators is less pronounced than for Bt cotton versus conventional cotton. This difference might be explained by the already well adapted varieties and pest management measures available in countries where Bt maize is mostly grown (e.g. the USA and Spain).

HT soybean

The statistical analysis of the effect of HT soybean on economic performance indicators indicate higher seed costs and lower herbicide costs, as well as lower management and labour costs for HT soybeans. No clear positive HT effect on yields could be detected across available data sets. However, while seed costs for HT soybeans are higher, reduced herbicide costs (and other benefits such as the easier adoption of no-till) led in some cases to an overall net benefit for HT soybean adopters.

Overall results from the statistical analysis

In general, results of the economic performance of GM crops follow a similar pattern set out in much of the literature: compared to conventional crops, GM crops can lead to yield increases mostly through reduced yield losses from insect infestation and weeds. They can also lead to reductions in pesticide costs. Seed costs for GM crops are usually substantially higher than for their conventional counterparts, yet in cases where higher yields and the reduction of pesticide inputs outweigh the higher seed costs, farmers receive higher income by growing GM crops. The type and magnitude of benefits from GM crops found in this study are, however, heterogeneous across countries and regions. While countries with well-established pest management can mostly benefit through reduced pest-management costs, other countries can benefit most from reduced yield losses (i.e. yield increases).

5. Results of critical analysis on conclusiveness of results

Many individual studies in the current literature show an economic advantage from growing GM varieties. However, the majority of these studies compared results generated in a particular region under specific conditions, with a specific methodology applied in data collection and data analysis. This must be taken into account when drawing general conclusions on the economic performance of GM crops.

The comparative assessment of this study highlighted that the manner in which data is gathered in studies (e.g. if a field trial or a survey was conducted) has an influence on the results. It could also be shown that the conductor of a study influences the performance estimates of GM crops. For example, statistical comparisons revealed that higher yield advantages of Bt cotton are observed when private companies conducted the study, compared to studies conducted by public institutions (e.g. universities).

Study type - field trials:

The experimental setup of field trials may bias the derived economic performance results in several ways, namely:

- The pest-control regimes applied by researchers in the field trials may not reflect those of a profit-maximising farmer. In the case of pesticide-inherent crops, the reduction potentials in pesticide use (and thus the economic potential), may be underestimated.
- On the other hand, assuming that farmers chose the variety that provides the highest yield and/or greatest benefit, the benefit of GM crop adoption for the farmer can be overestimated in field trial setups. The variety that was used as baseline (a commonly used variety or a less commonly used near-isogenic, i.e. highly genetically consistent, variety) influences the economic performance estimators of GM crops.

Study type – surveys:

In the context of a survey, a causal effect between the new technology and farm performance indicators must be presumed. However, there are many other effects (besides the use/non-use of GM crops) that may influence the economic performance at the farm or field level. These effects can best be separated from the true “GM crop effect”, through random sample selection. Surveys that are conducted to evaluate the economic performance of GM crops, however, are not usually based on fully randomized drawn samples and the estimated performance parameters are likely biased.

A group comparison to assess the effect of study type on reported Bt cotton performance indicators showed that field trials on average indicate a higher Bt yield effect (41%) when compared to surveys and other studies (24-25%). Compared to field trials and other studies, surveys indicate the lowest mark up for seed costs and highest pesticide costs savings for Bt cotton. Surveys also indicate higher management and labour costs for Bt cotton than field trials and other studies.

A regression analysis showed that yield data for cotton observed in field trials are up to 40% lower than those observed in surveys. In contrast, general gross margin levels indicated by field trial-based studies are about 55% higher than in surveys. The difference of seed costs and pesticide costs between Bt and conventional cotton are 36% higher in field trials than in surveys. In contrast, differences between GM and conventional crops are about 40% lower for management and labour costs in field trials compared to results derived from surveys.

Study conductor

Whether data was collected and published by a company or a public research institute also plays a role in the assessment of the economic performance of GM crops. Yield levels observed by companies are generally lower compared to public research. The yield surpluses of Bt cotton reported by company based studies, however, are higher (in the range of 97%) than those reported by public research.

Further examination of variations in results on the economic performance of GM crops between studies unveiled different explanations for inconsistencies found, especially within yield data. Yield levels achieved for a crop depend on a wide range of different factors that go far beyond the mere choice between GM and conventional crops. For example, it is also important, that the farmer chooses the adequate variety of a crop (no matter if GM or conventional) for the weather and climatic conditions under which he grows it. However, like-for-like or near-isogenic comparisons cannot be realistically achieved in respective studies, resulting inevitably in a distortion of results, that can both lead to an over- or underestimation of benefits from GM crops compared to conventional ones.

Other significant varying factors that influence yield levels include the degree of pest pressure experienced in the particular region where the crops are grown, which might strongly vary between growing seasons, the access to water for irrigation, which is of major importance in poor sub-tropical countries, and the individual level of experience a farmer has with growing a crop.

6. Conclusions

In the analysis undertaken in this study (raw) data from original papers was re-assessed to find out about trends in results across space, time and different crops and traits. It therefore differs from most other review studies which mostly use overall results from different (case) studies for a comparative analysis.

Due to the strong variations between regions and the additional varying factors found in the analysis that influence results on the economic performance of GM crops (see above), any generalised conclusions on the economic performance of GM crops for the whole world would inevitably be misleading. However, positive economic effects have been observed for a number of countries, which is in line with other review studies (e.g. Carpenter, 2010, Gouse et al., 2009, Bennett et al., 2004a, Frernandez-Cornejo et al., 2005, and Qaim, 2009) and explains the high adoption rates of GM crops in these countries.

It must be added that the study found general limitations in the collection of comparable data. In particular, the comparability between studies based on field trials and studies using surveys as a data source is limited and should be taken into account in future research. In addition, other varying factors, such as farms characteristics, crop varieties adopted and seasonal changes of growing conditions, can hamper the conclusiveness of comparative studies between GM and conventional crops because comparisons under equal conditions are difficult to achieve and are rarely made.

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1 Introduction

1.1 Overview on GM crops and their economic performance

Adoption of GM crops worldwide

The global area planted with GM crops has been increasing each year since they were first commercially cultivated in 1996. In 1996 2.8 million hectares were cultivated with GM crops, increasing to 90 million hectares in 2005 and 134 million hectares in 2009 (see Table 1).

The GM crop market value has expanded as more countries begin producing GM crops (see Table 1). In 2006, 90% of the planted area with GM crops was located on the American continent (Gómez-Barbero & Rodríguez-Cerezo, 2006). Officially in 2009, GM crops were cultivated in 25 countries.

The countries with major areas relying on GM crops in 2009 were: USA (64 million hectares), Brazil (21.4), Argentina (21.3), India (8.4), Canada (8.2), China (3.7), Paraguay (2.2), and South Africa (2.1 million hectares) (James, 2009). Fifteen of the 25 GM crop producing countries are classified as developing countries (FMI, 2008).

Of all the GM crops grown worldwide, only four dominate the market: soybean, cotton, maize and canola. In terms of area cultivated, soybean is the most successful. In 2009 more than three-quarters (77%) of the 90 million hectares of soybean grown globally were GM crops while for cotton, almost half (49%) of the 33 million hectares were GM crops. Over a quarter (26%) of the 158 million hectares of globally grown maize are GM crops and 21% of the 31 million hectares of globally grown canola are GM crops (James, 2009).

The two dominant agronomic traits currently available are herbicide tolerance (HT) and insect resistance (mostly in the form of Bt crops). Herbicide tolerance is the prevailing trait that is deployed in all four dominant crops, while maize and cotton are the only two insect resistant GM crops currently available at commercial scale (Sanvido, Romeis and Bigler, 2007). In 2009, herbicide tolerance used in soybean, maize, canola, cotton, sugar beet and alfalfa made up 62% (83.6 million hectares up from 79 million hectares in 2008) of the global GM crop area of 134 million hectares (James, 2009). In the future, crops with stacked traits are likely to become more important. In 2009, stacked traits were planted in 11 countries. Due to the limited number of studies and data availability, the present study does not include stacked traits in the analysis and is restricted to herbicide tolerance (HT) and insect resistance.

In the EU, seven countries (Spain, Czech Republic, Romania, Portugal, Germany, Poland and Slovakia) planted MON 810, a genetically modified maize variety from Monsanto, on a commercial basis in 2008. The total acreage for the seven countries increased from 88,673 hectares in 2007 to 107,719 hectares in 2008 (James, 2008), with Spain being by far the most important adopting country in Europe (Gomez-Barbero et al., 2008a,b). However, in 2009, the EU acreage decreased by 9 % compared to 2008, partially due to a German ban on MON 810. According to James (2009) the decrease was associated with several factors, including the economic recession, decreased total plantings of hybrid maize and perceived disincentives due to onerous reporting of intended plantings of MON 810.

Table 1. Area and countries where GM crops are cultivated (in million ha)

Year	Area	Countries
1996	2.8	US, China, Canada, Argentina, Australia and Mexico
1997	12.0	US, China, Canada, Argentina, Australia and Mexico
1998	27.8	US, China, Canada, Argentina, Australia and Mexico
1999	39.9	US, China, Canada, Argentina, Australia, South Africa, Spain, France, Portugal, Romania and Ukraine
2000	44.2	US, Argentina, Canada, China, South Africa, Australia, Romania, Mexico, Bulgaria, Spain, Germany, France, Portugal, Ukraine and Uruguay
2001	52.6	US, Argentina, Canada, China, South Africa, Australia, Mexico, Bulgaria, Uruguay, Romania, Spain, Indonesia and Germany
2002	58.7	US, Argentina, Canada, China, South Africa, Australia, India, Colombia, Honduras, Mexico, Bulgaria, Uruguay, Romania, Spain, Indonesia and Germany
2003	67.7	US, Argentina, Canada, Brazil, China, South Africa, Australia, India, Colombia, Honduras, Mexico, Bulgaria, Uruguay, Romania, Spain, Indonesia, Germany and Philippines
2004	81.0	US, Argentina, Canada, Brazil, China, South Africa, Australia, India, Colombia, Honduras, Mexico, Paraguay, Uruguay, Romania, Spain, Germany and Philippines
2005	90.0	US, Argentina, Canada, Brazil, China, South Africa, Australia, India, Colombia, Honduras, Mexico, Paraguay, Uruguay, Romania, Spain, Germany, Philippines, Iran, Portugal, France and Czech Republic
2006	102.0	US, Argentina, Canada, Brazil, China, South Africa, Australia, India, Colombia, Honduras, Mexico, Paraguay, Uruguay, Romania, Spain, Germany, Philippines, Iran, Portugal, France, Czech Republic and Slovakia
2007	114.3	US, Argentina, Brazil, Canada, India, China, Paraguay, South Africa, Uruguay, Philippines, Australia, Spain, Mexico, Colombia, Chile, France, Honduras, Czech Republic, Portugal, Germany, Slovakia, Romania and Poland
2008	125.0	US, China, Canada, Argentina, Brazil, Paraguay, India, South Africa, Uruguay, Bolivia, Philippines, Australia, Mexico, Spain, Chile, Colombia, Honduras, Burkina Faso, Czech Republic, Romania, Portugal, Germany, Poland, Slovakia and Egypt.
2009	134.0	US, Brazil, Argentina, India, Canada, China, Paraguay, South Africa, Uruguay, Bolivia, Philippines, Australia, Burkina Faso, Spain, Mexico, Chile, Colombia, Honduras, Czech Republic, Portugal, Romania, Poland, Costa Rica, Egypt, Slovakia.

Sources: Gómez-Barbero & Rodríguez-Cerezo (2006), James (2006), James (2007), James (2008), ISAAA (2010).

Economic performance of GM crops - current state of knowledge

The most recent overview study (Carpenter, 2010) covers 12 countries worldwide and summarises results from 49 peer-reviewed publications that report on farmer surveys comparing yields and other indicators of economic performance for adopters and non-adopters of currently commercialized GM crops. According to Carpenter, benefits from growing GM crops mainly derive from increased yields, which are greatest for small farmers in developing countries insofar as they have benefitted from the spill-over of technologies originally targeted at farmers in industrialized countries. Balancing the costs and benefits of GM crops the study found that, with few exceptions, GM crops have benefitted farmers.

Apart from increasing yields, the adoption of GM-crops can reduce production costs by reducing pesticide use, as well as labour and fuel costs. A study on the overall impacts of GM crops adoption in the US shows that the economic benefit for farmers has been highest for Bt crops, "particularly where insect pest populations were high and difficult to treat" (NRC, 2010). At the same time, due to a technology premium imposed by companies, seed cost for GM crops is higher than for non-GM crops. Production costs can be affected directly by the adoption of GM-crops or indirectly in relation to spill-overs to other technologies or farming practices, such as no-till farming which is often applied along with HT cultivars.

In most cases, output prices for GM crops remain at the same level as for non-GM crops, or are slightly higher due to better product quality for crops like cotton where insect damage can harm the quality of bolls. Barfoot and Brookes (2007) estimated that even with seed costs of GM crops being much higher, total farm benefits (gross margins) are higher for GM crop adopters, amounting to about $7 billion globally per year.

By drawing on a wide range of different sources, Brookes (2007) reported that yield increases through the introduction of Bt maize in Europe were typically around 15%. A survey conducted in Spain by Gómez-Barbero et al. (2008a) in 2002, 2003 and 2004 showed yield advantages for Bt maize growers compared to conventional maize growers, but with regional and temporal differences, depending on farmers' characteristics, pest pressure, and varieties grown (not all varieties including the Bt gene were adopted to local conditions). Gross margin differences are mainly yield dependent. For all three years, Bt growers obtained higher gross margins than non-adopters (Gómez-Barbero et al., 2008a). Brookes (2009) also found gross margin benefits due to Bt maize adoption. The JRC study of Gómez-Barbero et al. (2008b) estimated that the aggregated economic welfare surplus obtained by Bt farmers in Spain in 2004 amounted to €3.5 million.

In regions outside Europe a greater variety of GM crops are grown commercially by farmers, including maize, soybean and cotton. The uptake is much higher in developing and less developed countries but also in developed countries such as in the US and in Australia. Given that many farmers in developing countries are relatively resource-poor and pesticides, if available, can be expensive, they have a stronger incentive to grow a GM variety which promises to reduce costs while limiting losses from pests at the same time. For example, an adoption rate of almost 100% has been reported for Bt cotton in Makhathini Flats, Kwa Zulu Natal, South Africa in the 2004-2005 growing season (Morse and Bennett, 2008).

Since the Indian Government approved Bt cotton for commercial cultivation in 2002 (Raghuram, 2002), field trials and surveys confirm yield advantages of Bt over conventional cotton because of reduced losses due to effective control of bollworms. These yield advantages range from +29% (Ahuja, 2007) to +63% (Bennett et al., 2004a) depending on pest pressure, seasonal differences, region, variation in input levels, irrigation intensities, farm and farmer characteristics, and the adaptation of conventional as well as Bt varieties to local conditions (e.g. Qaim et al., 2006).

While some early studies (such as Marra et al., 1998, and Stark, 1997) that were conducted right after adoption of GM crops in the USA in 1996 indicated higher yields from GM crops in some regions (North and South Carolina, Georgia, and Alabama), subsequent studies conclude (at least for cotton) that no particular yield advantage is gained by growing GM crops instead of conventional crops (Jost et al., 2008). However, due to the reduction in time needed for management of GM crops, transgenic cultivars can create savings in labour costs at farm level.

While several studies exist that have proven the economic advantage of GM crops, the conclusions reached on the economic performance of GM crops are not unanimous. For example, it is not a general rule that insect resistant GM varieties require fewer pesticides (Benbrook, 2001; Men et al., 2004). Carpenter (2010) observed that little information can be found on reported changes in the amount of herbicide use with HT crops. The author argues that this is perhaps due to a switch to other types of herbicides. One particular issue reported in this context is 'pest replacement', which means that new ecological niches open up which other competitors then occupy. A recent study from the US reports that GM crops in more and more regions within the US Corn Belt are infested by larvae of the western bean cutworm (Striacosta albicosta), which causes substantial economic damage (Then, 2010). The effect of weed resistance on HT cultivars' economic advantages is also one of the main challenges emphasised in the US National Research Council study (NRC, 2010).

Productivity increases can also depress prices of GM products if their demand remains inelastic. Hence, if an increase in productivity puts a downward pressure on crops' market prices, the gains from GM crops tend to dissipate as the number of adopters increases (NRC, 2010). Moreover, initial surpluses arising from GM crop adoption might lead to higher land prices and thus decrease farmers' income in the long run (Bernard, Pesek and Fan, 2004).

1.2 Objectives and scope of the study

The study's objectives are firstly to provide an overview of the current state of knowledge on the economic performance of GM crops worldwide based on a wide range of data and sources from available literature and secondly, to evaluate the results in terms of their conclusiveness and consistency.

The study thereby focuses on the direct monetary and other effects of growing GM crops that influence farmers' income, such as crop yields, seed costs, pesticide and herbicide costs, and labour costs. The "economic performance" as understood in this study refers to the economic costs and benefits for farmers growing GM crops in comparison to the conventional equivalent. If the additional cost of using GM crops – such as higher seed costs – is less than the gains from increased yield and reduced pesticide and herbicide use, including labour costs, then the economic performance of adopting GM crops will be considered negative. In the opposite case, profit increase due to GM crops will constitute positive economic performance.

The gross margin is of particular interest to this study, as it represents the monetary value of output (calculated as unit revenue per hectare) minus the cost of variable inputs required to produce that output.[1] These costs include labour and variable machine costs, seed costs, herbicide and pesticide costs, irrigation costs, etc. They do not include fixed costs such as land rents or amortisation costs.

Macro-effects of growing GM crops, such as on the environment, social welfare, employment and development, as well as interactions with other markets or market segments, will be not be included in the analysis. Also, this study does not address the indirect effects of the cultivation of GM crops on non-GM agriculture (e.g. the issue of co-existence).

In order to consider most of the available data and to obtain an overall understanding of the issues, comparative analyses are conducted at different geographic levels, including field trials, farm level surveys and general reviews at the national or even regional level. The analysis focuses on ex-post studies of the most dominant GM crops – cotton, maize, soy and canola.

In addition to peer-reviewed publications, data from governmental reports and statistics, conference proceedings as well as other sources (which were considered reliable) are included in the comparative analysis of the study. In addition to a current and comprehensive assessment of the economic performance of GM crops, another main outcome of this study is a better understanding of data availability and data quality regarding global assessments of the economic performance that have been conducted.

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[1] Source: European Commission Farm Accountancy Data Network, http://ec.europa.eu/agriculture/rica/methodology1_en.cfm

2 Methodology

2.1 Overall approach

In order to achieve the objectives, the study was conducted in several working steps. The working procedure followed the steps in the order presented below. More detailed descriptions of the methodology can be found in sections 2.2 to 2.4.

- Design of a relational database
- Comprehensive literature review
- Statistical analyses
- Expert interviews
- Assessment of data availability and conclusiveness of results

The database functioned as the core element of the analysis undertaken in the study, enabling the collection of data in a structured and concise way and facilitating data queries and statistical comparisons across various parameters. After the first round of initial data entries taken from literature sources, the database design was adjusted by taking into account, in particular, the conditions under which key parameters of economic performance were reported in the literature.

The literature review formed the backbone of the study and provided the necessary data for the subsequent statistical analysis. After a substantial search for relevant sources and publications, literature was rigorously screened for the necessary economic information on GM crop performance. Publications used as a data source for the study had to contain raw data on at least one of the parameters of economic performance of GM and conventional crops: crop yield, revenue, gross margin or costs (of seeds, management labour, pesticides and herbicides). The screening process led to the removal of publications which only provided broad overviews rather than specific figures and numbers of GM crops (mostly reviews) and in turn the inclusion of the primary sources they used to support their results. That was mainly done in order to improve comparability of data, using disaggregated values according to time, geographic location, crop type, etc.

Drawing from the data gathered in the literature review and processed in the database, a number of different statistical tests were conducted for the assessment of the economic performance of GM crops compared to conventional crops for different geographic regions and worldwide. The general approach started with an illustration of the distribution of data for the parameter of interest followed by regression analysis leading in particular to country specific comparisons (see chapter 5). Results from the analyses were compared with and underpinned by some key references from the literature that came to similar or contrasting conclusions.

Subsequently, knowledge and results gained from the data analysis were discussed with regard to the conclusiveness of the results themselves and of other studies which used a similar approach to assess the performance of GM crops on a global scale (see chapter 6).

This critical analysis of data sources elaborates on strengths and weaknesses of the different methods which are currently available for such assessments.

The results from the statistical analyses also gave first indications of variations and trends in results and among data. The question of what is meant by "yield increases" is discussed in more detail in chapter 7, i.e. the variation arising from natural conditions on the economic performance indicators and differences in the baseline interpretations. These issues were considered in light of scientific literature and underpinned by expert knowledge obtained through the interviews.

The report closes with conclusions in chapter 8.

2.2 Design of a relational database

The database was designed in Microsoft Access and consisted of a number of different tables, which were partly related to each other (different m:n relations). Extra tables were created for predefined sets of possible attributes for certain parameters. This ensured consistent data entries and allowed for flexibility in order to expand the set of answers if necessary.

The tables 'study' and 'publication' constitute the core entities of the database. Many publications on GM crops – whether from peer-reviewed journals or others – use several case studies (e.g. field trials at particular sites for a specific year) for comparative assessments. Thus, the results published in these publications (e.g. articles or reports) were not compared in the statistical analysis but rather the raw data from the underlying sources that could be derived from the publications. This also means that only publications that contained quantitative data on at least one of the investigated economic parameters rather than mere qualitative statements were considered in the data base.

The 'study' table thereby represents the core table for the comparative quantitative data analysis. The attributes of the 'study' table are divided into three categories:

1. Type of study

Attributes relating to the type of study were mainly used to assess the quality of the data. For example, by indicating the methodology of data collection applied in the study (field trials, interviews, reviews etc.) the degree of aggregation by which data are presented in a study can be derived. The attributes allowed for the classification of a publication and a study according to its scientific reliability, the methods used for data generation and the conductor and the funding entity of the study. Altogether, this information provided necessary input to analyse trends and variation in the data and from which effects (attributes) may arise.

2. Geography and physical environment

This category included general information on the crop type (cotton, maize, soy, canola) and the crop trait (herbicide tolerance, Bt and conventional). Differentiation between studies based on the country where they were conducted is not only needed for country-specific analysis but also for comparative analysis between countries which have different economic (represented by the Gross Domestic Product (GDP)), climatic and legislative conditions which might influence the economic performance of GM crops. This category also included information on whether crops were irrigated or not. Whenever the necessary information was available, the database also differentiated between regions within a country to ensure that data was captured at the most disaggregated level available.

3. Economic performance

To assess the economic performance of a crop, different parameters were chosen depending on the availability and format of the data. In this respect, yield per hectare, costs of herbicides and pesticides per hectare, seed costs and gross margin per hectare turned out to be the most valuable. For other input costs such as fertilizer, labour and management and post-harvest processing, only limited information could be derived from the literature. Due to strong variation in data presented in the different publications and for analytical reasons, gross margin per hectare was regarded as the most comprehensive measure to compare the economic performance of GM and conventional crops, as it captures both costs and benefits which are often not further specified in the studies. However, it must be acknowledged that the ways in which gross margin was calculated did vary between studies, making it difficult to directly compare values.

A more detailed overview on the parameters and attributes used in the database is given in Annex B.

2.3 Data gathering

The literature review included peer-reviewed scientific articles as well as non peer-reviewed sources from grey literature that included raw data on the economic parameters and were deemed to be reliable. Such non peer-reviewed sources were official reports from governmental organisations or agencies/institutes funded by governments, official international and national statistics as well as conference proceedings in which scientists presented results from their research that were not published elsewhere.

Following the methodology outlined above, studies of non peer-reviewed sources that were used in peer-reviewed publications to conduct comparative analysis, were entered in the database by assigning a conductor of the study, which can be academic, governmental, from civil society or from a company. This distinction was necessary for the analysis conducted in chapter 6 (see further explanations in section 6.2.5).

Initially, a keyword search[2] was conducted on the Web of Science and Web of Knowledge, further sources were found through Google-scholar search. The review of grey literature was mainly based upon internet research. During the following phase the sources were scrutinised in accordance with the parameters and attributes selected for the database (see section 2.4). However, in order to ensure that the data had not been converted or even misinterpreted in the source document, the screening of the publication often led to another source to track the primary data. Such an approach was considered to be necessary in order

[2] Using keywords "gm crops" (bt cotton, bt maize, ht soy etc.),"economic performance", "input costs", "yield", "income" or "revenue" etc. and combinations

to avoid the duplication of data and possible bias derived from citation and re-interpretation of data by different authors.

Most publications, from which studies were entered in the database, originated from the sources presented in Table 2.

A comprehensive list of the references that have been included in the database, either as a publication only or providing single study entries, can be found in Annex G. This reference list also includes sources that have been consulted but did not provide adequate data for the database. Regarding the geographical coverage, the literature review aimed to include all available sources with the primary focus on the most significant GM crop-growing countries.

Table 2. Literature sources used in the study

Type of source	Examples
Scientific journals	Journal of Agricultural Science, Review of Agricultural Economics Science AgBioforum International Journal of Biotechnology
International organizations	FAO EU Commission UNCTAD CBD/Cartagena Protocol on Biosafety
National agricultural statistics	US Department of Agriculture (http://www.usda.gov) Brazil Ministry of Agriculture (http://www.agricultura.gov.br/) Australia: Department of Agriculture (http://www.daff.gov.au/agriculture-food/biotechnology/pamphlets)

In the review process all studies that could be found in each publication and which entailed robust and comparable data were entered into the database. Publications that consisted of merely qualitative statements about the economic effects of GM crops which were not underpinned by raw data were not processed in the database. The following citations provide some examples of such general statements. It has to be noted that many publications included such vague statements while referring to other sources of literature. Consequently, these were then checked for more detailed accompanying data and values.

"Growing GM crops increase the yields by 10 % comparing to conventional varieties"

"Income loss for poor farmers from growing GM varieties constituted 25 % comparing to conventional ones."

To guarantee comparability, data were entered in identical units. This often required the conversion of values. Values in various currencies were converted to US Dollars using the average exchange rate for the year of the study. When data were provided for a growing season, covering two years (for example, growing season 2001-2002), the exchange rate for the latter year was used (as revenues tend to occur with a time lag). All area values were entered in (and if necessary, converted to) hectares and weight figures were entered in kilograms.

2.4 Data analysis

In order to test the effects of GM crops on the economic performance indicators, a regression model of the following form was used:

$$\text{Log}(Y) = \beta_0 + \beta_1 \text{ Year} + \beta_2 \text{ Dummy\_GM} + \beta_3 \text{ Year} * \text{Dummy\_GM} + \beta_4 \text{ Dummy\_Country} + \varepsilon$$

As indicated by the equation above, the logarithm (log) of the economic performance indicators Y (yield per hectare, costs of herbicides and pesticides per hectare, seed costs and gross margin per hectare, see section 2.2 for details) is used because this improves the suitability of the regression models[3]. Furthermore, the estimated model parameters can be interpreted as the relative (percentage) effect of the explanatory variables on the right hand side of the regression model on the economic performance indicator Y under consideration (e.g. the effect of time on per hectare yields).

Three explanatory variables and one interaction term are included in the regression model: a) the variable "Year" indicates the year of the observation and is used to estimate a time trend in the economic performance indicators, b) the "Dummy_GM" indicates observations for conventional (GM=0) and GM crops (GM=1) and is used to estimate an effect of GM crops, c) the interaction term "Year * Dummy_GM" is used to estimate a time trend in the effect of GM crops, and d) the variable "Dummy_country" is a numeric value given for each country to make a comparison across all countries possible.

The regression coefficient β_1 measures the effect of technological change (using the proxy time, i.e. Year) on the economic performance indicator chosen (e.g. general increasing yield levels due to technological development). β_2 (Dummy_GM) measures the difference in the economic performance between GM and conventional crops. The regression coefficient β_3 shows time trends in economic performance of both – GM and conventional – technologies (e.g. a yield benefit of GM crops might decrease over time). β_4 measures the different levels of economic performance indicators across countries (e.g. yield levels may be on average higher or lower in one country compared to another)[4].

Finally, ε is the error term that captures all other factors which influence the economic performance indicators other than the Year, Dummy_GM, or Dummy_Country[5].

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[3] The suitability of the regression models is tested by model diagnostics (e.g. QQ-plots of the residuals).

[4] Thus, these dummy variables remove the average value of the economic performance indicators (e.g. yields) for each country from the observations. The country means are evaluated in the regression against an omitted reference dummy (i.e. reference country). The respective coefficient estimates are presented in the annex (See Annex C, Table 23, and Annex D, Table 25).

[5] In order to assess the quality and the suitability of the regression model, we tested to see whether the error terms were uncorrelated with the independent variables, whether they had a constant variance (homoscedasticity), were independent from each other (no autocorrelation) and whether they followed a normal distribution. We used graphical regression diagnostic tools (QQ-plots, plots of residuals, Tukey-Anscombe plots, etc.) for model checking. In addition, selected associated tests (e.g. the Breusch-Pagan test, the variance inflation factor, Shapiro-Wilks test) were used if the graphical inspection indicated violations of the assumptions.

In order to analyze the GM crop effects on the economic performance indicators (i.e. yield, gross margin, seed costs, pesticide costs, as well as management and labour costs) within a country as well as to show the different GM crop effects between countries, country specific analyses have been conducted.[6] In order to test for differences between GM and conventional crops, the Mann-Whitney (or Wilcoxon–Mann–Whitney) test has been applied.[7]

As a consequence of the data analysis, variations, contradictions and biases were identified and hypotheses formed in order to provide an explanation for their causes.

The main source of data was the articles, but by their very nature they consist of concise and focussed statements of the work that was done. To gain a broader and more comprehensive picture about the potential differences in economic impacts observed within and apart from their work selected authors of those articles were contacted for interviews. The rationale for the interviews was to gain further insight into causes of variation across space and time as well as to help identify reasons for any contradictory results that were observed. Hence those contacted for interview were assumed to have knowledge of the practice of GM crop research.

In order to avoid a potential omitted variable bias due to different climatic conditions, we also included the climate zone (that might be correlated with dependent variables and the independent variable) in the regression analysis, which had, however, no effect and did not change the effect of the other independent variables. We also expected the specific varieties used to have an influence on the Bt effect and the economic performance parameter, which is not testable due to a lack of data on varieties used.

[6] We have not included the GM effect by country in the regression analysis because this would have not allowed for an estimation of an overall effect of GM crops, but rather would have reflected the heterogeneity across countries.

[7] We used the Mann-Whitney test instead of the t-test because it is more robust against outliers in the data, and the efficiency loss under normally distributed observations is small compared to the potential gain for non-normal distributions (Gibbons and Chakraborti, 2003). The idea of the test is briefly described as follows: Given observations of 2 independent groups (samples with sample size m and n, respectively), the groups are arranged and ranked in a single series of m+n observations. In a second step, the ranks for the observations that come from sample 1 and sample 2 are added up. These sums of ranks are denoted as R1 and R2, respectively. The idea of the test is that if the observations in both samples are homogeneous, particularly with respect to their location parameter, the rank sums have to be equal. The smallest rank sum is used as the test statistic and is corrected by potential minimum value. This corresponds to a test statistic that can be defined more generally as the number of all pairs '(x[i], y[j])' for which 'y[j]' is not greater than 'x[i]'. All graphical presentations, regressions and tests are conducted with the statistical language and environment R (R Development Core Team, 2009).

3 Literature Review

3.1 Introduction

The aim of this chapter is to summarise the current state of knowledge regarding the economic impacts of GM crops. The recent review undertaken by Janet Carpenter (2010) provides an excellent starting point. Here we summarise some of the literature mentioned in the Carpenter review as well as others that were not included. Two points need to be made regarding the Carpenter review. First, it was published within the 'Correspondence' section of Nature Biotechnology rather than being a full paper and as a result the level of detail provided in the article is limited. Hence, where appropriate, in this literature review an effort has been made to provide more detail. Second, and perhaps more importantly, a 'competing financial interests' declaration was made at the end of the article and it should be noted that the research was supported by CropLife International, an umbrella group representing some of the major companies in the biotech industry.[8]

The Carpenter review identified 49 peer-reviewed journals, official reports and books from which 68 references to the economic benefits of growing GM crops were found. From these 68 references, 168 direct comparisons between GM and conventional crops were reported (note that a single paper could include a number of comparisons) of which 124 indicated a 'positive' outcome, 31 a 'neutral' outcome (no difference) and 13 indicated a 'negative' outcome, when comparing GM and conventional (non-GM) crop varieties. Carpenter raised a number of complicating issues with regard to comparing GM and conventional crop varieties, including:

- regional and annual variability in economic impact
- yield potential
- difficulty of isolating the effects of GM traits from the genetic background
- variability as to what factors were included as components of gross margin
- limited spatial coverage (results covered less than half of the countries currently growing GM crops)
- limited technology coverage (literature on some of the popular technologies such as HT maize and canola was sparse).

Some of these will be explored in more detail later in the report.

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[8] such as BASF, Bayer CropScience, Dow AgroSciences, Dupont, FMC, Monsanto, Sumitomo and Syngenta (http://www.croplife.org/public/our_members)

Peer-reviewed journals are broadly regarded as the most impartial source of evidence, although even here caution has to be taken. The majority of academic research is funded either through independent sources, such as research councils and other government and international organisations, or through funding obtained from industry, including those companies engaged in producing and marketing GM varieties. The risk with privately sourced research, although this can happen with government sourced funding as well, is that the research question(s) posed and the conclusions reached may be quite space and time-specific (e.g. a study that took place over a short time in one region of a country) and narrow (e.g. comparisons of a GM variety with a small subset of conventional varieties only in terms of yield or a limited number of gross margin components) (Dwan et al., 2008*)*. This narrowness may, of course, be a reflection of a desire by the funder (i.e. the company) to provide a positive picture for their product as a marketing device. These same issues could equally apply to the anti-GM pressure groups, although they are not an especially significant source of research funding. Hence in this chapter care has been taken to point out sources of funding behind the research reported in a publication where it was deemed to be relevant.

The chapter has been structured according to the crops and technologies that formed the basis for the statistical analyses reported later. Indeed a number of the sources mentioned here provide data that were used to generate the statistical analyses and consequently some overlap is inevitable.

3.2 Cotton

3.2.1 Bt cotton

The conclusions that emerged from most of the articles investigating the economic benefits of Bt cotton was that the technology increased yield primarily by limiting the damage incurred via insect pests (most notably the boll worm complex), and at the same time reduced insecticide costs as less insecticide was required for Bt cotton (Bennett et al., 2004a; Crost et al., 2007; Kambhampati et al., 2006). These conclusions have been reported for the following countries;

- South Africa (Bennett et al., 2004a; Fok et al., 2008; Gouse et al., 2003; Ismael et al., 2002)
- India (Barwale et al. 2004; Bennett et al., 2004; Bennett et al., 2005; Crost et al., 2007; Kambhampaati et al., 2006; Morse et al., 2007; Qaim et al., 2006; Ramasundaram et al., 2007; Subramanian and Qaim, 2009)
- USA (Cattaneo et al., 2006; Falck-Zepeda et al., 2000)
- China (Huang, 2002a; Huang, 2002b)
- Argentina (Qaim and de Janvry, 2005; Qaim and de Janvry, 2003)
- Mexico (Traxler et al., 2003)

While there is substantial evidence that the adoption of Bt cotton provides economic benefits for farmers in a number of countries, the question of whether these benefits are due solely to the Bt trait, or also to some other factors involved remains. A number of authors have explored this issue. For example, Gouse et al (2003) and Kambhampati et al. (2006) suggested that there was some indication that more efficient production methods were used by those farmers who were more likely to adopt Bt cotton. Crost et al. (2007), using data from India, attempted to evaluate the effect that farmer self-selection may have on the results. While it was difficult to fully isolate the effects of farmers' choices, the conclusion reached was that the farmers who selected Bt cotton tended to use more efficient production systems on their farms. Therefore, as with other agricultural technologies, there is a concern that effectiveness of the technology is due in part to the characteristics of the farmers adopting the technology first. Efficient or better educated or wealthier farmers may be better able to increase productivity. Certainly in the case of India, farmers were found to be heterogeneous, with yields and costs varying due to differing management regimes (including spraying habits) which are learnt through trial and error (Qaim et al., 2006). This point was supported by Wossink and Denaux (2006) who explored the use of pesticides on transgenic cotton in North Carolina, USA. Using Tobit regression, these researchers found that the education level of the farmers had a significant positive effect on the technical and cost efficiencies of the farm. As a result of this education they were able to make informed decisions such as choosing stacked GM varieties of cotton which performed better than other varieties. The size of the field was also found to have an influence on the amount of pesticides used, and through the Tobit regression analysis they were able to conclude that an increase in field size of 1% would lead to a reduction in pesticide use of 1.3%. The research from North Carolina supported evidence obtained from the Makhathini Flats region of South Africa, where excessive rain can lead to higher pest populations along with yield losses and increased pesticide costs.

Another contributing factor to differences between Bt and non-Bt cotton is the variety of cotton used as 'background' in which the Bt gene is introduced (Kambhampati et al., 2006; Qaim et al., 2006). This point has been demonstrated in India with the release of 'unofficial' varieties of Bt cotton. While the official varieties of Bt cotton produced, on average, the largest increase in yields relative to conventional varieties, unofficial GM varieties also allowed for better yields than the conventional varieties (Bennett et al., 2005). The official Bt varieties tended to out-yield the unofficial ones. Hence performance of 'Bt cotton' relative to conventional depended upon whether the comparison was made with official or unofficial Bt varieties (Bennett et al., 2005).

Results from India have suggested that not all of the Bt cotton varieties were suitable for the local conditions under which they were grown. In a study funded by Grain, a small international non-profit organisation assisting small farmers and social movements for community-controlled and biodiversity-based food systems, Qayum and Sakkhari (2003) examined the introduction of Bt cotton (Bt Mech 162) in the Warangal district of Andhra Pradesh, India. The variety became susceptible to the local weather conditions in that part of India, which were often hot and dry. The susceptibility of Bt Mech 162 to wilt was due in part to the fact that the conventional version of this variety (the background into which the Bt gene was introduced) was also susceptible to wilt. In addition to this disadvantage, the variety had a much larger seed to lint ratio which affected the price obtained by farmers, as well as the quality of the boll. Indeed the yield from Bt Mech 162 was lower than that of a range of conventional varieties already grown by farmers. Pesticide use was also similar for both Bt

Mech 162 and the conventional cotton varieties. A related story is provided by a study funded by the Gene Campaign, which has similar objectives to Grain. Sahai and Rahman (2003) also looked at the introduction of Bt cotton in the same region of India. Once again they reported yields were lower for Bt cotton and for much the same reasons as those given by Qayum and Sakkhari (2003). In addition they noted that no training in cultivation of the Bt variety had been provided for farmers. It has to be noted that the relative failure of the Bt Mech 162 variety in India, as highlighted by these two studies, reinforces the fact that with any change within an agricultural enterprise there is always risk. Shankar et al (2008) concluded that Bt cotton overall was very effective in reducing the risks of production, although there was some evidence that the technology increases output risks, which by implication means that simple gross margin comparisons may overstate the benefits.

While the general consensus from much of the research conducted so far is that Bt cotton reduced costs primarily through a reduction in use of insecticide, this is not always the case. Bennett et al (2004) concluded that in certain parts of India the benefits were due more to higher incomes obtained from higher yields rather than through any significant reduction in cost because the farmers continued to spray the same amount of insecticide to Bt varieties as they did to the conventional. Similarly, in China the greatest economic efficiencies were found among smallholders, but the insecticide costs were not always reduced for Bt varieties (Huang, 2002b). This has often been explained as being due to lack of information provided to farmers. Indeed the reported financial benefits from growing Bt cotton have not always been reported as uniform across all groups of farmers. Subramanian and Qaim (2009) observed in India that while substantial benefits were observed for both small and large-scale producers growing Bt cotton, the larger-scale farmers benefitted the most. In Argentina, while the adoption of Bt cotton was shown to be financially beneficial, it had only been taken up by large-scale farmers (Qaim and de Janvry, 2005). Because small scale farmers in Argentina did not use much, if any, insecticide on their cotton it was suggested that they would benefit most from adopting the new technology (Qaim and de Janvry, 2005).

While there are financial benefits to the growing of Bt cotton, there are also financial risks. Uncertainty of income and, as a result, the economic risk that smallholder farmers were taking with the introduction of Bt cotton to the Makhathini Flats region of South Africa was raised by Hofs et al. (2006). The research examined two growing seasons and concluded that the crop did not generate enough income to sustain the socio-economic improvements that were needed by households in that area. There were two reasons given for this conclusion. The first was that the performance of the common cotton variety grown in the area would vary year on year because of climate (Hofs et al., 2006; Kambhampati et al., 2006), pest pressure, input costs and output prices. The second reason was the absence of an effective market (Hofs et al, 2006; Ismael et al., 2002), as the control of credit facilities and the purchase of the final product were all under the control of a single company. Farmers had little choice as to where they could sell their cotton. This argument was supported by Fok et al. (2008) who concluded that the farmers' in the Makhathini Flats region of South Africa only benefited from Bt cotton when the pest pressure was high. When pest pressure was low, the yields of Bt varieties were similar to those produced by conventional cotton, and therefore with higher seed costs and having to pay for credit, the economic benefits were effectively negligible (Fok et al., 2008). Pemsl et al. (2004) also highlighted the risk to Indian farmers as a result of the low but highly variable yield that they faced from Bt cotton, which may in part be due to the poor quality of the varieties used by farmers, as well as the lack of an effective Integrated Pest Management System. As a result, farmers often found it difficult to know when to spray their cotton and when they did decide to spray it was usually late in the season, by which time there may have been insufficient funds to purchase pesticide.

Regional variations can also have an influence on the relative performance of Bt cotton (Bennett et al. 2005) and this could in part be due to variation in institutional practices. A prime example of this can be found in China. The adoption of Bt cotton has been significant in that country and farmers have benefited from increased yields and, in some instances, reduced insecticide costs (Huang, 2002a). The popularity of the technology has been due to the public sector being fully involved both in development and distribution (Huang, 2002a). Mexico has also witnessed an increase in cotton yield and decrease in the cost of production arising from the introduction of Bt cotton. However, the Bt cotton yields obtained in Mexico have exceeded anything that most developing countries would ever be able to achieve (Traxler et al., 2003). The reasons for this have been attributed to a diverse range of Bt varieties available to farmers via the private sector (hence good flexibility), availability of farm credit and the use of an effective Integrated Pest Management system. Mexico is also atypical in that it has excellent research facilities and most of its farms are irrigated.

With clearly identified economic benefits to growing Bt cotton as outlined above, it is instructive to note that constraints may be in place which prevent farmers from adopting the technology. Perhaps unsurprisingly, the higher price of Bt seed has often been cited as a major constraint to adoption (Qaim and de Janvry, 2003), but there are other factors. For farmers in Central India the identified constraints certainly include high seed prices, but also the perception of significant risks, poor refugia management, incidences of wilt, and poor monitoring of pests (Ramasundaram et al., 2007). A level of discontinuance has also been reported, where farmers stopped growing Bt cotton after a period of time as a result of these constraints. Ramasundaram et al. (2007) suggested that these issues could have been mitigated and higher adoption rates achieved if the varieties used as background for the Bt were local hybrids that had a degree of adaptation to the local environment and characteristics that farmers were familiar with. Indeed farmer perception can be an important factor in adoption, especially when the economic benefits may not be immediately obvious. The Australian Cotton Cooperative Research Centre, which has partnerships with many educational and government research organisations and is also closely connected to the cotton industry, commissioned a report from Fitt (2003) examining the benefits of Bt cotton to Australia. The introduction of the technology initially provided little economic benefit, but after a few years that benefit increased. This may in part be explained by how the technology is viewed in Australia, as it has not been treated as a ‘magic bullet’, but rather as an integral part of an Integrated Pest Management system. Hence it took time for the technology to become a successful component of IPM.

Conclusions reached by those researching the economic impacts of Bt cotton often contain a ‘health warning’. The majority of research projects examined data obtained over a relatively short period of perhaps one to three years (Bennett et al., 2004; Ismael et al., 2002; Pemsl et al., 2004). Hence authors are careful to stress that the economic benefits that may have been identified could not be extrapolated to future years due to a high level of uncertainty over whether similar conditions prevail (Ismael et al., 2002). Pest pressure, which can be affected by factors such as weather, is particularly important in creating this high level of uncertainty as the level of infestation is very difficult to predict, and indeed may become more so with climate change. As has already been noted, the benefits of Bt cotton relative to conventional varieties are often greater under high pest pressure. A similar point would apply to future trends in cotton prices.

Much of the evidence discussed above relates to developing countries but similar results have been found in the developed world. Fernandez-Cornejo et al. (2000) describe the results of a US Department of Agriculture-funded survey of farmers growing Bt cotton in the USA. Farmers believed that there were many benefits to growing Bt cotton, such as higher yields, lower pest management costs and greater crop flexibility, and these findings are in line with a previous report by Klotz-Ingram et al. (1999). As with the results from the developing world, yields and net returns varied depending on regional issues, pest pressure, the type of variety and technology. The 2000 report was updated two years later in 2002 (Fernandez-Cornejo et al., 2002) and five years later in 2005 (Fernandez-Cornejo et al., 2005). In both of these updates it was confirmed that there had been a sustained increase in production due to the introduction of Bt cotton. However, Price et al. (2003) have highlighted the dependency that many cotton growers in the USA have on the marketplace. The report, also for the USDA, investigated the benefits of GM crops, including Bt cotton, grown in 1997. While Bt cotton did provide benefits, these were dependent on the supply and demand elasticity of the market, as well as year specific factors such as weather and pest infestation.

3.2.2 HT cotton

The literature on the economic benefits of HT cotton included in Carpenter (2010) was not as extensive as that for Bt cotton. Indeed, while HT cotton is economically beneficial to farmers, the HT characteristic is not the only explanation given for any observed improvement in yield and income. Surveys conducted for the USDA have reported that farmers believed that despite unidentified environmental issues associated with any HT trait there were many benefits, such as higher yields, lower weed management costs and greater crop flexibility (Fernandez-Cornejo et al., 2000, 2002, 2005). HT cotton was found to give statistically significant increases in yield and gross margin when compared with conventional cotton. Indeed, the 2002 USDA report (Fernandez-Cornejo et al., 2002) indicated that while there had been a sustained increase in cotton production due to the introduction of GM crops, the HT trait was the most rapidly adopted trait in the US and that the growth in production would continue unless consumer sentiment changed.

3.3 Maize

3.3.1 Bt maize

Work funded by the Rockefeller Foundation and Monsanto (Gouse et al., 2005) looked at the economic benefits of white maize in South Africa and arrived at the conclusion that, while the technology allowed for increased yields and reduced pesticide costs, it was inconclusive as to whether the gross margins obtained by farmers were significantly higher than for conventional maize. Gouse et al. (2006 and 2006a) explored the economic benefits of Bt white maize in KwaZulu-Natal, South Africa, and their results indicated that for the first two years of the three year survey the farmers enjoyed higher yields, and in the third year the yields for Bt maize were similar to the conventional maize varieties. The explanation given for this difference was that for the first two years the pest pressure was lower than normal but still at a significant level, whereas in the third year the pest pressure was very low. It was therefore concluded that Bt maize could be used as an insurance policy against potential pest infestation but it remains a high risk strategy given the cost of Bt maize seed (Gouse et al., 2006a). In addition, they pointed out that farmers do not base their judgement on how beneficial a variety is by yield per acre but rather by yield per kilogram of seed sown (Gouse et al., 2006). Indeed, using this method as the basis for comparison, Gouse et al. (2006) established that there was no real difference in yield between Bt maize and conventional maize. The lesson which emerges from this study is that the interpretation of such comparison-based studies should be handled with care. Another example is provided by a study located in the Philippines. An economic analysis of Bt maize grown in the Philippines suggested that while it did produce a higher yield and had lower insecticide costs relative to conventional maize, the findings were only based on one year of data (Yarobe and Denaux, 2006) and were thus subject to changes in technology and, more importantly, changes in the perception of both farmers and consumers. Concern over the interpretation of limited datasets was also expressed by Gouse et al. (2009) but this time in spatial rather than temporal terms. Their research continued the examination of maize production in South Africa summarised above by surveying 249 smallholders. Bt maize was found to increase the gross margin, on average, by 200% over conventional maize. However, when the data were separated to identify the benefits by region these varied materially so that in one region the conventional maize even outperformed the GM maize.

The European Commission has also been looking at the adoption of Bt maize in the EU. Gomez-Barbero (2008a), of the European Commission Joint Research Centre, examined the benefits gained by farmers in Spain from growing Bt maize. The report was based on surveys conducted in three regions of the country. Farmers experienced higher average yields with Bt maize relative to conventional varieties, although this was only statistically significant for one region, and the yields were dependent on local pest pressure. The increase in yield was directly related to the gross margin as the selling price remained the same for all varieties of maize regardless of genetic trait. The research did not account for soil type, irrigation and weather, even though these factors are known to play an important role. The report reached the conclusion that the benefits were solely attributed to the Bt trait. The introduction of Bt maize to Spain was also examined by Brookes (2002) and he acknowledges that there were increases in yield arising from the technology. These increases were subject to pest pressures, location, year, climatic conditions, whether and when insecticides were used, as well as the time of planting. Savings were also made as a result of reduced use of insecticides. Brookes (2002) asserted that relative profitability of Bt and conventional maize was ultimately dependent on the level of pest pressure.

3.3.2 HT maize

As with cotton, the literature on the economic benefits of HT maize in Carpenter's (2010) review was not as extensive as that for Bt maize. This may be in part because of the low adoption rate of HT maize, especially in the United States of America. Benbrook (2009) attributed this to the way in which the crop grows naturally: Maize grows quickly and produces a closed canopy early, reducing the light available to weeds. As a result the weed management of the crop is much simpler than other crops, and expensive weed management systems are consequently impracticable. Based on US Department of Agriculture data, Benbrook indicates that up until 2001 HT maize was only planted on 8% of the total maize acreage, although by 2009 this had increased to 22% for HT varieties of maize and 46% for stacked varieties of maize. Benbrook (2009) points out that the level of herbicide use per acre between 1996 and 2002 decreased but started to increase after that and was expected to rise by an estimated 2% per year between 2005 and 2008.

Outside of the USA, Gouse et al. (2009), working in South Africa, have reported that the yield of HT maize increased by 85% compared to conventional maize. For farmers, the gross margin is often a more relevant indicator of performance and it was established that farmers growing HT maize benefited, on average, with an improvement of 500% on their gross margins. However, as with Bt maize, care has to be taken in interpreting the results as once the data was separated to identify the benefits gained by farmers in each of the regions surveyed, the results were found to vary.

3.4 Soybean

3.4.1 HT soybean

The results of surveys of farmers growing HT soybean within the USA have suggested that there was limited economic benefit from growing these varieties (Fernandez-Cornejo et al., 2000, 2002, 2005). HT soybean was reported as giving statistically significant but small increases in yield and reduced herbicide costs. It was also reported that the size of the farm did not influence the yield advantage. A survey of farmers in the State of Delaware, USA, also found that they gained an increase in yield as well as other benefits from growing HT soybean (Bernard et al., 2004). However, this survey suggested that larger-scale producers tended to obtain more of a benefit in yield compared to small-scale farmers. This scale-effect supports the findings of a review of HT soybean production undertaken in the USA during 1997 (Falck-Zepeda et al., 2000). It must be noted that the Bernard et al. (2004) review only covered a relatively small area of the country, making extrapolation difficult.

The introduction of HT soybean has also been reported to enhance the yields obtained in other countries besides the USA. Brookes (2005a) describes the introduction of HT soybean in Romania. The article originated from a report published in 2003 which had been funded in part from Monsanto, and indicated that economic benefits were largely due to increased yield as a result of improved weed control.

Increased soybean yields can be produced not only by the introduction of the HT trait, but also through the parallel introduction of no-till practices (Qaim and Traxler, 2005). Tillage is the agricultural practice that agitates the soil, whether through digging, stirring or overturning and can result in soil erosion and reduction in the nutrients contained within the soil. The HT trait allows farmers to plant their seeds directly into untilled soil as weeds can be killed relatively easily and cheaply by the application of a broad spectrum contact herbicide, such as glyphosate, while the crop is in the seedling phase. With conventional varieties farmers have to produce a fine seed bed for pre-emergent herbicides to work effectively or use more expensive and selective herbicides once the crop had germinated. The use of a no-till regime should theoretically minimise costs to the farmer. Additionally, it should also minimise disturbance to the soil, thereby reducing soil erosion (Fu et al., 2006). The Council for Biotechnology Information, whose members are some of the leading biotechnology companies, issued a report written by Brethour et al. (2002), who examined the agronomic, economic and environmental effects of glyphosate-tolerant soybean in Ontario, Canada. The major market for Canada's HT soybean is the United States of America. However, Canadian farmers were not able to obtain the full economic benefits from growing HT soybean because of the fixed prices that US farmers' received for their produce, thereby making the Canadian product uncompetitive. To assist in overcoming this problem the farmers adopted no-till practices which helped to reduce costs. However, as the farmers did not keep adequate records it was not possible to obtain evidence of any savings. Nonetheless, the perception of the farmers was that the introduction of the HT variety in combination with no-till systems saved time and ultimately money. Similar research conducted by Marra et al. (2004) and funded indirectly by Monsanto, examined the net benefits of HT soybeans grown in the USA. While financial reasons were identified as playing a role in deciding to grow the varieties, non-financial reasons were also important in the decision making process. Safety, environmental benefits and convenience were all positive factors perceived by adopters of HT soybean. Non-adopting farmers perceived a negative net benefit. Adopting no-till practices was also identified as playing an important role in increasing net benefit.

3.5 Non-peer-reviewed literature

While the main focus of this literature review has been on peer-reviewed journal articles, it should be noted that there is a body of reports and other literature that may contain important information but which has not been peer-reviewed. These types of literature include research reports for government organisations (Acworth et al., 2008; Carpenter, 2001); research conducted by trade associations (Carlson, 1998); consultants for trade and other organisations (Benbrook, 2003); campaign groups; and farmer associations. Authors who produce such material often go on to publish the findings in peer-reviewed journals, and indeed the non-peer-reviewed literature is often included within the references employed for peer-reviewed articles and vice versa. Hence there is inevitably some overlap between the categories. An example is found in Gómez-Barbero et al. (2008a) for Bt maize in Spain, where the authors cite the non-peer-reviewed work of Brookes (2002). Perhaps unsurprisingly, the conclusions reached in non-reviewed sources often match those within the peer-reviewed literature. For example, both the Brookes (2002) and Gómez-Barbero et al. (2008a) studies arrived at similar conclusions; even with 6 years between the publication dates. They both reported that the impact on yield difference between Bt and conventional maize was dependent upon the level of pest pressure, location, year, climatic factors, and timing of planting, as well as the insecticide used and the time of its application. Another example is provided in the ISAAA 2009 report on GM crops grown in India (ISAAA, 2009), where the amount of Bt cotton produced for 2008 was given as 82% of the total Indian cotton crop and the reasons presented for this significant increase were identical to the benefits given within the peer-reviewed literature, namely that popularity of Bt cotton was driven by increased yields for Bt cotton due to a reduction in losses from pest attack and a reduction in costs from lower insecticide use.

4 Data availability

The database contains 196 publication entries which have provided 721 single study entries.[9] Of the 196 publications, 109 were designated as peer-reviewed, and 87 are non peer-reviewed sources. It has to be noted that this distinction can only serve as an estimate since the status of peer-reviewed journals and articles is not always clear. There are different kinds of articles published in journals which do not indicate directly whether they have undergone a peer-review process.

Asia and Europe are the most well represented continents, with a significant amount of studies in India (220) and China (70) for the former and in Spain (65) for the latter. South Africa accounts for 58 studies. The largest shares of North and South American studies included in the database were located in the USA (120) and Argentina (55).

Table 3 shows that among the four crops that have been selected for this study (maize, canola, cotton, soy), cotton followed by maize, especially Bt trait, are best represented in the database. In comparison to the other crops, soy offers the best opportunity to analyse the economic performance of the HT trait. However, as data on economic parameters are also scarce for soy, an assessment of HT traits could only be carried out to a limited extent.

Table 3. Number of studies included in the database, according to crop type and trait.

Crop type/ trait	Total*	HT	Bt
Maize	177	7	105
Canola	23	15	2
Cotton	454	22	237
Soy	67	37	7

** The total amount of studies includes comparison studies on conventional crops*

Among study types, reviews and field trials provide the most appropriate type of information and data formats to be inserted in the database. Reviews (218) offer the advantage of presenting relevant information in an aggregated and comparative form while field trials (288) provide a firsthand source of data. Surveys based on interviews (190) have also provided a significant part of data, even though it should be noted that for various reasons their objectivity is more difficult to ensure (see chapter 6).

In accordance with the findings of Smale et al. (2006), most of the available literature on farm-level impacts of GM crops found in the framework of this study is related to Bt cotton in China, India and South Africa. In a more recent comparison of economic performance between GM and conventional crops drawing from peer-reviewed publications reporting on farmer surveys, Carpenter (2010) also noted Bt cotton in India as the most frequently studied

[9] A comprehensive list of references of the consulted publications can be found in Annex G to this report.

case. In this analysis, results from India and the US were best represented followed by South-Africa and China. The available survey results used by Carpenter for her analysis could only cover "*less than half of the countries currently growing GM crops and are sparse for some already widely adopted technologies, such as GM herbicide tolerant corn and canola*". In accordance with similar indications given by Smale et al. (2006), in particular Brazil and Argentina (and thus HT soybean) are underrepresented (given the large area under GM crops in these countries) in the database. This study focused on publications written in English. It can be expected that most of the literature on GM crops from these countries is only available in Portuguese and Spanish. Moreover, many farmers have adopted GM crops under uncertain legal conditions, which might have made participation in scientific studies impossible.[10] These findings are in agreement with those of Contini et al. (2003), who note that there is no consistent information about the benefits of using transgenic seeds in Brazil. Similarly, Carpenter's recent analysis (2010) does not include any farmer survey results from Brazil.

In accordance with findings by Maciejczak (2008) a lack of publications on farm-level GM crop costs and benefits in Europe, except from Spain, was observed during the literature review. One obvious reason for the small number of publications lies in the low overall adoption rates of GM crops in Europe compared to other regions. Moreover, the focus of European research related to GM crops is rather on coexistence, public acceptance, or environmental impacts than on farm-level costs and benefits. The studies of Brookes seem to be the most comprehensive source for farm-level GM crop costs and benefits for Europe (e.g. Brookes 2002, 2003, 2007; Brookes and Aniol 2005), which has also been indicated by Maciejczak (2008). An additional problem was posed by the fact that a great share of the work in Europe has been published in the form of reports or conference papers, which were no longer available or are even based on mere personal communication (as stated in some overview articles).

A similar problem occurred related to the availability of publications for Bt cotton in developed countries. The most important communication channel of costs and benefits of Bt cotton on the farm-level have been conference proceedings (e.g. the Beltwide Cotton Conference). However, most of the issues of the conference proceedings are no longer available. Therefore, numerous data sources for GM cotton are not included in the database, even though they are frequently cited in the literature. In addition, a general lack of available sources was observed for farm-level data of Bt maize for developed countries. In agreement with Gómez-Barbero and Rodríguez-Cerezo (2006), a particular lack of available observations was found for the USA, though it is the main adoption country of Bt maize. This lack of available data has led to an under representation in the database of farm-level costs and benefits from GM crops in the developed world.

In conclusion, the number of available publications in the database does not necessarily reflect the prevalence of a specific GM crop, or the GM crop adoption in a specific country. The encountered lack of observation is in agreement with other the findings of several other researchers. In order to overcome these problems, several conference proceedings have to

[10] Many farmers in South America use GM seeds from the black market. Moreover, Brazilian farmers have already adopted GM crops before the official ban of GM crops was lifted.

be made available and additional literature search has to be conducted in much more languages than English.

Interviews

The purpose of the interviews was to provide further insights from key informants as to the causes of variation across space and time as well as to help identify reasons for any contradictory results that were observed. A total of 108 email invitations were sent to the authors of articles, farming associations and government departments. From these, a total of 42 positive responses were received which resulted in 23 answering the eight initial questions (See appendix H, Table 30) or telephone questions.

Table 4. Summary of invitations and contacts

Description	Total
Initial email invitations issued, of which:	109
(1) Invitations declined	5
(2) Bounced emails	8
(3) No replies	54
(4) Positive response to invitation to which initial questions were then sent, of which:	42
(a) Email replies to the questions (plus telephone interviews)	10(5)
(b) Interviewed in person	4
(c) Telephone interviews	9
(d) No replies to questions	19

The response rate to the initial invitation was relatively good at 39%, but the response rate for the questions was poorer (21% of invitations).

5 Data analysis

In this chapter, the results of the data analysis undertaken in this study are presented. The chapter is divided by crop type: cotton (5.1), maize (5.2) and soy (5.3). Sufficient data was available to conduct regression analyses for Bt cotton and Bt maize. For HT soy, plots and descriptive statistics are presented but no regression analysis was possible due to a lack of data (see chapter 4 and section 6.2.3). Sections 5.1 to 5.3 are organised as follows: after giving a general overview on the main results, figures and regression results from all of the countries (i.e. at the global scale) are presented and discussed. Subsequently, country specific analyses are presented.

5.1 Data analysis for Bt cotton

Overview of main results

Effects of Bt cotton on economic performance indicators vary greatly from country to country, particularly due to the differences in pest management practices. In countries such as India, where pest management is not well-established, corresponding to low yield levels, the benefits from growing Bt Cotton were highest because of yield increases (of up to 50%) due to reduced yield losses. In contrast, countries with rather high yield levels and well-established pest management, such as Australia or the USA, benefitted most from reduced pesticide costs (16%-70%). In most cases, reduced pesticide costs and/or higher yields of Bt Cotton outweigh higher seed costs (in the range of 30%-230%). In countries where crops are well adapted to local conditions and pesticide control is efficient (e.g. Australia), Bt cotton shows the lowest net-benefit.

Graphical analysis

Figure 6 to 10 in Annex C show the economic performance indicators for cotton (i.e. yield, gross margin, seed costs, pesticide costs, as well as management and labour costs) by year, country and trait (GM and conventional crop).

In general, the figures show a large amount of heterogeneity within each of the economic performance indicators. This heterogeneity is caused by country-specific effects (e.g. yield levels in China generally seem to be higher than in the USA), variation over time (e.g. the yield levels seem to generally increase over time) and differences between Bt and conventional cotton. These aspects are empirically addressed in the following sections.[11]

[11] Test exercises showed, that climatic conditions, measured by variable ‘climate zones’ (see overview in parameters in Annex B), had no influence on the economic performance indicators and were therefore not included in the regression analysis.

Regression analysis of the economic performance indicators across all countries

In order to explain the heterogeneity within the observations, the regression model (see the equation in section 2.4) is used. Results from this model are shown in Table 5.

Table 5. Parameter estimates from the regression models on different economic performance indicators for cotton

Economic performance indicator	Yield model	Gross margin model[1]	Seed costs model	Pesticide costs model	Manage-ment and labour costs model
Variable	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)
Intercept	6.400 (36.45)***	5.641 (11.17)***	2.863 (10.49)***	3.776 (15.91)***	4.970 (21.50)***
Time Effect	0.085 (3.97)***	0.163 (1.98)**	0.038 (0.95)	0.117 (3.30)***	0.069 (1.50)
Bt Effect	0.463 (2.31)**	0.863 (2.05)**	0.979 (5.41)***	-0.482 (-2.29)**	-0.196 (-0.84)
Bt Effect * Time Effect	-0.01 (-0.73)	-0.109 (-1.33)	0.028 (0.84)	-0.003 (-0.01)	0.069 (1.34)
Adjusted R-squared	0.28	0.11	0.73	0.65	0.77
Degrees of freedom	292	172	105	164	98

*In order to allow for logarithmic regression, all gross margin observations are transformed in a way that all observations are above zero, with the lowest observation equal to 0.0001. *, **, and *** denote significance at the 10, 5, and 1% levels, respectively. The absence of notation indicates no significance at the 10% probability level. Note that the logarithm of the dependent variables is taken in the regressions, and the coefficient estimates thus represent percentage effects of the independent variables (i.e. the percentage change of the dependent variable due to a one unit increase in the independent variable). Error degrees of freedom are presented.*

The coefficient estimates of the regression model in which the dependent variable is the logarithm of the economic performance indicator can be interpreted as a percentage effect on the economic performance indicator: For instance, the coefficient estimate for the Bt effect of 0.463 in the yield model shows that Bt yields are, on average, 46% higher than conventional yields. The 0.085 for the time effect show that, on average, yields increase by 8.5% per year in all of the observed countries.

Time effect. Significant increases of cotton yields, gross margins and pesticide costs over time (time effect) can be observed across all observations, whether GM or non-GM crops. In addition, time effects are positive but insignificant for seed costs and management and labour costs. Increasing yields and costs might reflect general technological advances in agriculture that result in increasing yield levels and input costs (see e.g. Hafner, 2003, Khush, 1999, and Oerke and Dehne, 1997 for discussions on global trends in crop yields).

Bt effect. There are significant Bt-effects for all of the parameters except for management and labour costs at the global scale. The results suggest higher yield levels (of about 46%) for Bt cotton, but lower pesticide costs and management costs (insignificant) in the range of 48 and 20%, respectively. However, there is evidence of higher seed costs (up to twice as high) for Bt than for conventional cotton. In total, this results in gross margins that are significantly higher for Bt than for conventional cotton, i.e. about 86%. However, the exact values must be interpreted cautiously, particularly because of the unbalanced dataset concerning observations from India and some influential (leverage) observations that might determine the magnitude of coefficient estimates (see country specific analysis below).

Bt effect over time. The interaction between Bt and time effect is not significant for all of the economic performance indicators. Thus, the estimated Bt effects are expected to remain stable over time.

Country specific analysis of economic performance indicators

a) Analysis of economic performance indicators within countries

The country specific analysis allows for an analysis of the effects of Bt cotton on the economic performance indicators within a country and also shows the different GM crop effects between countries, see Table 6. To provide more explanations about the variations in economic performance indicators between countries, main findings from the literature are also highlighted. Due to the lack of observations for some variables and countries, results should be interpreted cautiously.

Yields. The analysis shows that the biggest yield advantages are observed for India, followed by South Africa, China, and then by Australia and the USA. Only in the case of India can a significant Bt effect on yields be observed (i.e. higher yields for Bt than for conventional cotton). For the other countries, the Bt yield effect is positive, but insignificant in statistical terms. The estimated Bt yield effect ranges from almost zero (USA, Australia, China) to about 50% (India). The results are in line with the review undertaken by Carpenter (2010) which observed an overall increase for Bt cotton in India even though some samples also showed declines in yields. India also represented the most frequently studied case in that review.

Table 6. Economic performance indicators by country for Bt and conventional cotton

Country	Trait	Economic performance indicator				
		Yield	Gross margin	Seed costs	Pesticide costs	Management and Labour costs
India	Conv	1315.31 (N=96)	294.09 (N=55)	24.13 (N=27)	113.89 (N=47)	221.69 (N=38)
	Bt	1982.77 (N=76) ***	389.52 (N=42)*	80.43 (N=27)***	79.73 (N=37)***	305.86 (N=26)***
	% Change	50.75	32.45	233.38	-29.99	37.97
China	Conv	2277.27 (N=15)	295.11 (N=24)	49.08 (N=6)	163.96 (N=7)	1163.98 (N=12)
	Bt	2342.89 (N=27)	-58.67 (N=17)***	62.93 (N=7)	46.48 (N=9)***	939.94 (N=19)***
	% Change	2.88	-119.88	28.23	-71.65	-19.25
South Africa	Conv	879.57 (N=7)	50.22 (N=5)	20.09 (N=5)	30.33 (N=7)	43.34 (N=3)
	Bt	1133.00 (N=7)	107.47 (N=5)*	39.53 (N=5)***	14.66 (N=7)***	43.19 (N=3)
	% Change	28.81	114.02	96.76	-51.66	-0.34
Australia	Conv	1764.31 (N=13)	n.a.	n.a.	326.70 (N=13)	n.a.
	Bt	1788.59 (N=13)	n.a.	112.9583 (N=6)	254.79 (N=13)**	n.a.
	% Change	1.38	n.a.	n.a.	-22.01	n.a.
USA	Conv	1055.92 (N=20)	1047.19 (N=17)	36.19 (N=16)	138.39 (N=17)	n.a.
	Bt	1064.63 (N=16)	938.46 (N=13)	116.54 (N=13)***	116.23 (N=13)	n.a.
	% Change	0.82	-10.38	222.04	-16.01	n.a.

*N denotes the number of available observations; n.a. signifies that no observations have been available. Comparisons are made using the Mann-Whitney-U test. *, **, and *** denote significance at the 10, 5, and 1% level, respectively. The presented numbers are mean values.*

Compared to India, lower yield advantages from Bt cotton adoption could be observed for China and South Africa (see e.g. Huang et al., 2002 and 2003 for data on China, and Carpenter, 2010). For South Africa, it was shown that even if farmers growing Bt cotton reach higher yields than conventional growers (Bennett et al., 2004), it would not lead necessarily to economic advantages (Thirtle et al., 2003). Therefore, the authors of the latter study suggest that for more meaningful results, the seeding rates of both adopters and non-adopters should be compared instead of focussing solely on absolute yield differences, since Bt cotton growers often use less seed per hectare.

The yield increases after Bt adoption are often related to reduced yield losses rather than to higher amounts of biomass being produced. Hence, countries with appropriate pest control mechanisms such as Australia or the USA do not witness significant yield increases with Bt cotton. The results presented here are consistent with findings from other authors in previous studies. For example, Acworth et al. (2008) and Fitt (2003) in Australia, as well as ReJesus et al. (1997) in South Carolina, USA, Marra et al. (1998) in North/South Carolina, USA, and Bryant et al. (2003) in Arkansas, USA do not report any yield increases of Bt cotton in comparison to conventional cotton. However, other studies did report higher yields of Bt cotton, for instance Gibson et al. (1997) in Mississippi, Bryant et al. (2003) (for two of the three years examined), Marra et al. (1998) for Georgia and Alabama as well as Price et al. (2003) for farmers in the Mississippi Portal and Southern Seabord. These contrasting results show that yields also depend on regional conditions and possibly also seasonal variations which often create ambiguous conclusions.

Pesticide costs. Table 6 shows lower pesticide costs for all of the countries (though not significantly for the USA). China is the country for which Bt cotton adoption shows the strongest effect on pesticide costs, followed by South Africa, India, Australia and the USA. Reductions in pesticide costs range from 16% in the USA to about 70% in China. In China, cotton bollworms (*Helicoverpa armigera*) have been a major problem for cotton production; rising pest infestation has led to a sharp increase in pesticide use (Huang et al., 2002). Therefore, the adoption of Bt cotton could significantly reduce pesticide costs (and pesticide applications) (Pray et al., 2001, Huang et al. 2002, Huang et al., 2004). Obviously, if farmers do not use pesticides at all or only to a limited extent, the adoption of Bt cotton would have less influence on pesticide costs but could possibly benefit yields due to more effective pest control. For instance, Qaim and Zilberman (2003) show that yield effects of Bt cotton adoption in Argentina are higher than in other countries, particularly due to the generally low level of insecticides used in this country. Even if relative pesticide cost savings are similar to other countries, these savings are much lower in absolute terms.[12]

Seed costs. Significantly higher seed costs for Bt can be observed than for conventional cotton in India, South Africa and the United States. A positive but insignificant Bt effect on seed costs is indicated for China. The estimated mark-up of seed costs for Bt cotton range from 28% (China) to more than 200% (in India and the USA).[13] Possible reasons for the

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[12] Due to the low number of observations, Bt cotton data for Argentina are not statistically analysed.

[13] Gómez-Barbero, Berbel and Rodriguez-Cerezo (2008) note that different price markups are related with regional pest hazard. In addition, market structure is expected to play a major role in determining price markups (e.g. Acquaye and Traxler, 2005).

insignificant differences in seed cost in China are given by Pray et al. (2001) and Huang et al. (2004), who observed a significant difference between the market prices and the seed prices actually paid by farmers. As Bt farmers save seed and need less seed per hectare compared to conventional cotton growers, they can partly offset seed price differences. It is possible that the results presented here for seed cost differences in India do not depict the current situation on the Indian Bt seed market. Due to governmental intervention, seed prices for Bt cotton strongly decreased in 2006/07 (price mark-up declined to 68%) resulting in its current price being similar to seed prices paid by Chinese farmers (Sadashivappa and Qaim, 2009).

Management and labour costs. Compared with conventional cotton, management and labour costs for Bt cotton are higher in India and lower in China. In India, Qaim et al. (2006) observed an increase in other variable inputs (e.g. fertilizer) and workload for crop maintenance and harvest of Bt adopters. Bt cotton adoption in China lead to a decline in pesticide applications from an average of 20 times to 8 times per crop season; thus are not only pesticide costs reduced, but labour is also saved (Huang et al., 2004).

Gross margins. Gross margins for Bt cotton as compared to conventional cotton are slightly, although insignificantly (below the 5% level of significance) higher for India and South Africa. No significant difference could be detected for the United States, whereas in China gross margin for Bt Cotton is lower than for conventional cotton.

b) Comparisons of economic performance indicators between countries

In *India*, under the assumption that there are similar prices for Bt and conventional cotton, increasing yields lead to higher revenues and lower pesticide costs that in turn offset higher seed, management and labour costs. Furthermore, product quality increases with the adoption of Bt cotton, resulting in an additional net benefit for farmers (Barwale et al., 2004). At first glance, the low effect of Bt cotton on gross margins seems to contrast with the regression results. However, the regression analysis took both the Bt effect and its (declining) development over time into account, which could not be detected in the country specific analysis due to the small sample sizes.

In *China*, where yield levels were are already high, the main benefits of Bt cotton can be derived from cost savings due to lower pesticide use. While yields in terms of biomass produced are similar between Bt and conventional cotton, pesticide, management and labour costs are substantially reduced. However, results of this analysis show that, on average, higher seed costs could not be offset in China, resulting in lower average gross margins.

While in India yield increases seem to correspond with a higher need for labour (e.g. because of increased workload for harvesting), in China Bt cotton adoption lead to substantial reductions in labour and management costs due to more efficient crop management. In general, these findings are in agreement with the large differences in performance and cost parameters between the countries reported in Brookes and Barfoot (2009).

In *South Africa*, yields are higher for Bt cotton adopters than for non-adopters, and pesticide costs are significantly reduced (see also Ismael, Bennett and Morse, 2002; Bennett et al. 2004). Shankar and Thirtle (2005) observed that even when seed costs for Bt cotton in South Africa are double the price of conventional seeds (see table 6 and Ismael, Bennett and

Morse, 2002), smallholders are offsetting the extra costs by lowering the seeding rate per hectare. On average, this results in higher gross margins for Bt cotton growers.

In the *USA*, the advantages of Bt cotton adoption are not entirely clear. Besides advanced pest control measures already in place, farmers can choose between a wide range of conventional varieties that are well-adapted to local growing conditions. Studies conducted by Bryant et al. (2003) and Jost et al. (2008) found that the profitability of cotton production strongly depends on the yield that is reached in particular regions which is not strictly related to the technology applied. Above all, the authors therefore suggest that farmers select the variety that has the highest yield potential under local conditions instead of choosing between GM and conventional crops.[14]

5.2 Data analysis for Bt maize

Overview of main results

Seed costs of Bt maize are higher (10%-36%) and pesticide costs are lower (25%-60%) than that of conventional maize. However, yield levels are higher (5%-25%) for Bt compared to conventional maize. In the majority of cases, higher seed costs can be offset by higher yields and/or lower pesticide costs, resulting in higher gross margins (10%-17%) for farmers. The overall effects (i.e. over all countries) of Bt maize on pesticide costs and yield levels are lower than for Bt cotton. This difference might be explained by the already well adapted varieties and pest management measures available in countries where Bt maize is mostly grown (e.g. in Spain). Moreover, the results indicate a significant variance of Bt maize effects between seasons and depending on the regions where the crop is grown.

Graphical analysis

Figure 11 to 15 in Annex D show the economic performance indicators for maize (i.e. yield, gross margin, seed costs, pesticide costs, as well as management and labour costs) by year, country and trait (Bt and conventional crop).

Most observations are available for yield and seed costs. For gross margins, the small amount of observations does not allow for regression inference. The plots indicate that the heterogeneity within the data is mainly caused by country specific effects.

[14] There are potential benefits from Bt cotton that are not covered by our analysis of economic effects but that are frequently mentioned in the literature. These are related to health effects and reduced environmental pollution (Ismael, Bennett and Morse, 2002, Thirtle et al., 2003). However, many of the environmental benefits depend on the type of insecticides used and how farmers perceive their pest problem (Bennett et al., 2004).

Regression analysis of the economic performance indicators across all countries

In order to explain the heterogeneity within the observations with regard to time trends and Bt effects, the regression model (see the equation in section 2.4) is used. The results are shown in Table 7.[15]

Table 7. Parameter estimates from the regression models on different economic performance indicators for maize.

Economic performance indicator	Yield model	Seed costs model	Pesticide costs model	Management and labour costs model
Variable	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)
Intercept	9.408*** (72.96)	5.331 (37.77)***	2.965 (3.86)***	6.452 (41.35)***
Time Effect	-0.012 (-0.57)	-0.090 (-1.85)*	-0.086 (-0.28)	-0.013 (-0.17)
Bt Effect	0.039 (0.22)	0.479 (2.56)**	-0.667 (-0.75)	0.051 (0.26)
Bt Effect * Time Effect	0.012 (0.51)	-0.109 (-2.27)**	-0.231 (-0.86)	-0.014 (-0.11)
Adjusted R-squared	0.33	0.78	0.54	0.96
Degrees of freedom	71	45	39	19

, **, and * denote significance at the 10, 5, and 1% level, respectively. Note that the logarithm of the dependent variables is taken in the regressions, and the coefficient estimates thus represent percentage effects of the independent variables (i.e. the percentage change of the dependent variable due to a one unit increase in the independent variable). Error degrees of freedom are presented*

Time effect. The results in Table 7 show that there is no significant change in any of the economic performance indicators over time (except for seed costs, showing a slight reduction over time at the 10% significance level). Increases over time in maize yields were expected, at least for most parts of the developed world (see e.g. Finger, 2010 and Hafner, 2003). However, such a trend could not be affirmed by the results of the analysis, partly because of the short time period of observations for Bt maize plantings (the database covers the period 1997-2007) and specific country effects.

[15] Note that two observations for Germany are not considered in the regression analysis because it was impossible to determine the year of the study.

Bt effect. Seed costs for Bt maize are significantly higher than for conventional maize (about 48%). Yields, pesticide costs and management and labour costs do not significantly change with the adoption of Bt maize. The results suggest that Bt maize leads to slightly higher yield levels than conventional maize; pesticide costs are lower.

Bt effect over time. No significant interaction effects could be found for yield or pesticide costs, or for management and labour costs. The analysis also indicates that the seed cost mark-up for Bt maize is declining over time. However, this is mainly due to the fact that seed costs were very low in some European countries in 2007 leading to a leverage effect of observations.

Analysis of economic performance indicators within and between countries

As for cotton, the effects of Bt maize on economic performance indicators are analysed for each specific country. The results are presented in Table 8.

Table 8. Economic performance indicators by country for Bt and conventional maize

Country	Trait	Economic performance indicator				
		Yield	Gross margin	Seed costs	Pesticide costs	Management & Labour costs
Spain	Conv	11840 (N=19)	1214 (N=5)	186.30 (N=12)	23.68 (N=11)	n.a.
	Bt	12500 (N=17)	1333 (N=5)	204.80** (N=13)	10.38** (N=10)	n.a.
	% change	+5.6	+9.8	+9.9	-56.2	n.a.
Germany	Conv	8921 (N=11)	36.50 (N=2)	142.70 (N=11)	117.50 (N=9)	631.00 (N=9)
	Bt	10010 (N=9)	88.50 (N=2)	166.60** (N=8)	88.63** (N=7)	673.7 (N=7)
	% change	+12.2	+142.5	+16.7	-24.6	+6.8
South Africa	Conv	7124 (N=12)	n.a.	n.a.	19.35 (N=5)	n.a.
	Bt	8874 (N=12)	n.a.	n.a.	8.49 (N=4)	n.a.
	% change	+24.6	n.a.	n.a.	-62.4	n.a.
Argentina	Conv	n.a.	62.81 (N=4)	69.3 (N=4)	n.a.	46.20 (N=4)
	Bt	n.a.	73.44 (N=4)	94.5** (N=4)	n.a.	46.00 (N=4)
	% change	n.a.	+16.9	+36.4	n.a.	0%

*N denotes the number of available observations; n.a. signifies that no observations have been available. Comparisons are made using the Mann-Whitney-U test. *, **, and *** denote significance at the 10, 5, and 1% level, respectively. The presented numbers are mean values.*

The available literature was reviewed to explain differences both between and within countries. Again, the lack of observations for most variables and countries requires a careful interpretation of the statistical results.

Yields. As indicated by the regression model, higher (but insignificant) yield levels for Bt than for conventional maize can be observed. For Spain, yield increases due to Bt maize adoption were on average approximately 6%, for Germany around 12% and for South Africa about 25%. The result for Spain[16] is in line with Brookes (2009), who estimated an average yield advantage of 6.3% between 1998 and 2003 and of 10% from 2004 onwards. However, yield advantages within a country vary over time and space. A survey conducted by Gómez-Barbero et al. (2008a, 2008b) in Spain over three years (2002-2004) shows yield differences between -1.3% in 2003 in Albacete to +12.1% in Zaragoza in 2002. Highly heterogeneous results (depending on region, infestation level and the effectiveness of common pest management practices) are also reported in German studies. While most studies show higher yields for Bt maize compared to conventional crops (e.g. Degenhardt et al., 2003, Schiefer, 2008, Schiefer et al., 2008 using a survey) others did not find any significant differences (Schiefer et al., 2008 by means of field trials). In Germany, Bt maize adoption seems to be most beneficial in the Oderbruch region (with high infestation levels), which is supported by the fact that it is the most important growing region for Bt maize in Germany (BVL, 2010). In South Africa, higher yields seem to be more stable over time and across regions as compared to Spain and Germany. Gouse et al. (2005 and 2006) show higher yield levels of smallholders as well as large commercial farmers who grew GM maize during the growing seasons of 2000/01 to 2003/04, even when farmers did not report high stem borer infestation levels before the adoption of GM crops (Gouse et al., 2005). Nevertheless, Gouse et al. (2006) also showed that yield benefits for Bt maize declined after three years of dry conditions and low stalk borer infestation levels.

Pesticide costs. The results indicate lower pesticide costs for Bt maize in all analysed countries, but significant effects were only observed in Spain and Germany. As for yields, pesticide reductions in Spain vary widely between regions. For instance, Gómez-Barbero et al. (2008) show that farmers in Albacete and Zaragoza only bore 33% and 37% of the pesticide costs of conventional maize growers, whereas in Lleida no reductions in pesticide cost were observed. Consmüller et al. (2009) reports that the ability to significantly reduce pesticide costs (see also Schiefer, 2008 and Schiefer et al., 2008) were mentioned as the main motive for the adoption of Bt maize by German farmers, reflecting the fact that other available pest control measures have not proved effective. Non-adopters argue that they could use other effective measures to control pests and therefore did not see a need to switch to Bt maize. In South Africa, the reduction of pesticide costs was highest in irrigated areas where the moist conditions favour insect growth and reproduction (i.e. high infestation levels) (Gouse et al., 2005).

Seed costs. Significantly higher seed costs were found for Bt compared to conventional maize in Spain, Germany and Argentina. Bt seed cost mark-ups range from 10% (Spain) to 36% (Argentina). In Spain, seed costs vary between regions because of differences in seed suppliers' pricing policies for the (formerly) two available Bt maize varieties (Bt 176 and MON

[16] See Gómez-Barbero et al. (2008a, 2008b) for an overview of economic performance of Bt maize in Spain.

810)[17], the bargaining power of farmers[18] and price discrimination (Gómez-Barbero et al., 2008). In general, seed prices are lower in regions where yield surpluses from GM crops are lowest (e.g. Brookes, 2007, Gómez-Barbero et al., 2008). The data for Germany show almost 17% higher seed costs for Bt than conventional maize. A study conducted in Saxony (Schiefer et al., 2008) revealed that costs for Bt seed per hectare were comparably low, because discounts were given and seed densities applied in the field were lower than for conventional maize. For South Africa, no seed cost data is available, but Gouse et al. (2005) found that differences in seed cost are dependent on the seed company. Bt seed might be offered free of charge by a seed company (e.g. Gouse et al., 2005), particularly because smallholders were not able to afford it (Gouse et al., 2005).

Management and labour costs. Data about management and labour costs are only available for Germany, showing increases after adoption of Bt maize that mainly relate to additional effort for cleaning the machinery used for Bt maize (Schiefer et al., 2008). On the other hand, the analysis of Brookes (2002) indicated an increased flexibility and convenience of crop management, reductions in contractor costs for spraying as well as reduced production risks due to the adoption of Bt maize in Spain. In South Africa, reduced labour and fuel costs could be observed for large commercial farmers because less pesticide applications were needed and less time was spent scouting fields. (Gouse et al., 2005).

Gross margins. The few observations of gross margins show some advantages of Bt over conventional maize, indicating that, on average, higher seed costs could be offset by higher yields and/or lower pesticide costs. In Spain, the main reason for gross margin differences derive from yield effects (Gómez-Barbero et al., 2008). German farmers benefit from higher yields (leading to higher gross margins), particularly where commonly used pest control measures were not effective (Consmüller et al., 2009). Schiefer et al. (2008) show that pest pressure (also affected by weather conditions) is one of the most important determinants for the (potential) benefit of Bt maize in Germany. In South Africa, the main advantage of Bt maize for farmers was higher yields, while the higher quality of the product was also important (Gouse et al., 2005). However, in growing seasons with low pest pressure, Bt growers are worse off than conventional farmers because Bt maize, in this case, does not provide for higher yields and seed costs remain higher (Gouse et al., 2005,2006). Quality advantages, i.e. a reduced mycotoxin content of Bt maize, were also observed in Germany (Consmüller et al., 2009, Schiefer, 2008, Schiefer et al., 2008) and can potentially contribute to higher gross margins.

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[17] Also Brookes (2007 and 2003) mentioned seed cost differentials dependent on the seed supplier.

[18] For instance, Demont and Tollens (2004) mentioned that many farmers pay lower prices through local cooperatives.

5.3 Data analysis for HT soybean

Main results for HT soybean

Only low yield effects of HT soybean have been observed worldwide. Results also show that reduced herbicide costs (and other cost reductions, e.g. through adoption of no-till farming) outweigh higher seed costs for HT soybean.

Data for HT soybeans is only available for Argentina, Brazil, Romania and the USA. Figure 16 to 20 (Annex E) show the economic performance indicators for soybean (i.e. yield, gross margin, seed costs, pesticide costs, as well as management and labour costs) by year, country and trait (HT and conventional crop).

Since the number of observations is smaller than 30 for all of the economic performance indicators, useful regression inference could not be carried out. Consequently, the results of the country specific analysis presented here have to be interpreted with care. In general, no significant differences in economic parameters between HT and conventional soybeans have been found. The results indicate that HT soybeans have slightly higher seed costs and lower herbicide costs, as well as lower management and labour costs. No straightforward effect of HT on soy yields could be found.

Other studies that analyzed the effects of HT soybeans for the highest volume countries, such as the USA, Argentina, Brazil and Canada (e.g. summarised by Brookes and Barfoot, 2009), show no particular effect of HT soybean on soy yield levels. In Romania, however, poorly applied weed management for conventional production led to much higher yields for HT soybeans (Brookes, 2003b).

In general, significant price mark-ups for HT soybean seeds can be detected in many countries (e.g. Marra et al., 2002, Carpenter and Gianessi, 2001). However, price mark-ups of GM seeds also depend on the legal framework of the country. For example, in Argentina, where intellectual property rights are less enforced and farmers are partly allowed to retain seeds after harvest, seed prices do not differ much (Qaim and Traxler, 2005, Trigo and Cap, 2003). In other Southern American countries, where black markets for seeds are flourishing, price differences hardly occur (Traxler, 2006).

Reduced herbicide costs have been reported for all countries adopting HT soybean (Brookes and Barfoot, 2009). In some regions, especially in Argentina (e.g. Finger et al., 2009) the adoption of HT soybean eases and often leads to shifts in farm practices towards no-till farming and/or double-cropping. No-till has the potential to reduce labour and fuel costs while double-cropping enables higher yields through prolonged cultivation periods.

Table 9. Economic performance indicators by country for Ht and conventional soybean.

Country	Trait	Economic performance indicator				
		Yield	Gross margin	Seed costs	Herbicide costs	Management & Labour costs
Argentina	Conv	2705 (N=4)	184.24 (N=15)	19.1975 (N=4)	22.31 (N=4)	162.16 (N=1)
	Ht	2927.5 (N=4)	191.2313 (N=4)	34.9* (N=4)	16.9* (N=4)	152.39 (N=1)
	% change	8.2	3.8	81.8	-24.2	-6.0
Brazil	Conv	2159.05 (N=2)	-29.56 (N=1)	46.535 (N=2)	94.985 (N=2)	11.31 (N=2)
	Ht	1973.135 (N=2)	-56.89 (N=1)	43.785 (N=2)	33.835 (N=2)	9.995 (N=2)
	% change	-8.6	92.5	-5.9	-64.4	-11.6
USA	Conv	3074.86 (N=1)	384.525 (N=4)	42.295 (N=4)	73.6675 (N=4)	267.71 (N=1)
	Ht	2684.65 (N=1)	541.205 (N=4)	63.825 (N=4)	50.20333* (N=3)	104.29 (N=1)
	% change	-12.7	40.7	50.9	-31.9	-61.0
Romania	Conv	2350 (N=2)	368.775 (N=2)	48.395 (N=2)	148.02 (N=2)	n.a.
	Ht	3075 (N=2)	146.89 (N=2)	126.544* (N=5)	60 (N=2)	n.a.
	% change	30.9	-60.2	161.5	-59.5	n.a.

*N denotes the number of available observations; n.a. signifies no available observations. Comparisons are made with the Mann-Whitney-U test. *, **, and *** denote significance at the 10, 5, and 1% level, respectively. The presented numbers are mean values.*

6 Critical analysis on the limitation of available data and the conclusiveness of results

6.1 Objectives of the analysis

Methods employed to determine GM crop performance have a strong influence on the results and outcomes. Regardless, surveys of the methods and their limitations are still rare (Smale et al., 2009). However, understanding the advantages and disadvantages of different methods can enhance the comprehension of available research findings and their further applications (e.g. up-scaling of farm-level results).

While there have been several attempts to conduct overall analyses of GM data (e.g. Marra, Pardey and Alston, 2002; Smale et al., 2008, Carpenter, 2010), empirical sensitivity analyses with regard to potential limitations of available data are not applied. Therefore, this analysis makes the first empirical attempt to test sensitivities in terms of the differences in data quality between studies on GM crop performance. The aim of this critical analysis of data sources is to discuss the strengths and weaknesses of the different methods applied.

In general, data sources (study types) for ex-post performance analyses of GM crops can be categorized into three classes:

- field trials,
- surveys, and
- modelling approaches.

The first part of the analysis is based on a literature review on data quality of GM crop performance estimations, providing an outline of relevant points to be addressed in further research. The different study types listed above are further characterized in section 6.2, followed by a discussion on several aspects of data quality and potential biases in estimates of GM crop performance on farm level (sections 6.2.3 to 6.2.5). Based on the discussion, hypotheses are developed stating how potential limitations of available data might influence the GM crop performance estimates and thus the conclusiveness of results.

Finally, in section 6.3, selected hypotheses are tested using the data from the database. Graphical presentation of the sensitivity analyses can be found in Annex F. Empirical analysis was restricted to Bt Cotton, representing the most abandon trait in the database.

The test approach follows four steps as follows:

(1) Descriptive statistics were used to explore the overall data availability. Furthermore, a correlation analysis was conducted to check for possible multi-colinearity problems in the regression (see point 4 further below).

(2) The data were plotted, as in the previous data analysis in chapter 5, but this time indicating the different study types (interview, field trials, reviews) and study conductors (company, public). The plots are shown in Annex F.

(3) Mann-Whitney U Tests were conducted to compare the different economic performance indicators for Bt and conventional crops for the different study types and study conductors (see section 2.4 for description and reasons for using this particular test).

(4) In order to take time trends and country specific effects into account, a regression analysis has been applied. To this end, the regression models of the trend analysis (section 2.4) have been extended by integrating study type and study conductor as dummies[19] into the regression model separately.[20] In addition, the interaction effects with the respective GM crop are considered in the models. Hence, the model for study type (and similarly for study conductor) is specified as follows:

$$Log(Y) = \beta_0 + \beta_1 \text{ Year} + \beta_2 \text{ Dummy\_Bt} + \beta_3 \text{ Year} * \text{Dummy\_Bt} + \beta_4 \text{ Dummy\_Country} + \beta_5 \text{ Dummy\_Study Type} + \beta_6 \text{ Dummy\_Study Type} * \text{Dummy\_Bt} + \varepsilon$$

In contrast to the trend analysis (see section 2.4), this analysis aims to test for differences in the economic performance indicators depending on different study types and study conductors. Therefore only the parameters β_5 (indicating the different levels of economic performance indicators with study type and study conductor respectively), β_6 (indicating the Bt effect dependent on study type and study conductor respectively) are used. Both variables, study type and study conductor, enter the model as dummy variables. Study type is divided into field trials, surveys, and data from other study types. Study conductor is divided into public institution and company.

6.2 Definition and characterization of different study types

Ex-post assessments of farm-level impacts of GM crops are based on field trial data (off-farm and on-farm field trials) and survey data (farm-level and field-level surveys) (see Table 10 for a summary of different study type characteristics).

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[19] The dummy for the study type distinguishes between surveys, field trials and others, respectively. A dummy for the study conductor is used to distinguish public institutions (e.g. universities, governments) and companies.

[20] Multicollinearity (i.e. correlations between study conductor and study type) preclude a regression model with both variables.

Table 10. Characteristics of different study types

Characteristics	Type of study			
	Off-farm field trial	On-farm field trial	Farm-level survey	Field-level survey
Place of the study	Off-farm	On-farm	On-farm	On-farm
Level of study	Experimental plots	Local to regional	Local to regional	national
Type of conductor	Private seed companies and public research bodies	Private seed companies and public research bodies	Public research bodies	Governmental authorities
Interest of research (data gaps)	Performance of quantitative indicators (mainly of yields, but also on herbicide or pesticide use)	Performance of quantitative indicators in a less controlled experimental setting compared to off-farm field trials	Performance of quantitative and qualitative indicators of interest including farm and farmers specific characteristics	Performance of quantitative and qualitative indicators of interest including farm and farmers specific characteristics
Control of output and input allocation decisions	Totally controlled experiment by the researcher	Totally or partly controlled experiment by the researcher	Not at all controlled by the researcher	Not at all controlled by the researcher
Biases in the study results because of…	Controlled output and input allocation decisions		Sample selection process	
Typical time of the conduction of the study	Seed development phase, before the GM seed release	Before the release of the GM seed but after the first quality check	After the release of the GM seed, when first adoption occurred	After the release of the GM seed, when adoption is wide-spread and GM crop is economically important
Availability of study results	(Detailed) data not available in the public domain if conducted by private seed companies; available if conducted by public research bodies	Public available if public research bodies are involved	Public available	Official data; public available
Sample size (number of observations per study)	Varying sample sizes; not known if conducted by private seed companies	Wide range between studies	Wide range between studies	Large
Time span of the study	On average 2.6 years in Europe (Lheureux and Menrad, 2004)	Approximately 2 to 3 years	Often 2 to 3 years	Over several years

Field Trials

Field trials are conducted as controlled experiments, comparing GM and non-GM cultivars under similar agro-climatic and management conditions. The goal of these field trials is to estimate one or more specific performance indicators (e.g. yield increases), while controlling all other influencing factors (e.g. soil condition, infestation level, input use). Because researchers often control field trials, the outcomes from estimated performance indicators might differ from those achieved by the farmers under uncontrolled conditions. In addition, the study interest determines if and how performance measures (e.g. yields) are reported and if these reports can be compared to each other.[21]

Off-farm field trials, mainly conducted by seed companies and public research bodies (e.g. universities), are strongly controlled experiments, which aim to address one specific performance indicator, such as the yield of a newly developed variety. On experimental plots, all other influencing factors such as agro-climatic conditions or management activities are kept constant and therefore are completely isolated from the biophysical and climatic reality in which farms operate (Demont and Tollens, 2001). In the European Union, more than 2400 field trials with GM crops have been conducted from 1992-2008.[22] Detailed data about the experimental setup, input use and crop allocation are seldom available to the public if seed companies conduct the trials. However, the results of such trials are sometimes reported in personal communication and cited in review articles (e.g. Brookes, 2007; Brookes and Barfoot, 2009). In contrast, when public researchers are involved, field trial results are usually publicly available.[23]

In contrast to off-farm field trials, **on-farm field trials** are conducted on commercial farm-land (farm-land that is usually managed by the farmer). The scope of on-farm field trials ranges from the local to the regional level. On-farm field trials are often conducted after preliminary off-farm trials. By deciding where to grow the crop and/or how to manage it, researchers have particular influence on these trials but do not control them entirely. An example for partially controlled field trials are those where researchers decide about where to grow the crop, but the farmer can decide about input allocation (fertilizer, pesticide, and/or herbicide use).[24]

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[21] For instance, field trials may compare differences in performance estimators of GM compared to non-GM crops, together with differences in management practices (Regúnaga et al. 2003), yields of seeds offered by different companies (Dillehay et al. 2004), or with respect to different genes (Bryant et al. 2008).

[22] Source: http://www.gmo-compass.org (accessed May 25, 2010). Note that the cited number also contains field trials that have not been conducted primarily for variety testing but also for other purposes such as risk assessments.

[23] In the U.S. a vast amount of field trial results is made available online by universities (e.g. variety trials of conventional and roundup ready soybean in Illinois between 2004 and 2009 http://vt.cropsci.illinois.edu/soybean.html#2008).

[24] Bt cotton field trials carried out in India in 2001 were initiated by the seed company Mahyco and supervised by regulatory authorities. The plots to grow Bt cotton, their non-Bt counterparts and commonly used varieties were chosen by agronomists, whereas the management of the trials were committed to the farmers themselves (Qaim and Zilberman 2003).

Surveys

Within a survey, adopters and/or non-adopters are interviewed about the performance of GM crops and/or non-GM crops on their farm. The primary goal of surveys is to identify the effect of GM crop adoption on one or more performance indicators (e.g. yields, costs, gross margins). To this end, surveys also account for various internal and/or external factors that may influence the economic performance of GM crops. In contrast to field trials, the researcher is neither involved in adoption nor in input allocation decisions. Biases in the study results occur mainly within the sample selection process.

Farm-level surveys are mainly undertaken by public research bodies, and focus on quantitative as well as qualitative factors that influence the economic performance of GM crops, such as yields, input use, infestation levels, and farm and farmers characteristics (e.g. farm size, location of farm, distance to markets, and socio-economic parameters). They employ well-defined spatial and temporal scales. Sample sizes can vary substantially between surveys. **Field-level surveys** conducted by governmental authorities, often contain panel data on a range of quantitative and also qualitative issues. The USDA and NASS provide examples of publicly-available field-level surveys.[25]

Due to the different approaches, goals and methodologies employed in off-farm and on-farm field-trials, as well as farm- and field-level surveys, the following hypothesis has been formulated:

> **Hypothesis I**: The type of study influences the economic performance estimators of GM crops (e.g. yields, gross margins, costs).

6.2.1 Potential biases of performance estimators when using field trials as data source

The experimental setup of field trials may bias the derived economic performance results in several ways.

If conventional crops are compared with GM crops in a side-by-side variety trial, bias can occur through the so called "halo-effect". The halo effect comes in when the insect repellent used for the Bt crop spills over onto the conventional treatment. Thus, it provides another source of pest control, which may increase the yield of the conventional crops tested. Subsequently, yield increases due to Bt crop adoption might be underestimated in such field trials (Demont and Tollens, 2001; Marra et al., 2002).

Researchers typically manage pests in field trials to maximize yields, whereas farmers aim to maximize profits. Thus, pest-control regimes applied by researchers in the field trials may not be the same as a profit-maximizing farmer, possibly leading to an underestimation of the

[25] http://www.ers.usda.gov/Briefing/ARMS/

reduction potential in pesticide use (and thus the economic potentials) in field trials (Demont and Tollens, 2001; Marra et al., 2002).

Depending on the experimental setting, field trials conducted by researchers bear the advantage of randomized allocation of GM and conventional crops to different plots. In contrast, if farmers manage the field trials, they are expected to assign GM- and conventional crops taking the recent cropping history into account, e.g. natural fertility, pest incidence, and other factors that determine the relative profitability of the alternatives. For instance, farmers might plant herbicide tolerant varieties on heavily weed-infested fields to "clean them up", and traditional varieties on cleaner fields. Thus, yield benefits of GM-crop adoption are expected to be underestimated in cases where the farmer allocates GM crops to plots. This is also true for pesticide-inherent crops, if those are grown in remote fields where pest control is generally more difficult, or if they are grown primarily in fields with heavier infestations of both target and non-target pests (Marra et al., 2002).

Hypothesis II: The variety that was used as baseline (commonly used variety or not commonly used near-isogenic variety) influences the economic performance estimators of GM crops (e.g. yields, costs).

6.2.2 Potential biases in performance estimators when using surveys as data source

Surveys aim to assess the economic performance of GM crops on farm-level, usually compared to conventional crops. To this end, casuality between the new technology applied and the farm performance itself is presumed. However, many other effects besides the use/non-use of GM crops potentially influence the economic performance of a farm or the related field. Separating these effects from the true "GM crop effect" is a challenging task, which is usually realized by random sample selections. However, biases often occur when surveys are not based on fully randomized drawn samples. The counterfactual framework can reveal these potential biases and is outlined as follows with special regard to Winship and Morgan (1999).

In theory, the effect of GM crops must be assessed by the difference between the way a particular farm performs with GM crops and the way it does without GM crops. However, one individual farm cannot be assessed in both situations because they are mutually exclusive. Therefore, the key assumption of a counterfactual framework is that each farmer, either planting GM crops or not, has potential outcomes in both states: one outcome in which the farmer is observed and one in which he is not observed. As only one outcome can be observed in practice, no individual-level causal effect can be defined. Instead, an average treatment effect in the population can be estimated. This is done by measuring the farm performance of farmers planting GM crops and those who do not and take the difference between both estimated means.

To ensure a consistent estimation, the average farm performance outcome of the GM adopters and the average outcome of the non-adopters must be equal in the absence of GM crops. On the contrary, if a 'natural' difference in performance between adopters and non-adopters exists, the estimation of changes in farm performance parameters due to the GM crop is biased. This bias automatically occurs due to the differences in comparison baselines.[26]

If GM plots of adopters are compared with non-GM crop plots of non-adopters, observed revenue increases are partially caused by different traits as well as by differences in farmer' characteristics. Because farmers independently decide whether or not to adopt GM crops, it is impossible to determine *a priori* the direction of the causal effect that underlies an observed correlation. This correlation could either be due to a positive effect caused by the technology (the average treatment effect), or to a self-selection effect as adopters can be different from non-adopters in a number of ways (Crost et al., 2007; Morse et al. 2007).

Several studies (e.g. Fernandez-Cornejo et al. 2001; Marra, Hubbell and Carlson, 2001) indicate that more efficient farmers with larger farms and a higher education level than their peers tend to adopt GM crops more eagerly (Crost et al., 2007). In addition, GM-crop adopters are likely to use more conventional insecticides and can usually save more money by adopting GM crops (Carlson, Marra and Hubbell, 1998; Demont and Tollens, 2004; Carpenter and Gianessi, 2001; Gianessi et al., 2002). In contrast, non-adopters may be less educated, have smaller farms and, consequently, tend to have lower yields and profits (Marra, Hubbell and Carloson, 2001; Ervin et al., 2000). In particular older farmers are over-represented in non-adopter groups because they are less willing to absorb new information and more likely to adjust traditional cultivation practices with regard to changing conditions, rather than introducing new technologies (Quaim, 2003). Thus, farm and farmer characteristics as well as income levels influence the adoption decision of the farmer (Yorobe and Quicoy, 2004), potentially leading to an overestimation of GM crop benefits.

Field-level surveys

This survey type, an example of which is provided by the US Department of Agriculture (USDA) together with the National Agricultural Statistical Service (NASS), is based on a randomly selected, large scale sample that is conducted over a long time period. It thus represents various types of geographic regions throughout the country. Moreover, the sample represents the basic demographic characteristics of the population of farmers targeted by the study. Thus, the survey is representative for the entire population, and enables nation-wide analysis (Scatasta, Wesseler and Demont, 2006). Panel data allows for a distinction between early, late and non-adopters (Doss, 2006). Thus, panel-data can be used to study if GM-crop costs and benefits persist once the technology has been adopted. In addition, the extent to which new technologies have changed the relative and absolute

[26] A second bias occurs if the GM crop adoption would have different effects on the economic performance of farmers planting GM crops and those not planting GM crops. For instance, the farm performance of GM crop adopters increases more than the farm performance of a non-adopter if he would have adopted GM crops. This bias is called the differential effect of treatment and is likely to be present when there are recognized incentives for individuals to select into the treatment group (Winship and Morgan, 1999). However, many researchers (or the methods that they use) assume that the treatment effect is constant across the population (Winship and Morgan, 1999). In this project we will not discuss the problem related to the differences in the treatment effect.

incomes of farmers can be measured and panel data can be used to test if differences in income or wealth are causes or effects of the technology adoption (Doss, 2006).

Officially collected field-level panel data can be biased by the fact that adopters are directly compared to non-adopters while ignoring systematic differences between them (Marra, Pardey and Alston, 2002). In addition, as only average values of these data are published, statistical distribution cannot be detected and adjusted if needed (e.g. variability in yields, costs, prices) (Smale et al., 2008).

Farm-level surveys

Farm-level surveys provide background information about the adopters and non-adopters of the technology. Thus, differences between adopters and non-adopters can be controlled for and baseline differences can be reduced. In the following, different methods to eliminate baseline differences in farm-level surveys are described:

Farmers are randomly selected into adopters and non-adopters. The self-selection biases can be avoided by randomly selecting farmers into the group of adopters and non-adopters. Thus, the decision to adopt GM crops is not taken by the farmer, and the technology is no longer an endogenous variable (Crost et al., 2007, an example of this approach is given in Huang et al., 2005).

Before - after comparison. One of the most appropriate baselines for the assessment of GM crop performance is to use baseline data from previous cultivations of non-GM crops on the same farm (and same field) (Schmidt et al., 2008). Thus, this approach controls for all farm and farmers characteristics and the average treatment effect can be estimated consistently.

Within-farm comparison. Another approach to eliminate or at least reduce the baseline difference is to measure the performance of both GM- and conventional crops on the farm of a GM-crop adopter (within-farm comparison) (Marra, Pardey and Alston, 2002). In this way a number of producer-related factors (including unobserved farmer characteristics) can be controlled for, and productivity differences across plots can be observed (Doss, 2006). Within-farm comparisons allow for the estimation of the GM crop advantage as it is perceived by the farmer (Morse et al,. 2007).

The non-GM crop plot of adopters is compared to the non-GM crop plot of non-adopters. Another possibility to eliminate the baseline difference is to compare the non-GM crop plot of adopters to the non-GM crop plot of non-adopters. Thus, this survey design can provide information about factors such as management differences between adopters and non-adopters (Morse et al., 2007).

The main disadvantage of the three latter proposals is caused by the profit optimizing behaviour of the farmer: Farmers will allocate their transgenic and non-transgenic acres according to the relative advantages of the alternatives within their farm. Both technologies are applied by the farmer where they do comparatively better. Therefore each variety will do - on average - better than if the varieties had been assigned randomly. Hence, even within-farm comparisons tend to underestimate the GM-crop performance (Marra, Pardey and Alston, 2002).

Unfortunately, whether performance indicators are positively or negatively affected cannot be identified for most surveys because of missing information. However, differences between surveys that try to eliminate the baseline and those that do not, are expected. Therefore, the following hypothesis is formulated:

Hypothesis III: The choice of baseline (adopters vs. non-adopters, within-farm comparison) influences the economic performance estimators of GM crops (e.g. yields, gross margins, costs).

Further possible limitations of surveys

A major drawback of several survey based studies is that they often lack basic information about the sampling procedure (Scatasta et al., 2006). Also Marra, Pardey and Alston (2002) observed that detailed information about farm-level surveys is hardly available in the public domain. Moreover, the sampling selection process is indicated to be not random in other cases. Therefore, selection biases can be expected. For example, a private seed company considered only larger and richer farmers (i.e. potential clients) for an adoption study in South Africa, as described by Shankar and Thirtle (2005) and Ismael, Bennett and Morse (2002). Selection biases also occur if participating farmers are chosen on the basis of their willingness to cooperate and a minimum endowment with productive sources such as described by Qaim (2003) for Bt cotton in India. A further shortcoming of surveys is that farmers are asked about past input allocation decisions, which they might not remember precisely. While surveyed farmers generally have good knowledge of plot outputs and inputs such as pesticide, they have often problems with their recollection of the labour used for crop cultivation (Morse et al., 2007). In particular, GM crop adopters might be influenced by mostly positive experiences from a retrospective view and thus overestimate GM-crop performance (Finger et al., 2009). Scatasta et al. (2006) show that many surveys do not meet scientific quality standards as applied for consumer surveys. Additional biases may occur if respondents answer strategically or formulate their expectations rather than basing their answers on observations.

Also, the scope of commercial application within a country or region might restrict the conclusion that can be drawn from surveys or from the analysis of statistical data. In several countries GM crops cultivation is restricted to a small total acreage within specific regions. Thus, results derived from these farms are not at all representative for the country at large. Moreover, a small number of regions and farmers involved in GM crop cultivation (and thus small samples for statistical analysis) might lead to large variations due to individual farm and farmer characteristics.

If data are missing (i.e. not collected within the survey), they can be approximated by other data sources, for instance by national or regional averages of official agricultural censuses. However, biases in performance estimators are likely and the overall reliability of these studies decrease because the baseline of comparison cannot be controlled. For instance, comparing the yields of GM crops measured in a field trial or survey with a national average will over- or underestimate GM crop performance dependent on the representativeness of the samples. Benbrook (2003) finds, considering the herbicide use changes due to GM crop cultivation, that GM adoption reduces herbicide use in the short run, but increases herbicide use in the long run. In his analysis he compared the herbicide use rates of GM crops to national average rates. The result was criticized by Gianessi et al. (2002), who suggest that it would be more reasonable to follow Carpenter and Gianessi (2001) and identify herbicide use rates above national averages as stemming from adopters (as those farmers who have more significant weed problems are more likely to adopt GM crops) (Scatasta et al., 2006). The sample and the targeted population might differ with regard to farm- and farmers characteristics as well as with regard to environmental conditions.

6.2.3 Biases in performance estimators due to the sample size

As a statistical matter of fact, sampling errors decrease with an increase in sample size. Field trials and farm-level surveys are heterogeneous with respect to sample size (observation per study). Some studies count about 20 observations while others observe several hundred farmers (see e.g. Smale et al., 2009). In general, studies with larger sample size have a higher likeliness of delivering more reliable estimates of GM crop performance (see hypothesis below).

Besides the observations per study, the time span of the study can also influence the performance parameters. It is expected that the credibility of performance estimators decreases for shorter time spans because the influence of external events (e.g. exceptional environmental conditions) cannot be controlled. For instance, a farm-level survey conducted in South Africa spanned two seasons (1998-1999 and 1999-2000), but neither year was normal as there was drought in the first season and heavy rainfall in the second (Gouse et al., 2003). Another example is given by an Indian Bt cotton survey conducted in 2001 where the bollworm pressure was exceptionally high and influenced the estimation of economic performance indicators (Quaim and Zilberman, 2003). In contrast, in a field-level survey provided by the United States Department of Agriculture (USDA) and the National Agricultural Statistical Service (NASS), equal information about a number of years is collected (Marra, Pardey and Alston, 2002). This database provides a source of long term panel data, and therefore allows for the control of e.g. extreme environmental events.

Hypothesis IV: The higher the number of observations per study is, the lower is the variance within economic performance parameters (e.g. yields, costs, profits).

6.2.4 Biases in performance estimators relating to the publication channel

Peer reviewed studies use more rigorous sampling and analytical methods, whereas the authors of grey literature (e.g. working papers) often do not outline their methodlogical approach sufficiently (Doss, 2006; Gruère et al., 2008). Furthermore, grey literature is more squarely in the realm of polemics (Smale et al., 2009). Also, Gruère et al. 2008 report differences in the average economic effects of GM crops reported in peer-reviewed compared to other studies, even if these differences were not found to be significant. Hence, differences in GM crop costs and benefits between peer-reviewed and non-peer-reviewed literature can be expected.[27]

Hypothesis V: Reported GM crop performance estimators differ between peer-reviewed articles and grey literature.

6.2.5 Biases in performance estimators because of the study conductor

Because of the large number of interest groups involved in research, the political dimension of the topic and direct implications of study results for commercial applications, biases in the performance estimators caused by the study conductor are likely. Different interest groups have polarized perspectives and polarization is evident even in the peer-reviewed literature (Smale et al. 2006). For instance, field-trial data from Mahyco-Monsanto Biotech Ltd. indicated high yield advantages of Bt crops in three Indian States, whereas data from trials conducted by Punjab Agricultural University showed higher yields for non-Bt crops compared to Bt-crops (Aranachalam and Ravi 2003; Smale et al. 2006).[28] Highly negative yield estimates of Bt cotton were also observed in non-governmental organization studies, as these studies were mostly conducted in areas known for their difficulties with growing Bt cotton (Gruère et al. 2008). Moreover, different expectations of yield increases due to the adoption of herbicide tolerant soybeans between early and late adopters have been reported by Argentinean farmers (Finger et al. 2009), which might have been influenced by communications from seed companies. Thus, the study conductor (which is not necessarily the author of the study) seems to have an influence on the communicated performance of GM crops. This hypothesis is emphasized by public debates in the media (e.g. Lean 2008; Sheridan 2009).

Hypothesis VI: GM crop performance estimates are independent from the study conductor.

6.3 Results of empirical applications

For the empirical application of the hypotheses, several factors have been encountered that limited the analysis: Few papers and reports stated which variety was used for comparison (Hypothesis II) and which baseline was used as comparison (Hypothesis III). Moreover, sample sizes have been dominated by differences between study types and countries, and could not be tested independently (Hypothesis IV). Finally, the peer-review status of papers

[27] Significant differences between peer-reviewed and grey literature are also reported in other economic disciplines (see e.g. Tol, 2008).

[28] See a detailed discussion of contradictory results regarding Gm crop performance in dependence on the study conductor in Smale et al. (2006).

particularly varies between crops, e.g. most Bt maize studies for Europe (except for Spain) are not peer reviewed, while most Bt cotton papers are. Moreover, non peer reviewed reports appear often as peer-reviewed articles later, making an analysis of the influence of the peer-review status impossible. Thus, it was only possible to test the related hypotheses I and VI.

As shown in Table 11, most data are available from public research (547 observations presenting 76% of all entries for Bt cotton). However, there are still 174 entries from companies and therefore enough observations to statistically test differences of performance parameters reported by both conductors (public and company).

In total, 190 observations are available for interviews (surveys) and 288 for field trials. A high number of observations (243) were taken from review studies, where the original data source (field trial or survey) could not always be indicated. This limits the number of observations available for statistically testing the differences of performance parameters between interviews and field trials. Table 11 shows that most data are available from field trials.

Table 11. Data availability for study type and study conductor

Count (%)		**Study type**			
		Survey	Field trial	Others	Total
Study conductor	Company	2 (0.28%)	41 (5.69%)	131 (18.17%)	174 (24.13%)
	Public[a]	188 (26.07%)	247 (34.26%)	112 (15.53%)	547 (75.87%)
	Total	190 (26.35%)	288 (39.94%)	243 (33.70%)	721 (100%)

[a] *The category "Public" study conductor include research from universities and governmental authorities. The category "others" study type include data taken from articles where no information was given on how data were collected.*

A correlation analysis is carried out to check for possible interaction effects between the different study characteristics, including the study type, study conductor, year, the variety that was chosen as baseline for the comparison with Bt maize (variety comparison), and sample size. The results are shown in Table 12.

A small but significant correlation exists between study type and study conductor (r=0.23; p=0.000)[29]. In addition, the year the study was conducted and the variety chosen as baseline is significantly correlated[30] (r=0.56, p=0.000). Furthermore, a significant but very low

[29] r denotes the correlation coefficient, p denotes the p-value (i.e. the level of significance).

[30] The economic performance of Bt cotton can be compared to the a near-isogenic variety, which is not commonly used by the farmers or with a commonly used variety.

correlation between study conductor and year can be observed (r=-0.09, p=0.080). No other significant correlations between the different variables used in the following analysis exist. Due to the correlations between the variables, separated regression models for study type and study conductor are used, because multi-colinearity would affect coefficient estimates in a joint regression model.

Table 12. Correlations between study characteristics+

Variable	Study Type	Study Conductor	Variety Comparison	Year
Study Type	1			
Study Conductor	0.227*** (N=421)	1		
Variety Comparison	0.074 (N=52)	(a)	1	
Year	-0.001 (N=415)	-0.086* (N=415)	0.563*** (N=46)	1

*+) This table shows the correlations coefficient (p-value) and the number of observations. *, **, and *** denote significance at the 10, 5, and 1% level, respectively, based on Kendall's Tau for categorical variables (study type, study conductor, selection procedure. Variety comparison), and Pearson correlation coefficients for continuous variables (year, sample size). (a) Information about the baseline variety is only available for public study conductors. Hence, because of missing variation in the data, no correlation coefficient can be presented. N denotes the number of available observations.*

As visualised by the plots in Figure 21 to 24 (Annex F), analyses with regard to study type can be carried out for the economic performance indicators yields, gross margins, seed costs, pesticide costs, and management and labour costs. However, an analysis for differences in economic performance indicators with regard to the study conductor can only be provided for yields (Figure 25 in Annex F) and gross margins (Figure 26 in Annex F). For all other variables, only public study conductors report data.[31] This result is in line with the expectations about the different research interests of companies and public researchers. Whereas companies are interested in yield differences, public researchers are also interested in other performance parameters.

6.3.1 Results from group comparisons with respect to study type

In Table 13, the results of the group comparisons comparing the economic performance indicators of Bt and conventional cotton in dependence on study type are shown. Mean values, the differences as percentage and the number of observations are presented. Significant differences are indicated.

[31] Therefore only the figures for yields and gross margins are presented in Annex F.

Table 13. Results from group comparisons – study type

Variables	Trait	Economic performance indicator				
Study type		Yield	Gross margin	Seed costs	Pesticide costs	Management & Labour costs
Interview	Conv	1714.90 (N=59)	214.57 (N=37)	31.36 (N=17)	161.41 (N=29)	445.74 (N=30)
	Bt	2284.74*** (N=57)	305.78 (N=29)	71.97*** (N=21)	93.42*** (N=33)	570.91** (N=21)
	% change	24.94	42.51	129.47	-42.12	28.08
Field trial	Conv	1163.70 (N=79)	441.37 (N=51)	29.23 (N=36)	114.28 (N=46)	538.81 (N=17)
	Bt	1639.66*** (N=70)	466.38 (N=51)	98.56*** (N=31)	96.89 (N=32)	614.65 (N=21)
	% change	40.90	5.67	237.23	-15.21	14.07
Others	Conv	1410.61 (N=22)	299.72 (N=10)	27.85 (N=5)	178.03 (N=20)	179.65 (N=9)
	Bt	1751.61 (N=21)	488.53 (N=8)	89.23*** (N=10)	119.59 (N=19)	195.11 (N=8)
	% change	24.17	62.99	220.44	-32.83	8.61

*N denotes the number of available observations; n.a. signifies that no observations have been available. Comparisons are made with the Mann-Whitney-U test. *, **, and *** denote significance at the 10, 5, and 1% level, respectively.*

As already observed, Bt cotton has advantages compared to conventional cotton in terms of higher yields, higher gross margins, and lower pesticide costs. On the other hand, seed costs and management and labour costs are higher for Bt than for conventional cotton. These effects are stable when study type is controlled for:

Surveys indicate higher yields (+25%), gross margins (+43%), seed costs (+130%), and management and labour costs (+28%) of Bt cotton compared to conventional cotton. Pesticide costs are much lower for Bt than for conventional cotton (-42%). The differences are significant for yields as well as for all costs.

Field trials indicate higher yields (+41%), gross margins (+6%), seed costs (+237%), and management and labour costs (+14%) of Bt compared to conventional cotton. Pesticide costs are in average 15% lower for Bt than for conventional cotton. The difference is significant for yields and seed costs.

Other (mainly review) studies indicate higher yields (24%), gross margins (63%), seed (220%) and management and labour costs (9%) of Bt cotton compared to conventional cotton. Pesticide costs are on average 33% lower for Bt than for conventional cotton. The differences are significant for seed costs only.

Field trials indicate the highest Bt yield effect (41%) compared to surveys and other studies (24-25%). Compared to field trials and other studies, surveys indicate the lowest mark up for seed costs and highest pesticide costs savings for Bt cotton. Surveys also indicate higher management and labour costs for Bt cotton than field trials and other studies.

6.3.2 Results from the regression analysis with respect to study type

Table 14 contains the regression results (parameter estimates) from five models according to the models specified above. The second column shows the estimation results of the yield model. On average, yields from field trials are significantly lower compared to yields indicated in surveys. In addition, field trials indicate higher Bt effects than surveys (the interaction term Bt*study type=field trial indicates a higher differences between Bt and conventional cotton yields than observed by surveys).

Table 14. Regression models for study type

Variable	Yield model	Gross Margin Model	Seed Costs	Pesticide Costs	Management & Labour Costs
	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)
Study type=1 (field trial) compared to surveys	-0.400*** (-4.40)	0.557** (1.98)	-0.205 (-1.62)	-0.133 (-0.89)	-0.126 (-0.89)
Study type=2 (others) compared to surveys	-0.047 (-0.37)	0.251 (0.56)	0.430 (2.11)	0.095 (0.60)	-0.031 (-0.15)
Bt Effect * Study type=1 (field trial)	0.107 (0.87)	-0.489 (-1.27)	0.358** (2.40)	0.320* (1.72)	-0.396** (-2.00)
Bt Effect * Study type=2 (others)	0.008 (0.05)	-0.24 (-0.37)	-0.192 (-0.71)	-0.055 (-0.26)	-0.338 (-1.29)
Adjusted R-squared	0.34	0.11	0.76	0.66	0.79
Degrees of freedom	288	168	101	160	94

, **, and * denote significance at the 10, 5, and 1% level, respectively. Note that the logarithm of the dependent variables is taken in the regressions, and the coefficient estimates thus represent percentage effects of the independent variables (i.e. the percentage change of the dependent variable due to an one unit increase in the independent variable).*

The estimation results of the gross margin model are shown in the third column of Table 14. On average, gross margins observed in field trials, are significantly higher than gross margins observed in surveys. However, the differences of gross margins between Bt and conventional cotton are much lower in field trials than in surveys.

The fourth column of Table 14 shows the estimation results of the seed costs model. On average, seed cost data observed in field trials are lower than those observed in surveys. However, the seed costs mark up for Bt cotton is significantly higher in field trials compared to surveys.

In column five of Table 14 the effect of study type on pesticide costs is shown. On average, field trials indicate slightly lower pesticide costs than surveys. However, the difference of pesticide costs between Bt and conventional cotton is significantly higher in field trials than in surveys.

The last model (column six) shows the effect of study type on management and labour costs. On average, field trials indicate slightly lower management and labour costs than surveys. Furthermore, the difference of management and labour costs between Bt and conventional cotton is significantly lower in field trials than in surveys.

In summary, the type of study seems to influence the performance indicators. Yield data observed in field trials are in general significantly lower than those observed in surveys. In contrast, gross margins are significantly higher in field trials than in surveys. The difference of seed costs as well as pesticide costs between Bt and conventional cotton are significantly higher in field trials than in surveys. In contrast, differences between GM and conventional crops are lower for management and labour costs in field trials compared to results derived with surveys. Thus, Hypothesis I cannot be rejected. The type of study influences the economic performance estimators.

6.3.3 Results from the regression analysis with respect to study conductor

Table 15 contains the regression results (parameter estimates) for two models. The yield model in Table 15 indicates significantly lower yields if the study was conducted by a company as opposed to a public entity. However, the difference between Bt and conventional cotton yield is significantly higher when the study was conducted by a company.

Furthermore, gross margins indicated by companies are higher than those indicated by public researchers. Also the Bt effect on gross margins is higher if a company conduct the study. However, both effects are not significant.

Table 15. Regression models for study conductor

Variable	Yield model	Gross Margin Model
	Parameter (t-value)	Parameter (t-value)
Study conductor=1 (company)	-0.881*** (-6.43)	0.263 (0.36)
Bt Effect * Study conductor=1 (company)	0.969*** (4.75)	0.314 (0.32)
Adjusted R-squared	0.37	0.10
Degrees of freedom	290	170

, **, and * denote significance at the 10, 5, and 1% level, respectively. Note that the logarithm of the dependent variables is taken in the regressions, and the coefficient estimates thus represent percentage effects of the independent variables (i.e. the percentage change of the dependent variable due to an one unit increase in the independent variable).*

In summary, the hypothesis that GM crop performance estimates are independent from the study conductor cannot be rejected. Differences in estimated overall yield levels and yield surpluses of Bt cotton with respect to the study conductor are found. Although, yields observed by companies are generally lower compared to yields observed by public research, the yield surpluses of Bt cotton reported by company based studies are much higher than those reported by public research.

7 Explanations of variances and contradictions in results – some selected examples

In chapters 5 and 6, a number of difficulties were revealed which hamper a straightforward interpretation of the results. Also the statistical analyses applied have to work with presumptions that sometimes deviate from actual conditions, leading to variations and contradictions in results. These and other variations are often based on underlying causes that deserve further examination. This chapter will, by reassessing the literature used for the statistical analysis and by making use of interviews conducted with experts, substantiate some of the varying results found in chapters 5 and 6 or will deliver further explanations. Regarding improvement in yields, a critical issue for cautious interpretation that has been touched in several parts of chapters 5 and 6 is picked up again and will be underpinned with some further insights. In addition, other issues with distorting effects on the results of the comparative estimates that were found in the literature research such as country specifics, access to water and self selection of farmers in different contexts are discussed.

7.1 Improvement in yields

7.1.1 Assumption of normal distribution

In statistical tests, if not specified further, it is generally assumed that data sets follow a normal distribution. A normal distribution accounts for the probability that the distribution of data within a sample is clustered around a specific mean. However, results of statistical tests would look different if data are distributed in another way. This study had to rely on mean values from the literature, as most of the studies used do not provide for the raw data that lie behind the mean values.

In the following, Bennett et al. (2004) is selected as one rare example where raw data were made available in order to demonstrate the degree of variation in yield values that can occur if a normal distribution is presumed.

Table 16 details the reported yield data (Bennett et al, 2004, p670) together with the 95% confidence limit. Table 16 was derived from data collected from the records of Vunisa Cotton, the main supplier of cotton for the Makhathini Flats, South Africa, and represented 89% of the growers for 1998/99, 32% for 1999/2000 and 33% for 2000/2001. The figures in Table 16 suggest that in each of the seasons the yield obtained from Bt plots was greater than that from non-Bt plots.

Table 16. Cotton Yields Makhathini Flats 1998/1999 – 2000/2001 (Reported)

	1998/99	1999/2000	2000/01
Non Adopters - Yield (kg/ha)	452	264	501
Non Adopters (- 95% Confidence limit)	±26.9	±23.4	±82.5
Adopters – Yield (kg/ha)	738	489	783
Adopters – 95% Confidence Limit	±118.8	±68.8	±94.6

Source: Bennett et al. (2004)

There are statistical tests that can be performed to determine whether or not sample data have a normal distribution. Using the statistical package *Minitab,* the Anderson-Darling model was applied to the Bt and non-Bt cotton data that formed the basis for Table 16, The results of this test are shown in Figure 1 (Bt) and Figure 2 (non-Bt). The straight line in each of the figures represents what the distribution should normally be. The dots are plots of the observed data. The difference between the two illustrates the gap between observed and normal distributions.

Figure 1. Anderson-Darling Probability Plot Bt Cotton, Makhathini Flats 1998/99 – 2000/01

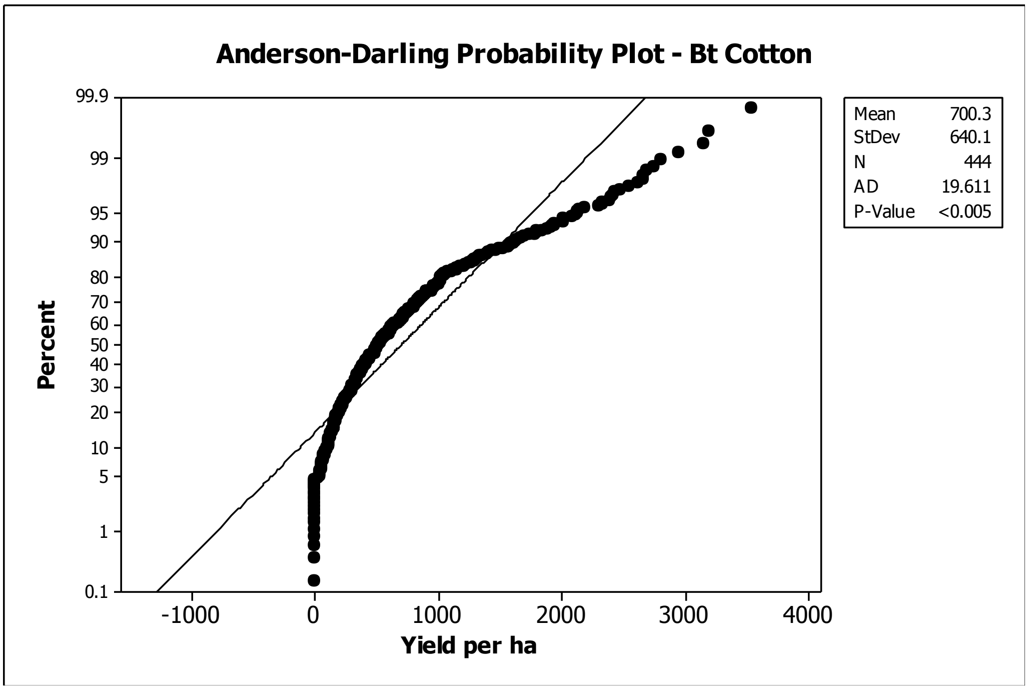
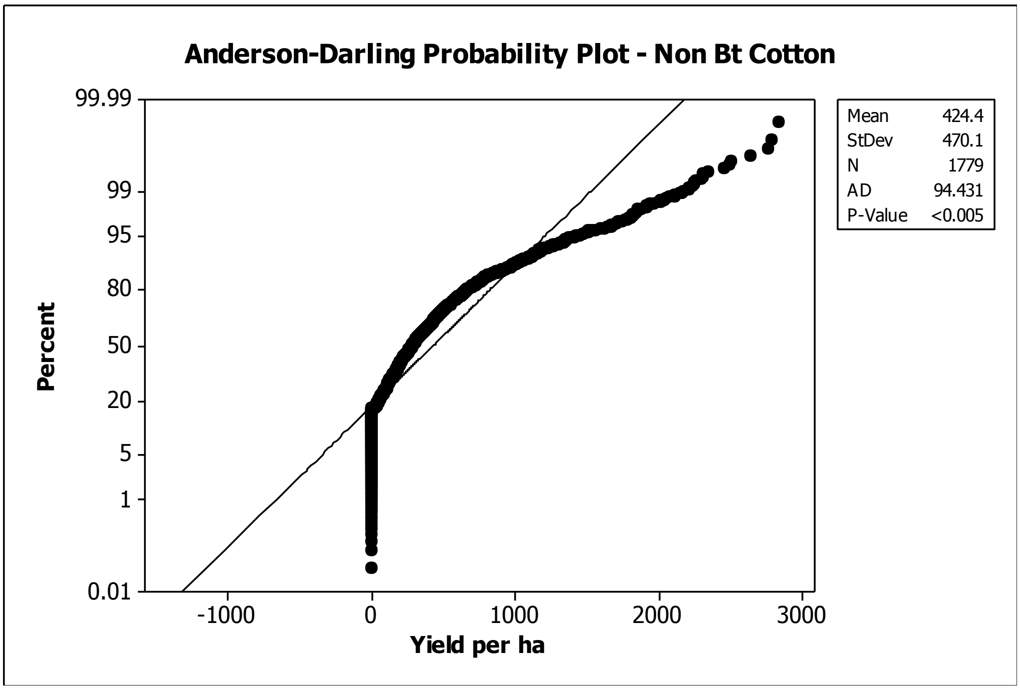


Figure 2. Anderson-Darling Probability Plot – Non Bt Cotton, Makhathini Flats 1998/99 – 2000/01



If the distribution of the samples were normal, then all the data plots would be close to the probability line indicated on the graphs. However, for both traits (Bt and non-Bt), the results in Figure 1 and 2 suggest the data did not reflect a normal distribution. This result is supported by Harri et al. (2008) who examined yield data for GM and non-GM varieties of corn, wheat, cotton and soybeans grown in the United States of America.

The data from the Makhathini Flats did, in fact, reflect a distribution that was positively skewed. As can be seen in Table 17, this can lead to a distortion of results, with a crop having a mean yield which is higher than the central tendency or midpoint.

Table 17. Yields of Bt and non-Bt cotton producers 1998/99 – 2000/01 (Original data)

	Mean (kg/ha)	Median (kg/ha)	Difference between mean and median (kg/ha)	Difference as a % of the median
Bt Cotton	700.25	515.71	184.54	35.78
Non Bt Cotton	424.40	284.50	139.90	49.17

In general, data can be adjusted in order to reduce this effect. Hence, the data are usually transformed by taking logarithms, so as to reduce the skew before tests such as ANOVA or the t-test are applied. Most articles reviewed in this study appear to have only presented the sample means and measures of variation around the mean (such as the confidence limit, standard deviation or standard error) and used them as a direct comparison between GM and non-GM varieties.

7.1.2 Heterogeneity of crops

In most comparative studies reviewed, various varieties of the respective crop traits ('Bt', 'HT' and 'Non GM') were pooled and the differences between pooled values were calculated. When variations between varieties within a trait are widely neglected, this can lead to another distortion of results. The so-called "yield gap" is the difference between the potential yield of a variety and the yield actually obtained from the crop trait grown by the farmer. The latter is also known as the effective yield (NRC 2010).

The potential yield is defined 'as the yield of an adapted crop variety or hybrid when grown under favourable conditions without growth limitations from water, nutrients, pests, or diseases' (Lobell et al., 2009, p181). The yield potential of any crop is not only dependent on the location where it is planted, but when the crop is planted and its maturity rating. The maturity rating is a genetic trait and determines the length of the growing season from the date of planting, which varies among varieties (Lobell, 2009, p182). The density of the plants is also important in determining the potential yield, as incorrect spacing can allow the plant canopy to block solar radiation at an early stage of the plant's life cycle. There is a theoretical upper yield limit that a particular variety can produce, which is dependent on how much energy the crop canopy can absorb and the efficiency of photosynthesis in each plant (Lobell, 2009, p182)

Some research has been carried out which adopted like-for-like comparisons between near isogenic varieties of crop, i.e. those that had the same genetic background but differed only in terms of the GM trait. One such article is provided by Bambawale et al. (2004). These authors compared Bt Cotton (Mech-162) with a non-Bt Mech-162 and other unidentified conventional cottons within and outside an Integrated Pest Management (IPM) scheme. The two Mech-162 varieties were near isogenic, differing only in terms of one having the Bt gene while the other did not. They were able to record the estimated damage to the reproductive parts of the plants from bollworm as shown in Table 18.

Table 18. Damage to plants from Bollworm

Crop type	Percentage Damage
IPM Bt Mech-162	11.55
IPM Non-Bt Mech-162	32.88
IPM Conventional (not Mech 162)	29.38
Non IPM Conventional (not Mech 162)	54.23

Source: Bambawale et al. (2004)

This level of damage can then be used to estimate the minimum yield loss per hectare and from that the maximum yield per hectare from each crop that the farmer could realistically obtain (Table 19).

Table 19. Estimation of Potential Yield

Crop	Actual mean yield Kg/ha	Estimated loss Kg/ha	Estimated maximum yield Kg/ha
IPM Bt. Mech-162	1237.5	161.6	1399.1
IPM Non-Bt. Mech-162	962.0	471.3	1433.3
IPM Conventional	706.0	293.7	999.7
Non IPM Conventional	370.4	438.9	809.3

Source: Bambawale et al. (2004)

The results shown in Table 19 clearly highlight the weaknesses in the use of the harvested or net yield. From the data available it would be easy to conclude that Bt Mech-162 was superior to all the other varieties of cotton grown because of what appears to be an improved yield (1237.5 kg/ha against 962.0 kg/ha, 706.0 kg/ha and 370.4 kg/ha). However, the different varieties have sustained different levels of pest damage and loss. As a result it can be seen that the yield difference between the Bt Mech162 and conventional Mech-162 was actually quite small and the Non-Bt Mech-162 variety would have produced a better yield if there were no losses from pests.

Pooling of data is, strictly speaking, only effective when a like-for-like comparison is being made. Most of the evidence presented within academic papers whilst making some indication that like-for-like comparisons were not made, did not always clearly identify the conventional varieties that were examined and the results obtained from each variety of crop irrespective of trait. As a result it becomes difficult to evaluate whether the benefits of each specific variety were accurately reflected within the results and whether or not the conclusion reached was applicable in all cases. In reality there are 'trade-offs' with this type of 'on-farm' research, as researchers can only analyse what farmers do, including the varieties which they like to plant. Farmers may not necessarily cultivate near isogenic varieties of GM and non-GM.

7.1.3 Access to water

Access to water at the correct time in the growth cycle of plants has been shown to be an important factor when researching the economic costs and benefits of any crop. Research carried out by Ismael et al. (2002a) and Gouse et al. (2003) on smallholder farmers in the Makahthini Flats and large-scale farmers of South Africa for the years 1998/99, 1999/2000 and 2000/01, identified that irrigated cotton did produce a significant yield increase both for Bt and non-Bt cotton (Table 20).

Table 20. Cotton yields (Irrigated and Dryland) 1998/99 – 2000/01

		Non-Bt Small-holder	Bt Small-holder	Non-Bt Small-holder	Bt Small-holder	Non-Bt Large-Scale	Bt Large-Scale
growing season		98/99	98/99	99/00	99/00	00/01	00/01
Irrigation (kg/ha)	Mean					3413	4046
	Std Deviation					1372	1210
Dryland (kg/ha)	Mean	434	511	395	576	832	987
	Std Deviation	49	82	389	547	56	66

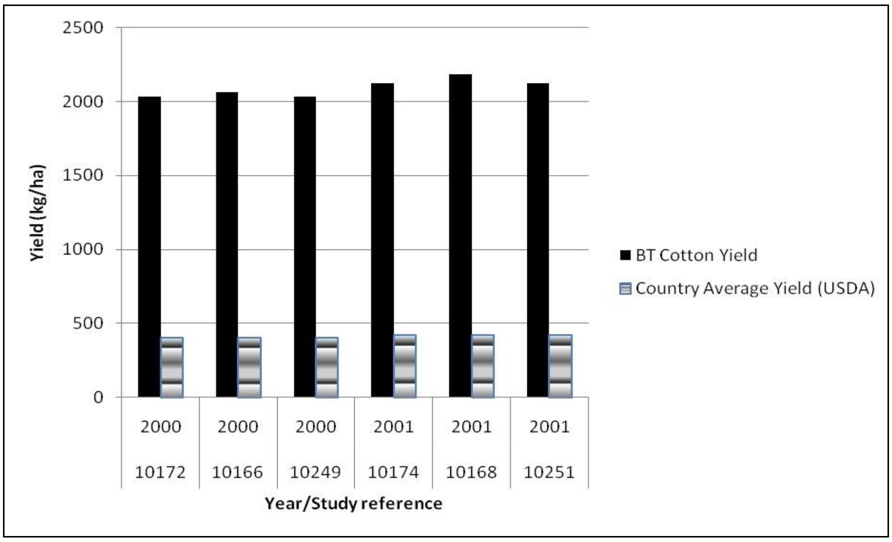
In addition to irrigation, the level of rainfall was also noted as having a material effect on yields. It was acknowledged that the poor results occurring in 1999/2000 for the smallholder farmers of the Makahthini Flats were a result of heavy rain in that season which increased bollworm populations. Therefore the yield advantage for Bt cotton was more noticeable in that season.

7.1.4 Differences between farmers

The preparation of the statistical data may be open to bias due to the number of farmers growing GM crops at any given moment in time. This can be shown through the research on Bt cotton and HT soy in Argentina (Qaim, 2005). Bt cotton was introduced to Argentina in 1999. By 2001, 5% of farmers had adopted Bt Cotton. The results cited in Qaim (2005) indicated that Bt cotton significantly outperformed the conventional cotton used. However, if the results were compared with the national average of cotton yield for Argentina, a certain bias can be unveiled.

The United States Department of Agriculture (USDA) provides a database of yields for various crops and countries throughout the world.[32] These data are provided from a number of sources, including government websites and official data from the Food and Agriculture Organization of the United Nations (FAO).[33] Whilst these data do not provide a breakdown of yields between the various traits, they do provide average yields for the whole of the country. To this end, if it is known that the level of GM up-take is low, and the yield of conventional crops identified within the farmer sample included in the research are shown to be higher than the national average, then there is a significant possibility that bias in the sample selection has taken place. In Figure 3, the mean yield for the Bt trait in Argentina taken from the database used for this study was compared against the USDA average country yield for cotton.

Figure 3. Bt cotton yield (Argentina) compared against national average yield



Source: Own database (Study Reference 10172, 10174 – Qaim (2005a); Study Reference 10166, 10168 - Qaim (2003a); Study Reference 10249, 10251 –Qaim (2003b))

If the take-up of Bt cotton by 2001 was only 5% nationally, it can be assumed that the sample taken of conventional cotton should be much closer to the national average.

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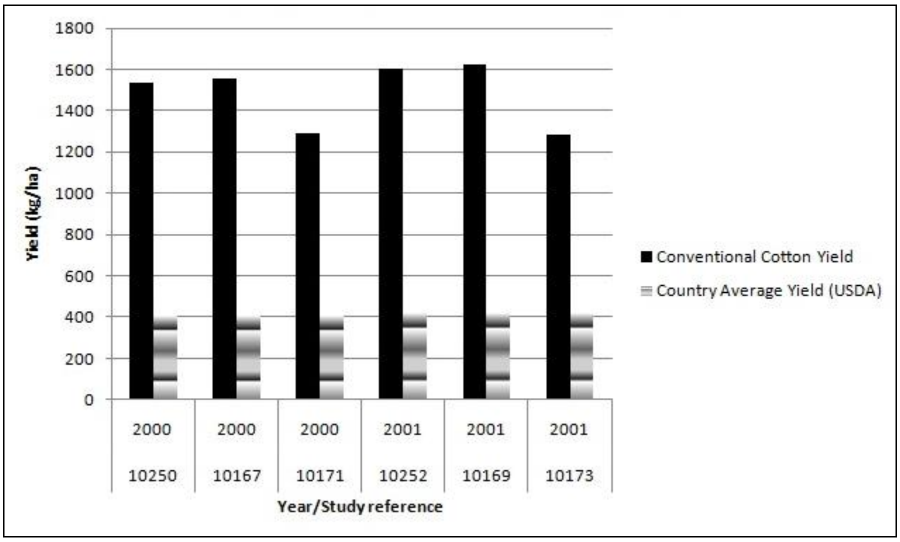
[32] http://www.fas.usda.gov/archive.asp

[33] http://www.fas.usda.gov/data_sources.asp

However, as Figure 4 shows, farmers in the sample who grew conventional cotton had yields some 400% greater than the national average, suggesting that they may have been more efficient. As a result, extrapolating the costs and benefits of growing GM cotton from this sample may be misleading as differences might come from the group of farmers who were selected for providing data rather than from the GM trait itself. Qaim (2005) confirms that the bias in the Argentinean data arose from the fact that Bt Cotton had only been taken up by some large-scale farmers (p.191).

Figure 4. Conventional cotton yield (Argentina) compared against national average yield

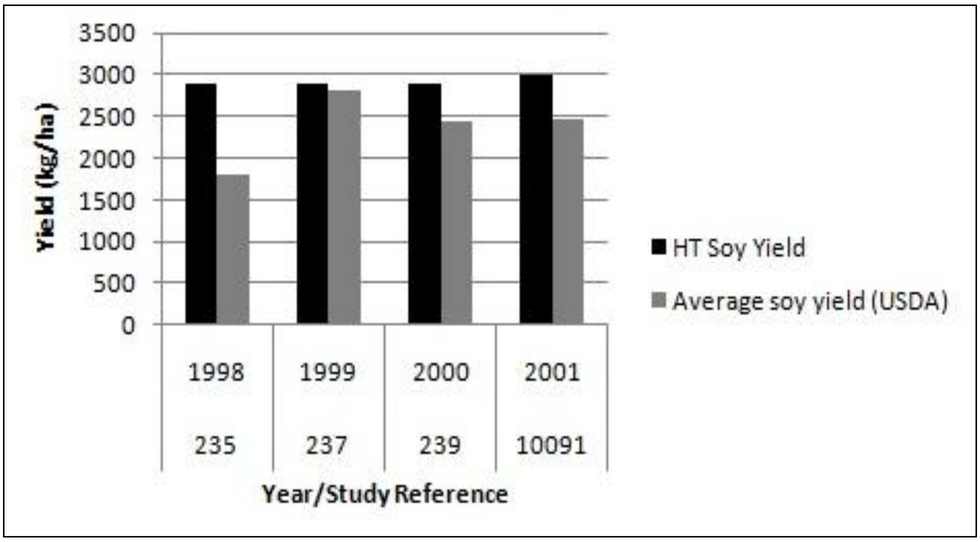


Source: Own database (Study Reference 10171, 10173 – Qaim (2005a); Study Reference 10167, 10169 - Qaim (2003a); Study Reference 10250, 10252 –Qaim (2003b))

In the above example, the conclusion that bias is contained within the sample is based on a comparison with USDA data and that it is therefore important to prove the reliability of that comparison. Qaim (2005), when commenting on the low take-up of Bt cotton in Argentina, also pointed out that the take-up by farmers of HT soy was almost complete throughout the whole country. Therefore, if the USDA figures are reasonably accurate, any sample data on soy yields from 1999 onwards when the HT crop was introduced should be reasonably close to the national average (Figure 5).

Indeed, as can be seen in Figure 5, the soy yields are reasonably close to the USDA national average. The wide disparity seen with the cotton data (GM and non-GM) is not apparent with soy. It can therefore be concluded that whilst not completely accurate, the USDA average crop yield figures can be used in controlled circumstances as a guide as to whether or not sample data being analysed reasonably reflects the whole of the country.

Figure 5. HT soy yield (Argentina) compared against national average yield



Source: Study Reference 235,237,239 – Penna (2002); Study Reference 10091 – Qaim (2005b)

Pest control

The control of pests, even for the insect-resistant Bt cotton, is important, and the way in which farmers control those pest is usually with pesticides. How farmers actually use pesticide varies and, in developing countries, can at times become highly inconsistent. In Makhathini Flats, South Africa, whilst smallholder farmers obtained advice or used their own knowledge on how to use pesticides, most of the farmers guessed the amount of pesticide to use and did not use precise measuring devices (Bennett et al, 2003). This inconsistency was also made clear in some of the interviews.[34] In China, the farmers had a major pest infestation at the end of the 1990s, which seriously reduced cotton production. As a result the Chinese *'were prepared to spray pesticide irrespective of whether or not they had an infestation'* (interview A4). The researcher was conducting her field work for her PhD in China. Her research found that their control of pests through pesticides was ineffective.

'The problem was that in the provinces farmers were using in excess of 200 different types of pesticide, and very few had adequate labelling, so no one knew what pesticide they were spraying.' (interview A4)

As a result, it was questionable as to whether or not pesticides were the reason for low infestation pressures.

Deciding when to spray is also dependent on insect scouting, where the farmer is required to check for a prescribed level of infestation (Hofs et al, 2006). Hofs et al. (2006) found that the practices in Makhathini Flats were more haphazard as to when to spray. When Bt cotton was introduced, there was a prevailing misconception that it did not require any spraying of pesticide. This issue was also identified within the interviews. For example:

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[34] See chapter 4 for an explanation of the interviews conducted. Details of those interviewed are contained in tables 27 to 30 of Annex H.

'as in many cases developing country farmers were not using insecticides to control target pests' (interview R5).

'With regard to risk, one of the most interesting questions is why some Bt cotton farmers are continuing to spray pesticides as well. Part of the explanation seems to be that they lack reliable information about the seeds they are planting or cannot be confident in their performance, indicating market and institutional failures.' (Interview R2)

'Farmers will not obtain most of their information on the product from the seed companies but from their neighbouring farmers.' (Interview A3)

The interviews suggested that perceptions were also enhanced by a lack of adequate information that farmers could easily access and understand.

A serious problem has occurred in the tolerance of weeds against glyphosate in the south east region of the USA and, to a lesser extent, in the mid-west region. The problem is believed to have been caused by the seed producers 'bundling' both their herbicide tolerant seeds together with glyphosate herbicide. As a result,

'the farmers have been using too much of the same herbicide allowing for tolerance amongst weeds to develop. In order to kill the weeds the farmers have had to resort to the more dangerous herbicides which are known to have a detrimental effect on humans.' (Interview R7)

Seed dispersion

Seed dispersion can also have a significant influence on the interpretation of yield data. Seed dispersion, which is the density of seed sown (weight of seed/area), is dependent on the skill of the farmer, especially if he cannot revert to machinery or an accurate method of measuring. A review of Bt Maize in South Africa (Gouse et al., 2006) noted that farmers measured their yield in kilograms of seed sown instead of kilogram per hectare. When South African yield data were reanalysed against the amount of seed sown, it was shown that Bt Maize produced only 1.5% more yield per kilogram of seed than non-Bt crops. Therefore the large increase originally identified for Bt versus non-Bt was largely attributable to the amount of seed sown. In other words, farmers were planting Bt at a higher density than non-Bt and thus yields would be higher for Bt as there were more plants per unit land area.

There was also a problem with evaluating the size of the plot of land the crops were grown on. Gouse et al. (2006) found that the farmer could frequently overestimate the size of the plot and by implication any calculations of yield etc. would have been inaccurate.

7.2 Variation in Exchange Rates

A further important influence on the results was the fact that most of the financial data identified were converted to US$. As a result, transactions that may have cost the same in the host country year on year could have increased or decreased depending on the strength of the currency. A good example is the South African Rand. The rate used within this example (Table 21) is the average rate of exchange given by OANDA.

Table 21. South African Exchange Rate against the US$

Year	Exchange rate	1US$=SAR	1SAR=US$
1999	0.16378	6.11	0.16378
2000	0.14493	6.90	0.14493
2001	0.11782	8.49	0.11782

Source: OANDA, www.oanda.com/currency/historical-rates

From this example it can be seen that if the exchange rate goes down, the US$ value also declines, suggesting a reduction in costs when it may not necessarily be the case. Similarly if a product such as seeds is purchased in US$, a fall in the exchange rate may result in an increase in price but in fact this may not be true. Indeed the prices of inputs (in local currency) may be relatively constant.

7.3 Discussion on the variances and contradictions of results

It could be argued that the contradictions and variations which have been identified throw a negative view of the economic performance of GM crops. However, despite the aforementioned methodological weaknesses and inconsistencies, there is evidence that farmers benefit from the adoption of GM crops in many instances, with less of their crops being lost and the overall costs of growing the crops being reduced. There is also evidence that the non-GM crops can provide similar levels of benefit, although their environmental costs may be higher through the use of more pesticides. Importantly, whatever seed is used, the methods employed by the farmer are key in determining how well the crops perform, with well established and expert farmers achieving the best results.

8 Conclusions

The study's main objectives were, firstly, to assess the current state of knowledge on the economic performance of GM crops worldwide based on data from available literature and, secondly, to evaluate the results in terms of their conclusiveness and consistency.

This chapter is therefore divided into two sections. The first part will briefly summarise the results of the statistical analysis conducted in chapter 5 for different GM crops, followed by a short discussion on what conclusions could be drawn from merely reflecting on the outcomes.

Secondly, observed data gaps are discussed together with findings from the analysis of conclusiveness and consistency in results that have been undertaken in chapter 6 and 7. Conclusions will be drawn on the status and information value of overall global assessments of GM crops performance.

8.1 Outcomes from data analyses on GM crops worldwide

Briefly summarised, the analyses conducted in this study showed the following for the economic performance of Bt cotton, Bt maize and HT soybean:

Bt cotton

Across all countries considered, yield levels of Bt cotton are on average about 46% higher than for conventional cotton. Furthermore, pesticide costs could on average be reduced by about 48% and management and labour costs by about 20% respectively. In contrast, seed costs are on average twice as high for Bt cotton seed compared to conventional cotton seed. As a result, gross margins of Bt cotton adopters could on average be increased by about 86%. The effects of Bt cotton on the different economic performance parameters (e.g. yields, costs and gross margins) are stable over time and thus, up to now, no general decrease in the economic advantage of Bt cotton over time could be observed.

However, the effects of Bt cotton on economic performance indicators show a high degree of heterogeneity across countries, which is mainly a result of differences in pest management practices. Countries lacking well-established pest management and, consequently, low yield levels benefit most from growing Bt cotton because yield losses could be reduced. In India, for instance, yield increases of up to 50% could be observed. In contrast, countries with rather high yield levels and well-established pest management, such as Australia or the USA, benefitted most from reduced pesticide costs (16%-70%).

In most cases, reduced pesticide costs and/or higher yields of Bt cotton outweigh higher seed costs (mark-ups of between 30% to 230% for Bt cotton seed compared to conventional seed could be observed). In countries where crops are well adapted to local conditions and pesticide control is efficient (e.g. Australia), Bt cotton shows the lowest net-benefit.

Bt maize

Across all countries considered, the effect of Bt maize on yields is lower than that observed for Bt cotton. On average, yield increases of about 3.9% could be observed for Bt maize. Pesticide costs could be reduced by on average 67% and management and labour costs by about 5%. Seed costs are on average 48% higher for Bt maize seed than for conventional maize seed. While a statistical analysis of Bt maize adoption on gross margins was not possible due to the lack of a sufficient amount of data, single study results show higher gross margins for Bt maize growers (see e.g. the results on gross margins for Bt maize adopters in Spain by Gomez-Barbero et al., 2008a).

The difference in yield advantages between Bt cotton and Bt maize might be explained by the already well adapted varieties and pest management measures available in countries where Bt maize is mostly grown (e.g. in the USA and Spain). However, going from the global to the country level a high heterogeneity of Bt maize effects can be observed. For instance, the statistical analysis shows that for Spain, yield increases due to Bt maize adoption were on average approximately 6%, for Germany around 12% and for South Africa about 25%. Pesticide cost reductions range from on average 25% in Germany, to 56% in Spain, to 62% in South Africa. Seed costs increases of about 10% for Spain, 17% for Germany, and 36% for Argentina could be observed. Data on gross margins are scarce and therefore no statistical results can be presented here.

HT soybean

The statistical analysis of the effect of HT soybean on economic performance indicators indicate higher seed costs (3%-41%) and lower herbicide costs (24%-32%), as well as lower management and labour costs for HT soybeans. The HT effect on yield is, however, ambiguous. Also, the results of the literature review show only low yield effects of HT soybean worldwide. However, while seed costs for HT soybean are higher, reduced herbicide costs (and other benefits such as the easier adoption of no-till) lead to an overall net benefit for HT soybean adopters.

In general, results of the economic performance of GM crops found in this study follow a similar pattern set out in much of the literature: compared to conventional crops, GM crops can lead to yield increases mostly through reduced yield losses from insect infestation and weeds. They can also lead to reductions in pesticide costs, whereas seed costs are usually substantially higher. In cases where higher yields and the reduction of pesticide inputs outweigh the higher seed costs, farmers receive higher income by growing GM crops.

The kind and magnitude of benefits of GM crops, however, are heterogeneous across countries and regions. While countries with well-established pest management can mostly benefit through reduced pest-management costs, other countries can benefit most from reduced yield losses (i.e. yield increases).

Consequently, growing insect-resistant GM crops is most advantageous when there is an evident pest pressure in the region. In regions, where pest management is already well established (e.g. in USA, Australia), adoption of GM crops is only profitable for farmers if pesticide input (and costs) can be reduced sufficiently enough to outweigh higher seed costs for GM crops.

8.2 Do the results tell the whole story?

While a wide range of literature on the analysis of GM crop performance is available, empirical sensitivity analyses with regard to the potential limitations of available and comparable data were not widely applied. This study has aimed to generate a more complex picture on how different kinds of research methods, as well as other varying factors, may affect results on the economic performance of GM crops.

The assessment conducted in this study shows that the manner in which data is gathered (e.g. if a field trial or a survey was conducted) has an influence on the results. For instance, cotton yield data observed in field trials are generally lower, but gross margins are higher, than those observed in surveys. Differences in seed costs and pesticide costs between Bt and conventional cotton are higher in field trials than in surveys. In contrast, differences between GM and conventional cotton are lower for management and labour costs in field trials compared to results derived with surveys.

It could also be shown that the study conductor influences the performance estimates of GM crops. For example, higher yield advantages of Bt cotton are observed if private companies conducted the study when compared to studies conducted by public institutions (e.g. universities and governments).

Crop yields have a strong effect on the perception of the economic performance of GM crops as higher seed costs of GM crops often have to be compensated by more income from the crop itself, which can largely be achieved by higher yields. But yield levels in general depend upon a wide range of different factors which go far beyond the mere choice between GM and conventional crops. For example, this study demonstrated that the crop yields highly depend on the appropriate variety (no matter if GM or conventional) chosen by a farmer in relation to the weather and climatic conditions, under which the crop is grown. That leads to the fact that only like-for-like or near isogenic comparisons between crops would ensure a high reliability of results on crop yields, which, of course, cannot be realistically achieved in all comparative studies. However, this might lead to an over- or underestimation of benefits from GM crops compared to their conventional counterparts in some cases.

Other significant varying factors influencing the yield levels of both GM and non-GM crops, and which are not always sufficiently addressed in the literature found, include the degree of pest pressure experienced in the particular region where the crops are grown, the access to water for irrigation (which is of major importance in sub-tropical countries), and the individual level of experience (and education) a farmer has.

Subsequently, the study unveiled a lack of sufficient comparable (raw) data when screening the literature for figures and numbers on economic parameters to allow for a robust quantitative comparison analysis.

Positive economic effects of GM crops have been indicated in this study for several countries, which is in line with other review studies (e.g. Carpenter, 2010) and explains the high adoption rates of GM crops in these countries. But the study also underlines, through the various reasons given above, that such outcomes cannot be generalised across the globe.

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Annex A. Glossary

Publication refers to the source document (scientific article, news article, project report etc.) that has been reviewed. The economic performance data that is available in a publication can only be entered in the database in the form of studies. Some publications do not contain the actual data necessary to insert studies in the database but nevertheless refer to a second publication that contains these studies. In this case the first publication is also linked to the studies it uses as a reference (even though it has not generated these studies). This explains why some studies are linked to multiple publications.

Study refers to a unit of data entry. A study represents a unit of economic performance data (e.g. on yield, costs, revenue) for one type of crop, one year and one region. Studies are thus almost always entered in groups, e.g reflecting an analysis over multiple years and regions. The studies are then linked to the publication that they originate from and if possible to other publications that refer to these data.

Geographical region: the study distinguishes 43 different geographical regions; these were inserted on a case by case basis, whenever a publication systematically differentiated results according to geographical regions.

Yield is measured in kg per hectare. Varying entry formats were allowed in the database: yield in kg per hectare, yearly growth of yield in kg per hectare, absolute growth of yield in kg per hectare, yield of kg of grain harvested per kg of seed planted.

Revenue (in USD per hectare) is income from sales. Varying entry formats were allowed in the database: revenue per hectare, yearly growth of revenue per hectare, absolute growth of revenue per hectare.

Gross margin (per hectare) refers to the actual economic benefit that remains after deducting all variable costs from the total revenue per hectare. Varying entry formats were allowed in the database: gross margin per hectare, yearly gross margin per hectare, absolute gross margin per hectare, net increase in gross margin in USD per hectare

Annex B. Database design

Table 22. Selected parameters from the database

Category	Table	Attributes	Explanation
Publication	publication_type	article, book, report, book section, thesis, internet, conference paper, private communication, working document	Characterizes the (quality of) source the study and data is taken from
	publication	Title, year, author, …	Basic information about reference
	Peer_review	yes, no	Standard information about scientific quality of publication
Type of study	study_type	Review, Interview, Field Trial, Official data, Modeling study	Relevant for assessing the origin of data and its aggregation level
	conductor_of_study	Academic, Company, Governmental, Farmer, Civil society	Might be different from author; indicates the background of the one who produced the data
	sponsor_of_study		Provides information on who paid for study
	horizon_of_study	1 year, 2 years, …, 10 years	Indicates the timeframe of a study and the data gathering
	selection_procedure_random	yes, no	Indicates if the random selection of data was representative (mainly relevant for interviews)
	Baseline	comparison group, regional/national average, within farm comparison	Indicates which baseline the study uses to compare adopter vs. non-adopter of GM crops
	sample_size		Indicates the number of data sets for studies with aggregated figures
Geography and physical environment	geographic_country	List of all countries	Further specified in developing, developed and newly industrialized in another table
	Geographic_region	List of regions identified	Identifies specific regions of studies where data are available
	Climate conditions	polar, sub-polar, temperate, continental, Mediterranean, sub-tropical, tropical, desert, very dry, dry, humid, very humid, cold, hot	rough division of climate zones in the world; specific terms for extreme weather events
	Irrigation	yes, no	Indicates, if irrigation was conducted, relevant for interpretation of costs and yields
Economic performance	yield_kg_per_hectare	yield per hectare and year, absolute growth	
	cost_pesticides_per_hectare	Annual pesticide costs, absolute growth	
	costs_herbicides_per_hectare	Annual herbicide costs, absolute growth	
	management_labour_costs_per_hectare	Annual management and labour costs, absolute growth	
	seed_costs_per_hectare	Annual seed costs, absolute growth	
	revenue_per_hectare	Revenue, absolute growth	
	gross_margin	Gross margin, absolute growth	

Annex C. Data analysis for cotton

Figure 6. Cotton yield.

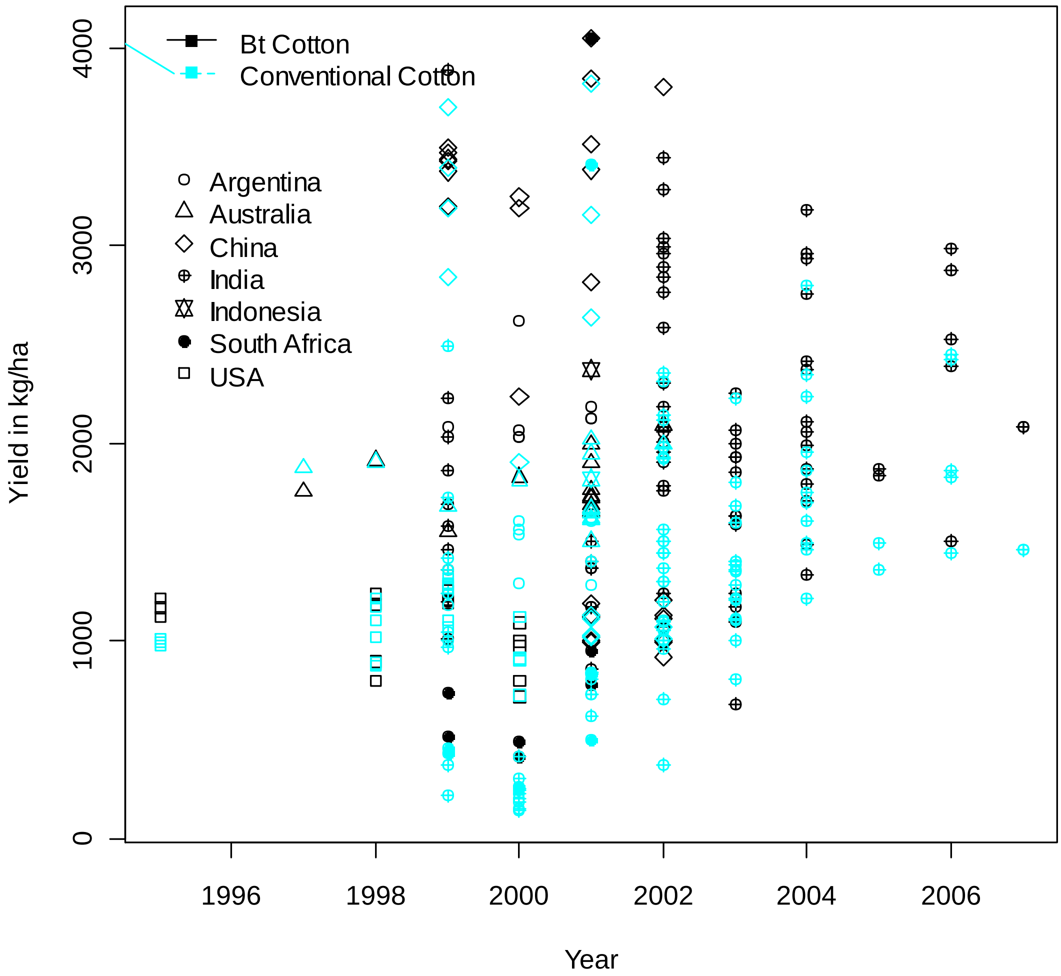

Figure 7. Cotton gross margin

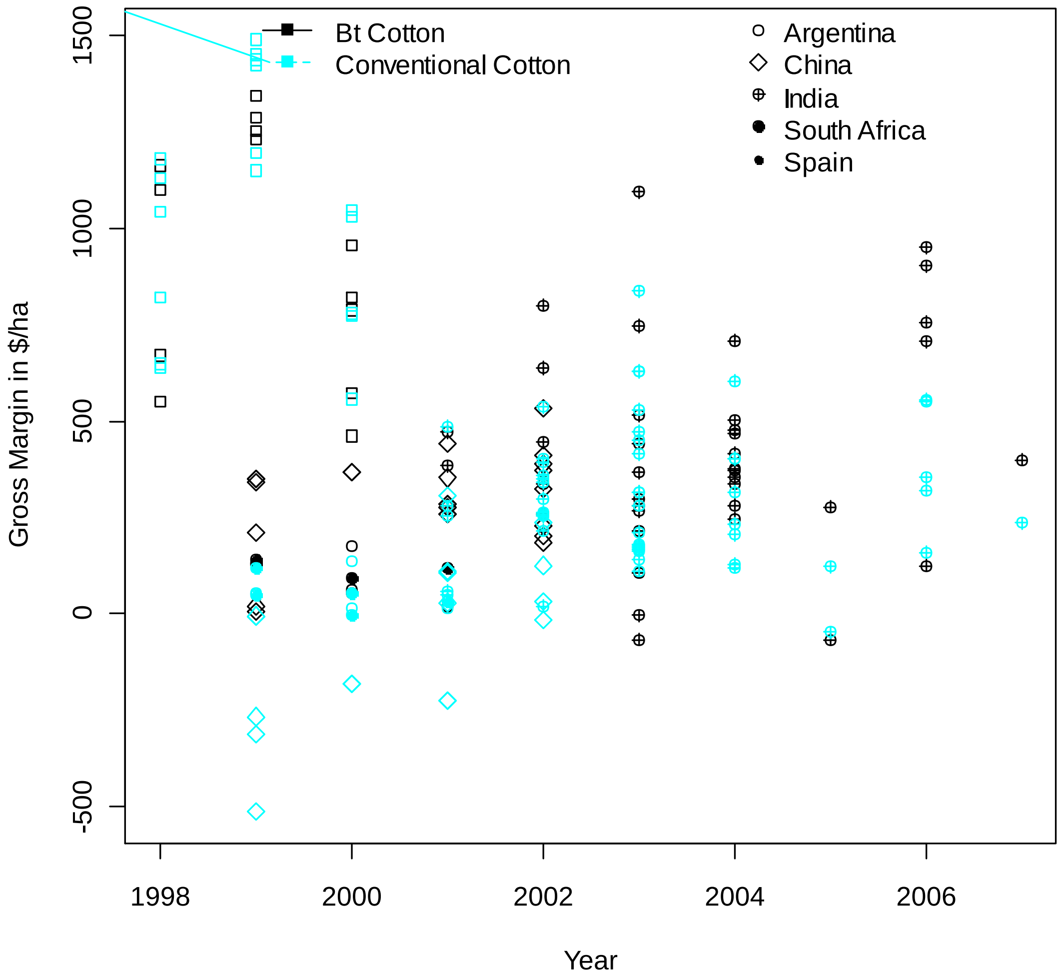

Figure 8. Cotton seed costs

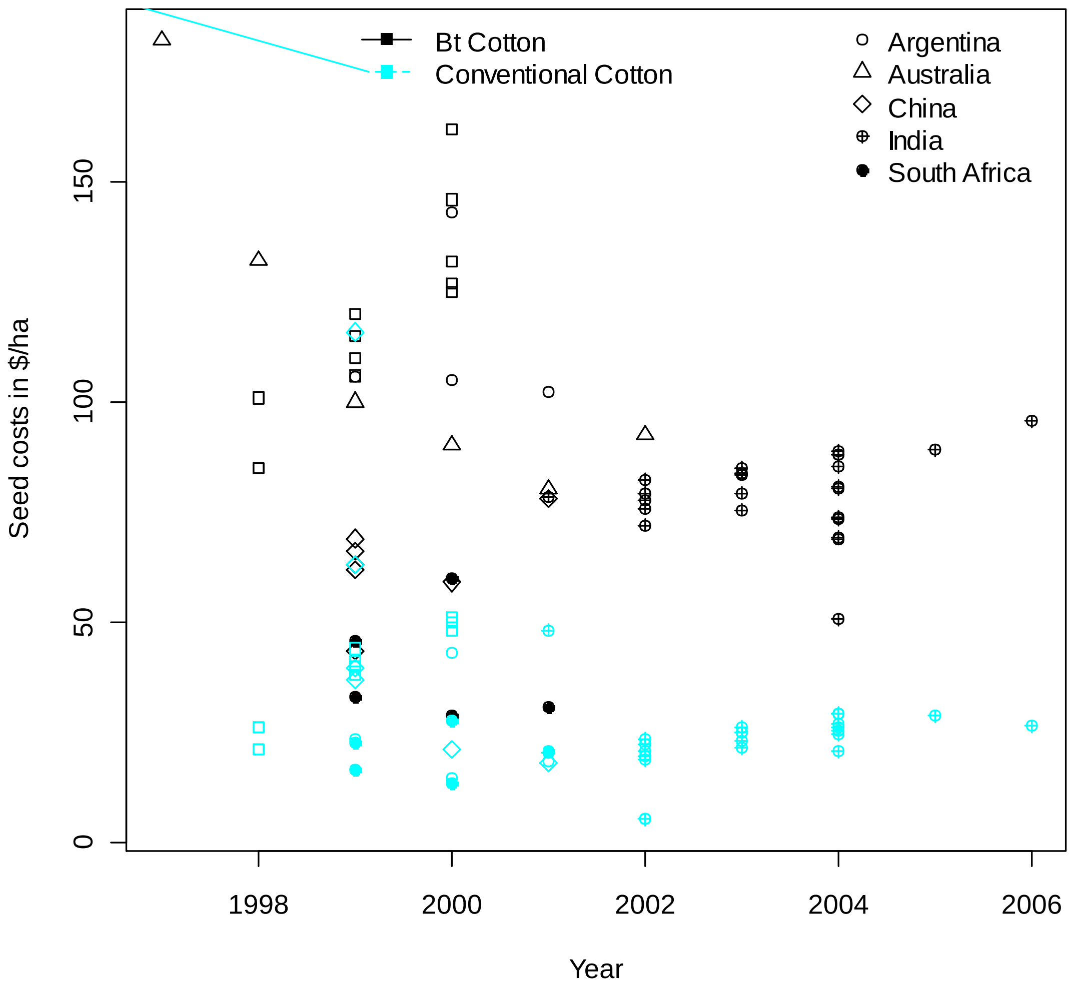

Figure 9. Cotton Pesticide costs

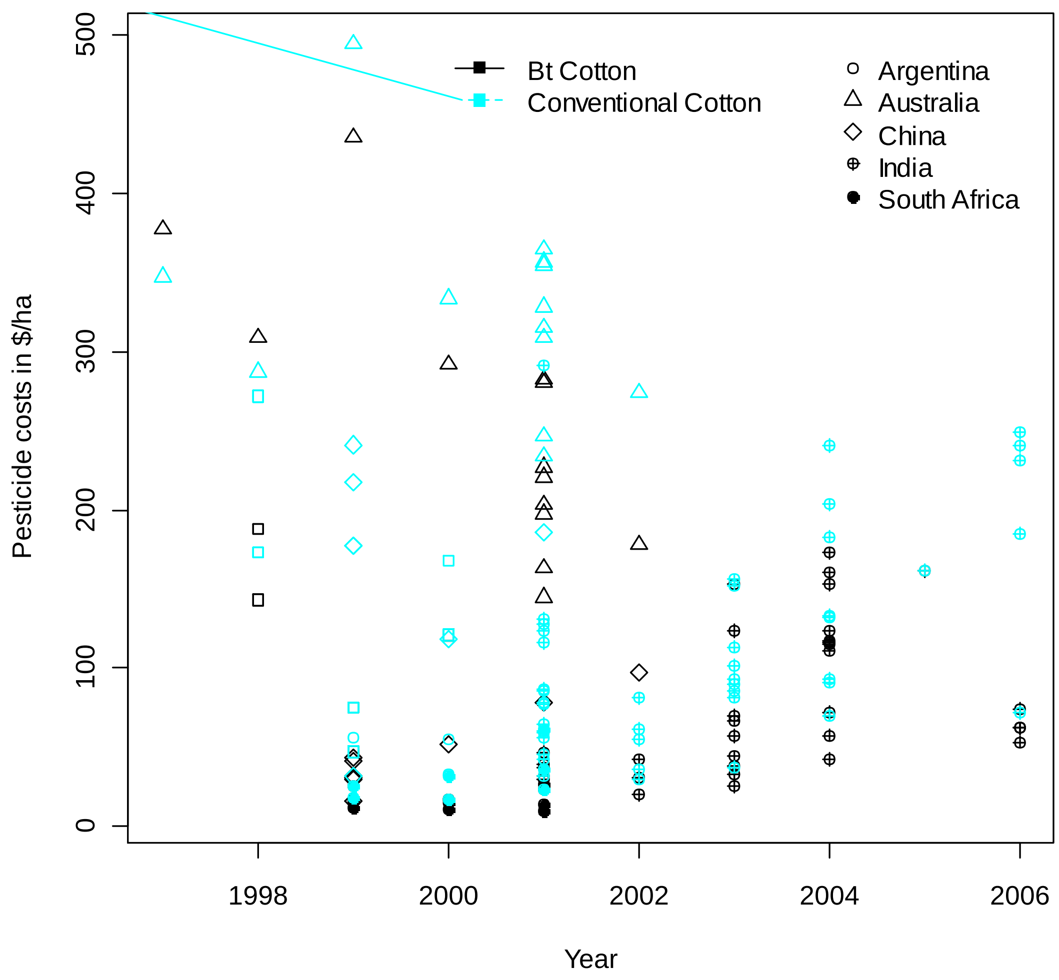

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Figure 10. Cotton management and labour costs.

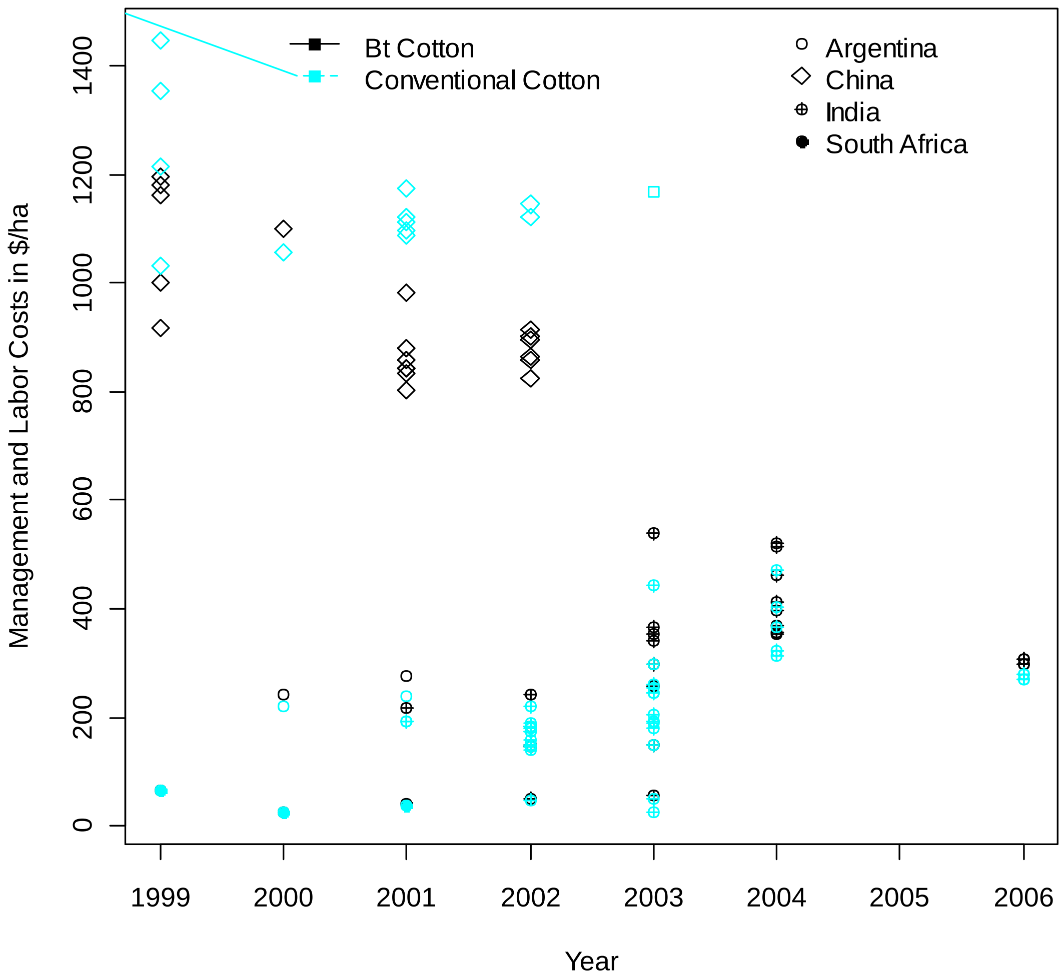


Table 23. Parameter estimates from the regression models on different economic performance indicators for cotton, including country effects.

Economic performance indicator	Yield model	Gross margin model[1]	Seed costs model	Pesticide costs model	Management and labour costs model
Variable	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)
Intercept	6.40031 (36.453)***	5.640648 (11.172)***	2.86297 (10.486)***	3.776202 (15.913)***	4.96992 (21.497)***
Time Effect	0.08543 (3.974)***	0.162901 (1.978)**	0.03739 (0.951)	0.116733 (3.304)***	0.06943 (1.504)
Bt Effect	0.46267 (2.311)**	0.863330 (2.052)**	0.97902 (5.405)***	-0.481912 (-2.293)**	-0.19634 (-0.841)
Bt Effect * Time Effect	-0.01936 (-0.732)	-0.108603 (-1.332)	0.02753 (0.841)	-0.003134 (-0.085)	0.06865 (1.341)
Australia	0.36922 (3.307)***	n.a.	0.61628 (2.902)***	1.599720 (11.100)***	n.a.
China	0.42336 (4.561)***	-0.431838 (-1.457)	0.35414 (2.026)**	0.337557 (1.894)*	1.77562 (12.154)***
Argentina	0.37134 (2.723)***	-0.023985 (-0.048)	0.36880 (2.036)**	-0.590679 (-2.749)***	0.36204 (1.368)
Indonesia	0.47671 (1.332)	n.a.	n.a.	n.a.	n.a.
South Africa	-0.57622 (-3.977)***	0.006829 (0.015)	-0.24446 (-1.391)	-1.037937 (-5.926)***	-1.38781 (-5.875)***
USA	0.01352 (0.117)	1.059318 (2.668)***	0.62804 (3.667)***	0.813195 (4.934)***	1.74602 (3.655)***
Adjusted R-squared	0.28	0.11	0.73	0.65	0.77
Degrees of freedom	292	172	105	164	98

*1) In order to allow for logarithmic regression, all gross margin observations are transformed so that all observations are above zero, with the lowest observation equal to 0.0001. *, **, and *** denote significance at the 10, 5, and 1% levels, respectively. Note that country effects are country means that are evaluated in the regression against an omitted reference dummy (i.e. reference country), which is India for cotton. Due to the small number of observations for some countries, the interpretability of country effects is limited.*

Annex D. Data analysis for maize

Table 24. Parameter estimates from the regression models on different economic performance indicators for maize.

Variable	Yield model	Seed costs model	Pest costs model	Management & Labour costs
	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)
Intercept	9.40815*** (72.957)	5.33144 (37.772)***	2.96521 (3.863)***	6.45246 (41.351)***
Time Effect	-0.01152 (-0.573)	-0.09009 (-1.847)*	-0.08640 (-0.283)	-0.01291 (-0.167)
Bt effect	0.03912 (0.221)	0.47887 (2.564)**	-0.66627 (-0.754)	0.05133 (0.255)
Bt Effect * Time Effect	0.01166 (0.505)	-0.10937 (-2.266)**	-0.23052 (-0.868)	-0.01371 (-0.114)
Adjusted R-squared	0.3316	0.765	0.5423	0.9639
Degrees of freedom	71	45	39	19

, **, and * denote significance at the 10, 5, and 1% level, respectively.*

Table 25. Parameter estimates from the regression models on different economic performance indicators for maize.

Country	Trait	Economic performance indicator				
		Yield	Gross margin	Seed costs	Pesticide costs	Management & Labour costs
Spain	Conv	11840 (N=19)	1214 (N=5)	186.3 (N=12)	23.680 (N=11)	n.a.
	Bt	12500 (N=17)	1333 (N=5)	204.80** (N=13)	10.380** (N=10)	n.a.
	% change	+5.6	+9.8	+9.9	-56.2	n.a.
Germany	Conv	8921 (N=11)	36.50 (N=2)	142.7 (N=11)	117.50 (N=9)	631.0 (N=9)
	Bt	10010 (N=9)	88.50 (N=2)	166.60** (N=8)	88.63** (N=7)	673.7 (N=7)
	% change	+12.2	+142.5	+16.7	-24.6	+6.8
South Africa	Conv	7124 (N=12)	n.a.	n.a.	19.35 (N=5)	n.a.
	Bt	8874 (N=12)	n.a.	n.a.	8.485 (N=4)	n.a.
	% change	+24.6	n.a.	n.a.	-62.4	n.a.
Argentina	Conv	n.a.	62.81 (N=4)	69.3 (N=4)	n.a.	46.20 (N=4)
	Bt	n.a.	73.44 (N=4)	94.5** (N=4)	n.a.	46.00 (N=4)
	% change	n.a.	+16.9	+36.4	n.a.	0%

*N denotes the number of available observations; n.a. signifies that no observations have been available. Comparisons are made with the Mann-Whitney-U test. *, **, and *** denote significance at the 10, 5, and 1% level, respectively.*

Figure 11. Maize yield

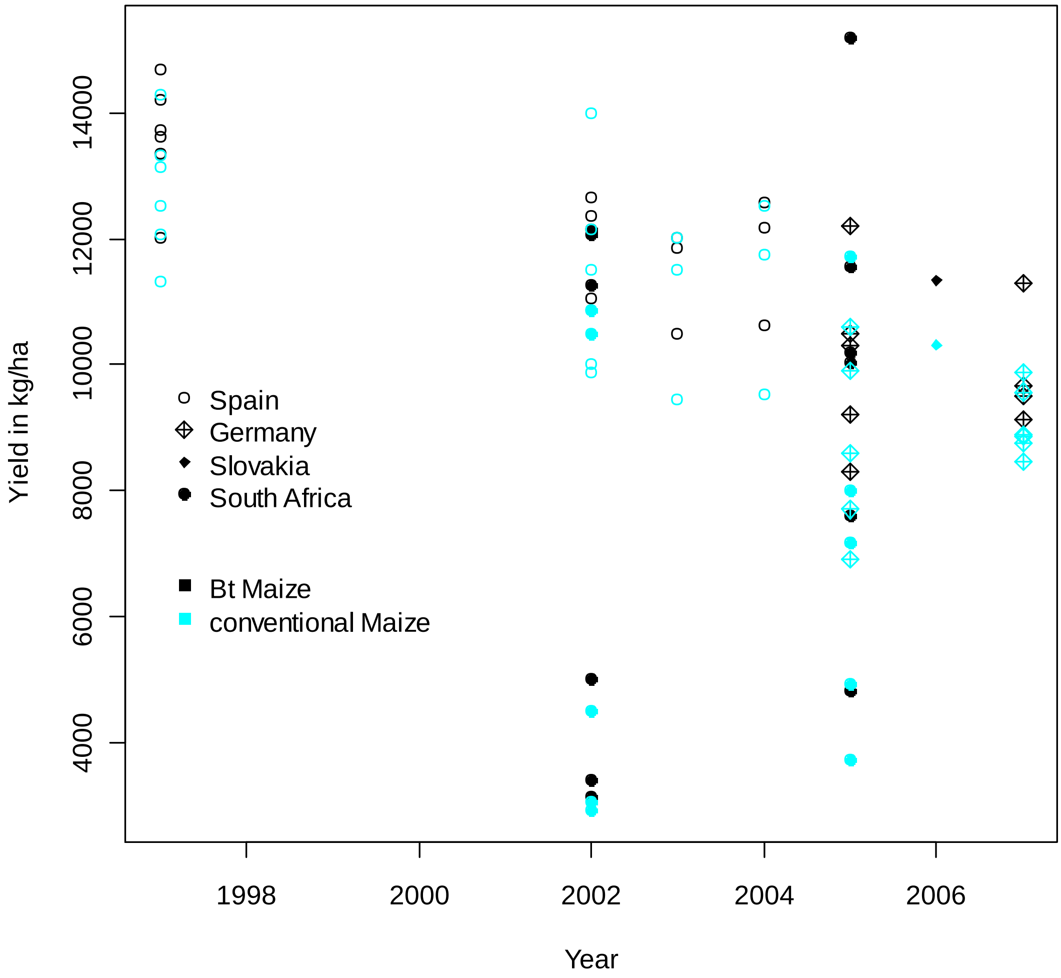


Figure 12. Maize gross margin

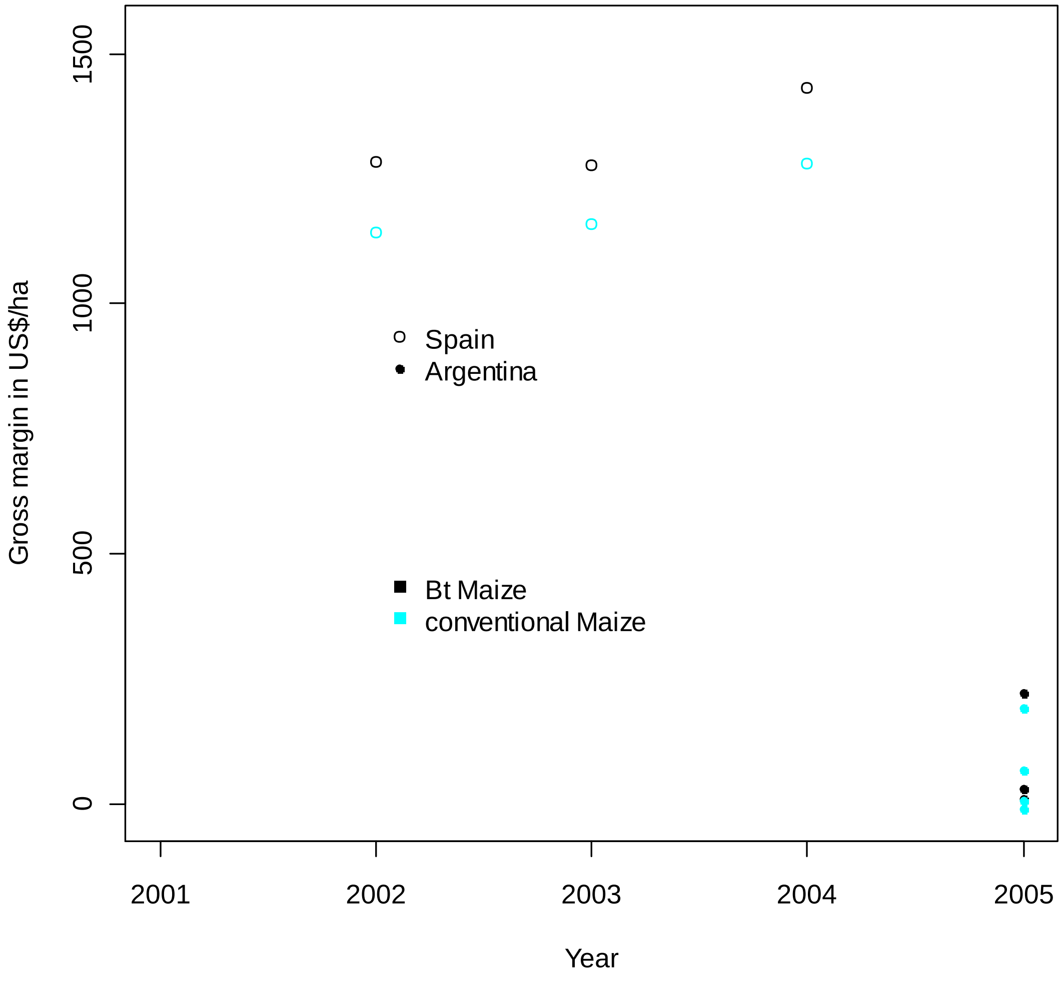


Figure 13. Maize seed costs

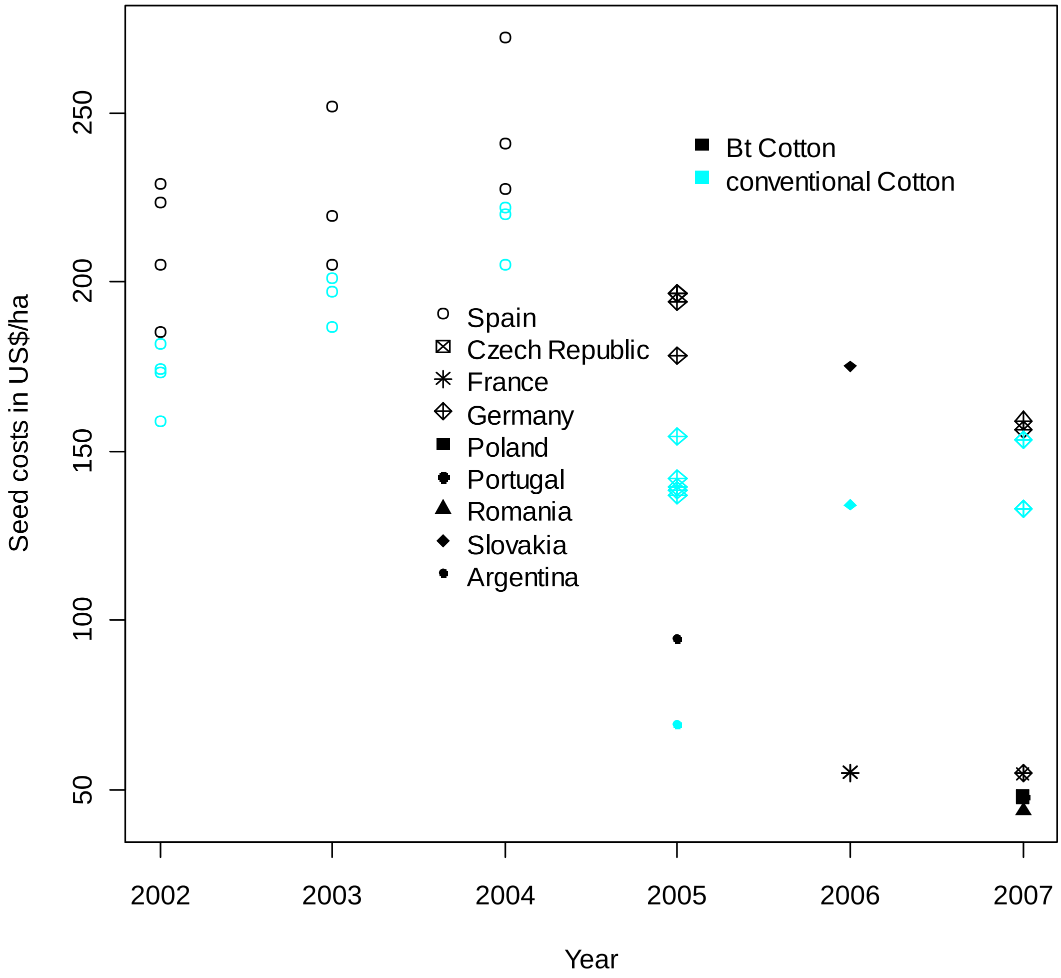


Figure 14. Maize pesticide costs

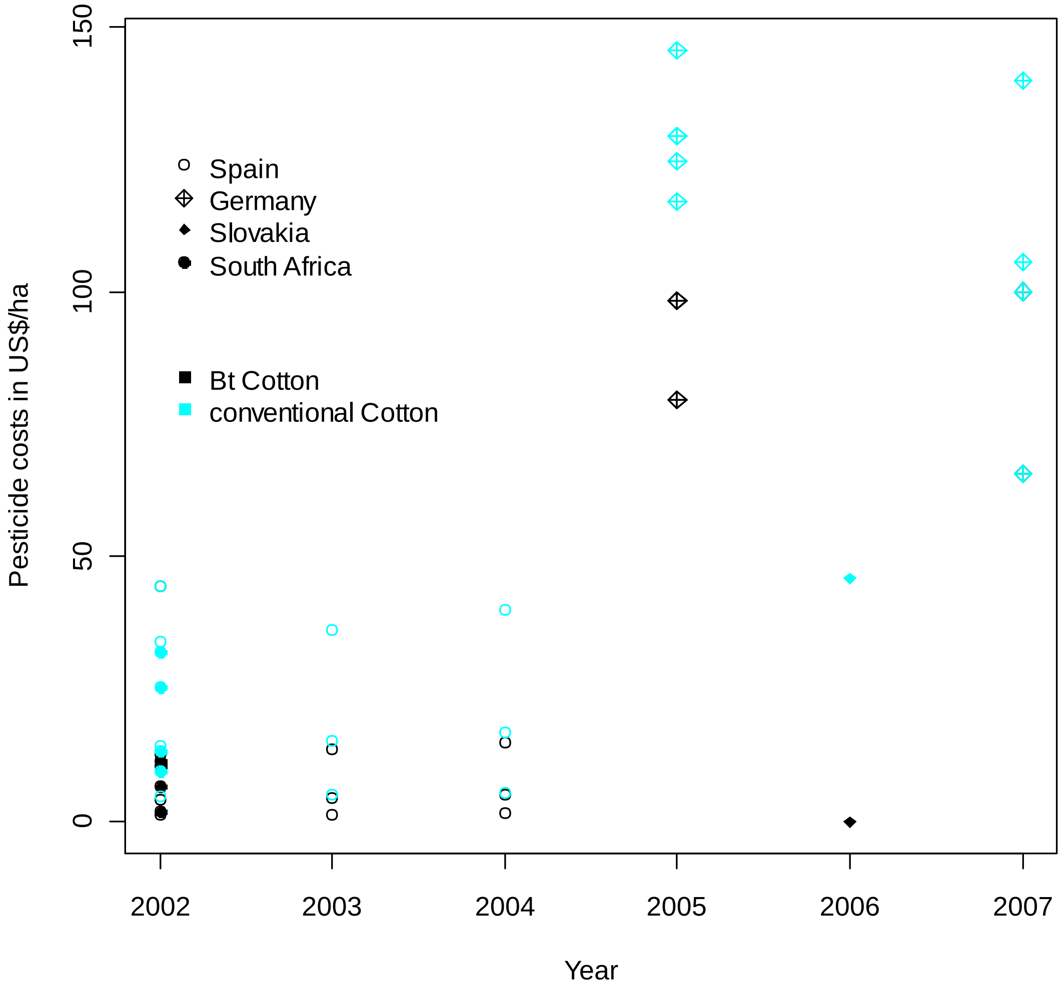


Figure 15. Maize management and labour costs

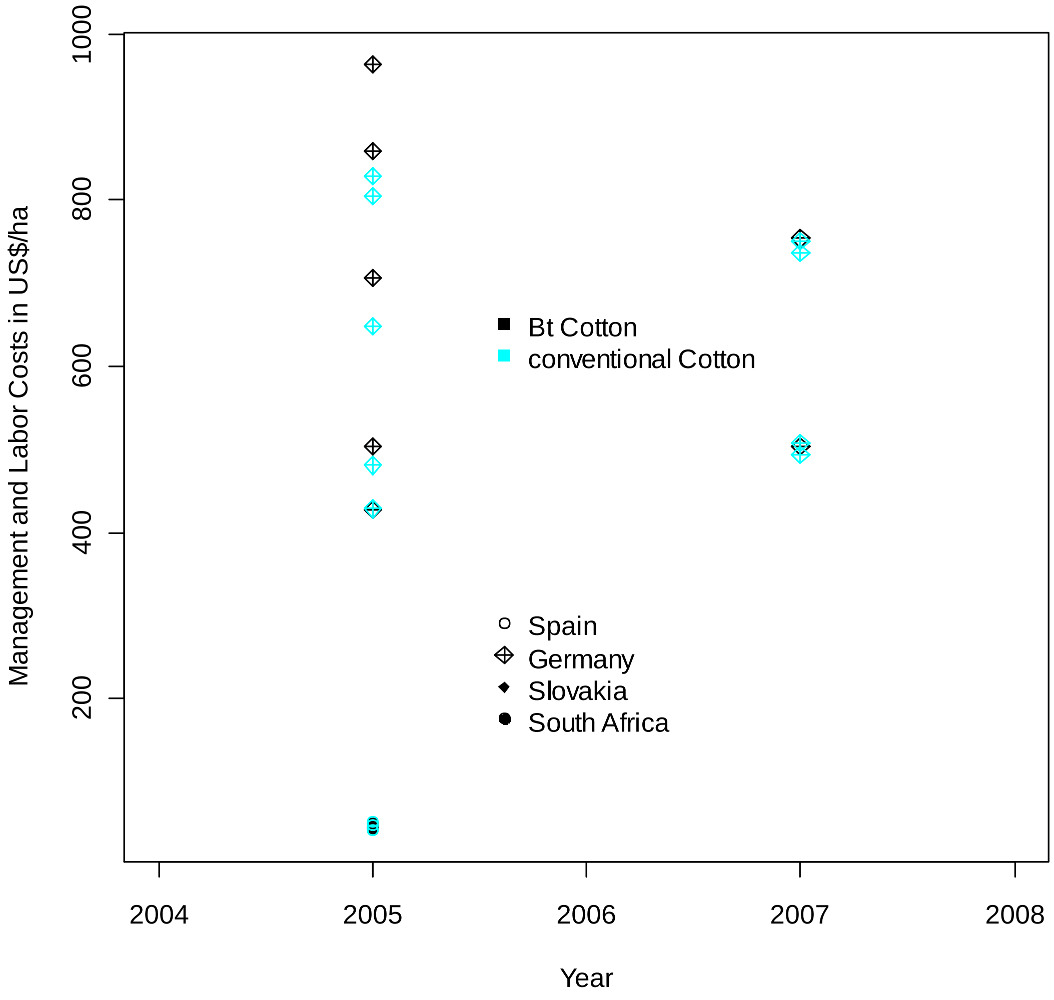


Table 26. Parameter estimates from the regression models on different economic performance indicators for maize, including country effects.

Economic performance indicator	Yield model	Seed costs model	Pesticide costs model	Management and labour costs model
Variable	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)	Parameter (t-value)
Intercept	9.40815*** (72.957)	5.33144 (37.772)***	2.96521 (3.863)***	6.45246 (41.351)***
Time Effect	-0.01152 (-0.573)	-0.09009 (-1.847)*	-0.08640 (-0.283)	-0.01291 (-0.167)
Bt Effect	0.03912 (0.221)	0.47887 (2.564)**	-0.66627 (-0.754)	0.05133 (0.255)
Bt Effect * Time Effect	0.01166 (0.505)	-0.10937 (-2.266)**	-0.23052 (-0.868)	-0.01371 (-0.114)
Czech Republic	n.a.	-0.74275 (-2.316)**	n.a.	n.a.
France	n.a.	-0.75657 (-3.847)***	n.a.	n.a.
Germany	-0.22090 (-1.770)*	0.12533 (0.890)	2.82300 (2.890)***	n.a.
Poland	n.a.	-0.74275 (-2.316)**	n.a.	n.a.
Portugal	n.a.	-0.74275 (-2.316)**	n.a.	n.a.
Romania	n.a.	-0.83253 (-2.596)**	n.a.	n.a.
Slovakia	-0.08236 (-0.340)	-0.12470 (-0.593)	-4.31459 (-2.945)***	n.a.
South Africa	-0.51890 (-5.415)	n.a.	-0.07233 (-0.103)	n.a.
Argentina	n.a.	-0.59825 (-4.399)***	n.a.	-2.63030 (-22.824)***
Adjusted R-squared	0.3316	0.765	0.5423	0.9639
Degrees of freedom	71	45	39	19

, **, and * denote significance at the 10, 5, and 1% level, respectively. Note that country effects are country means that are evaluated in the regression against an omitted reference dummy (i.e. reference country), which is Spain for maize. Due to the small number of observations for some countries, the interpretability of country effects is limited.*

Annex E. Data analysis for soybean

Figure 16. Soybean yield

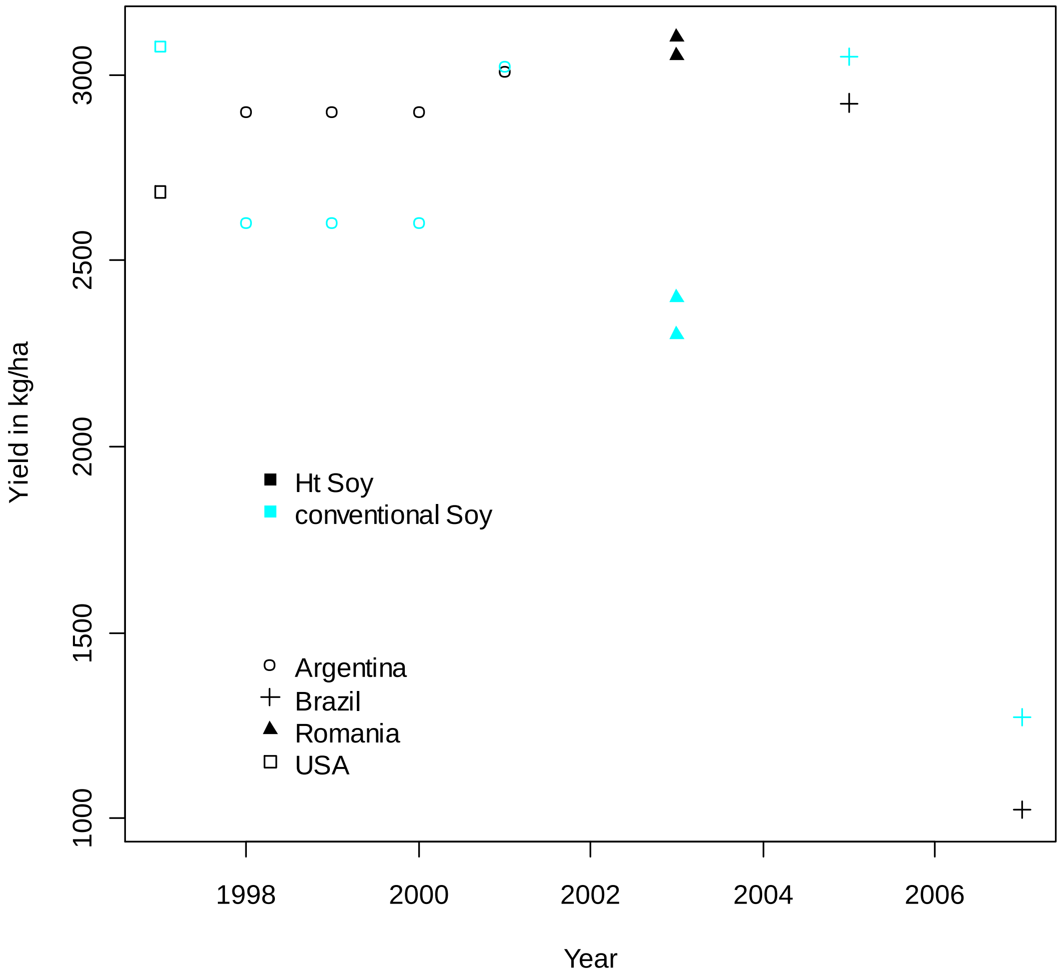


Figure 17. Soybean gross margin

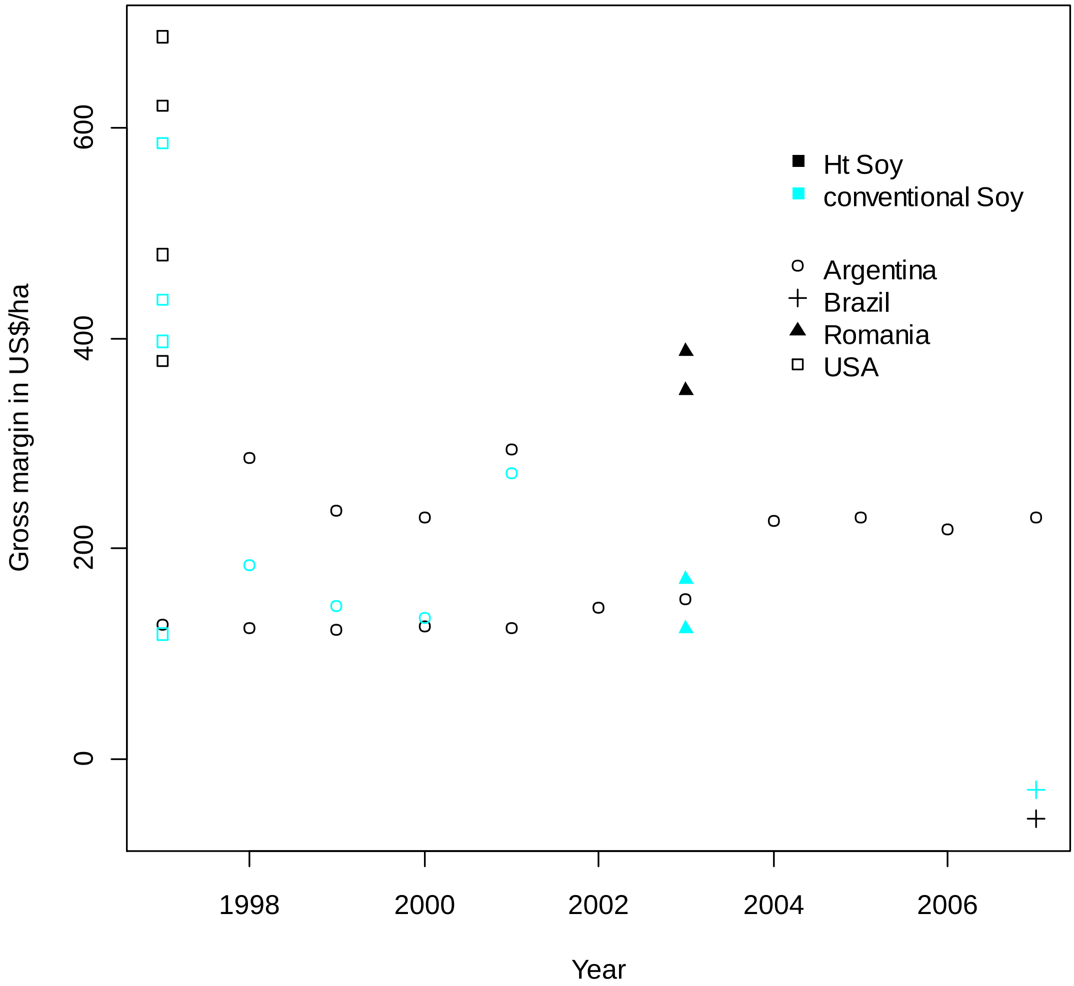


Figure 18. Soybean seed costs

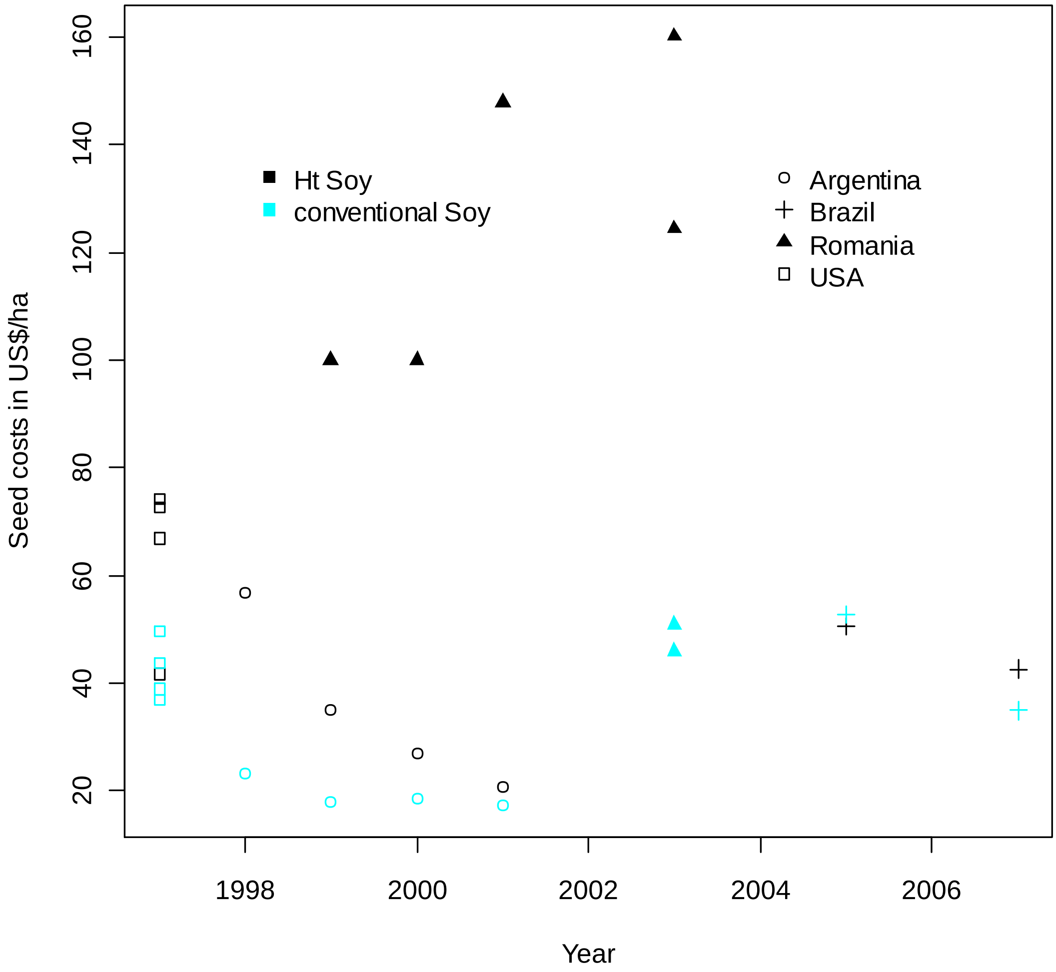


Figure 19. Soybean herbicide costs

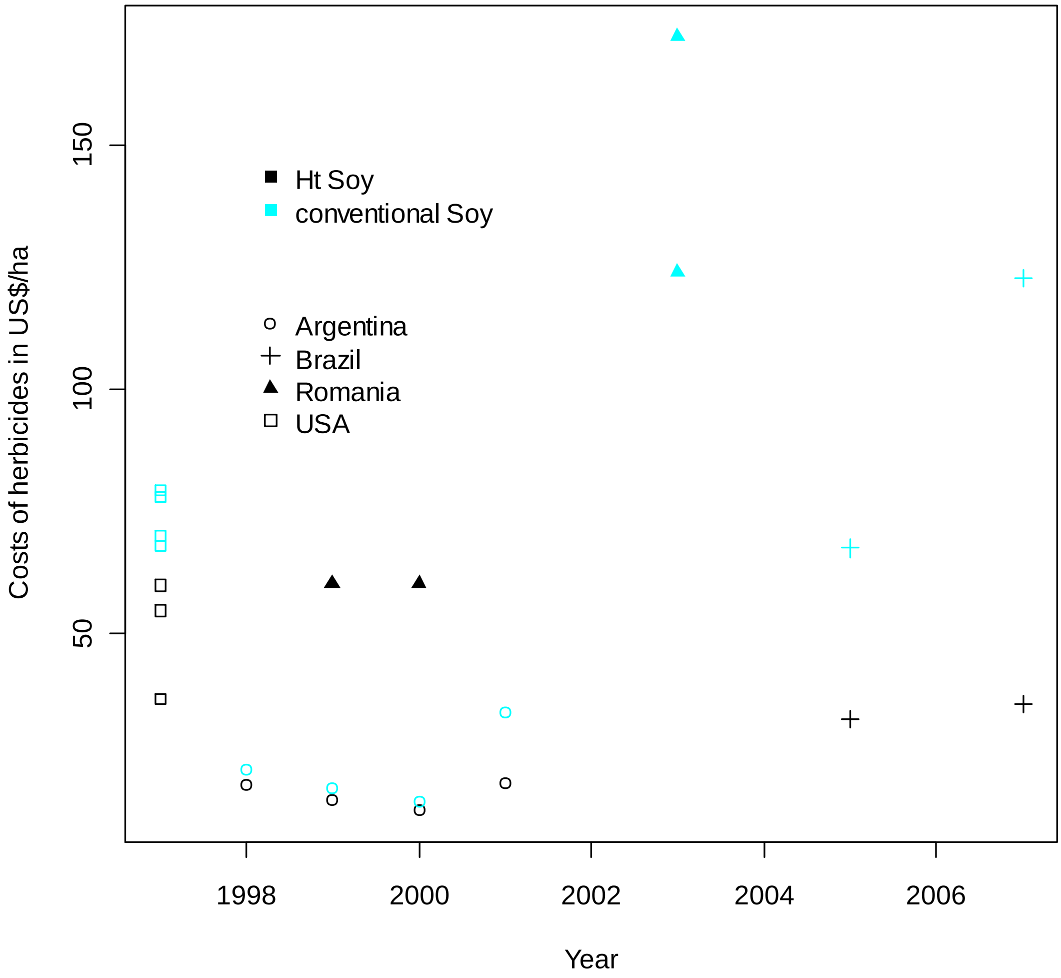
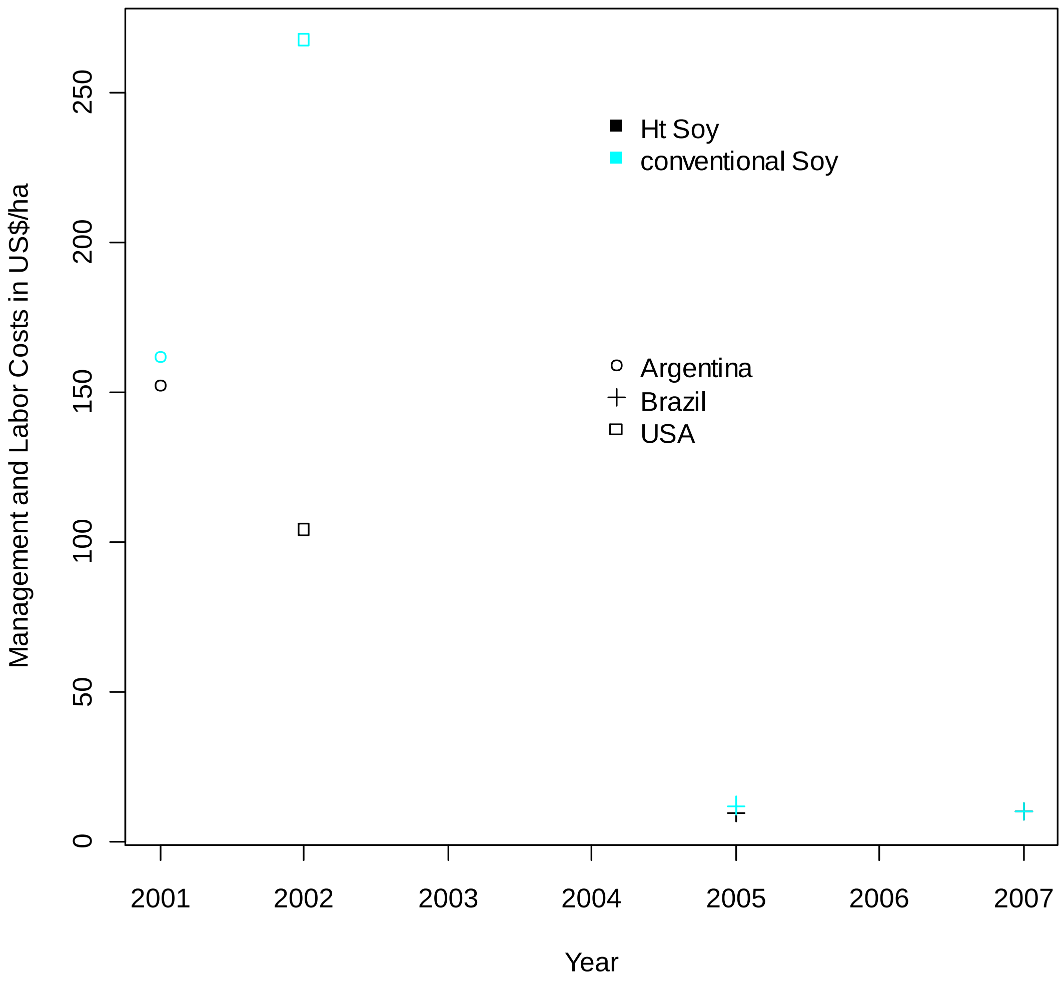


Figure 20. Soybean management and labour costs



Annex F. Statistical analysis with regard to study type

Figure 21. Yield data and study type

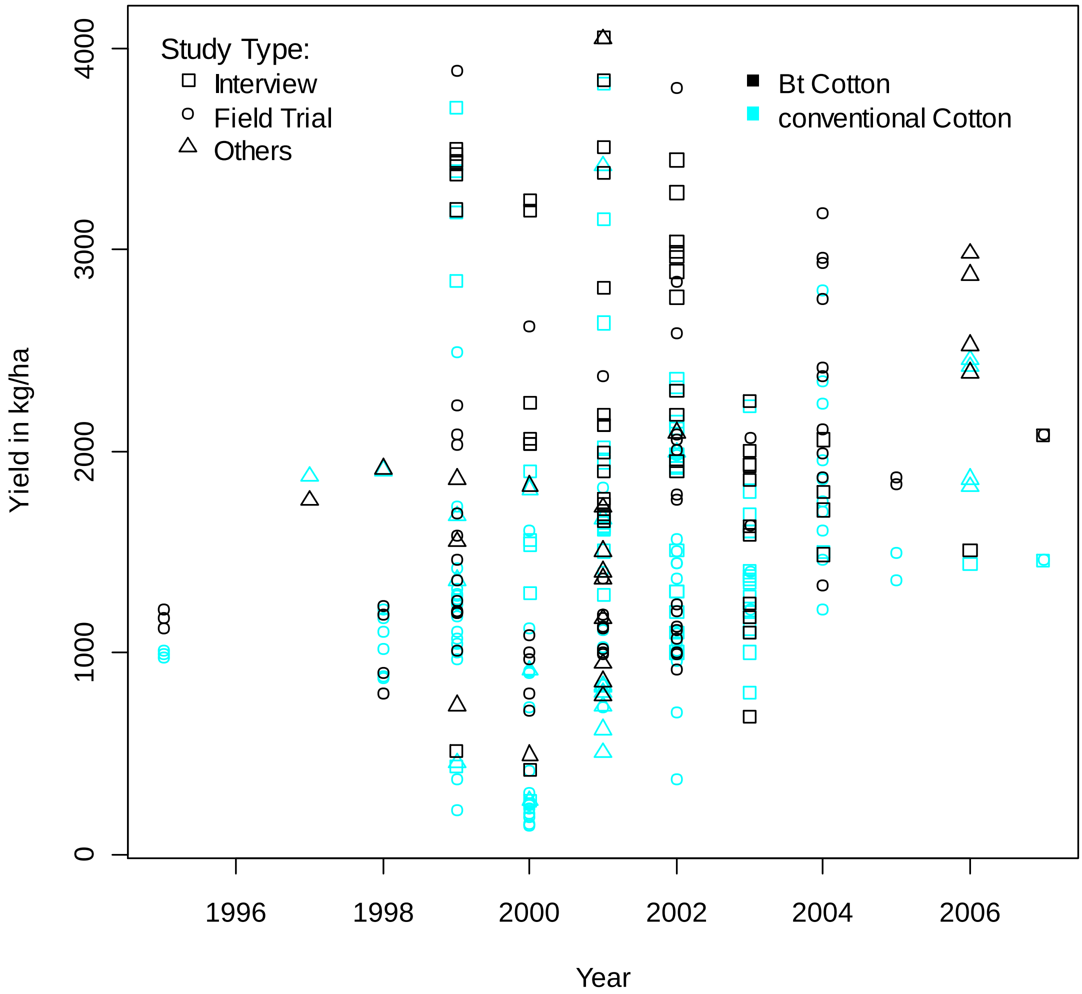


Figure 22. Seed costs data and study type

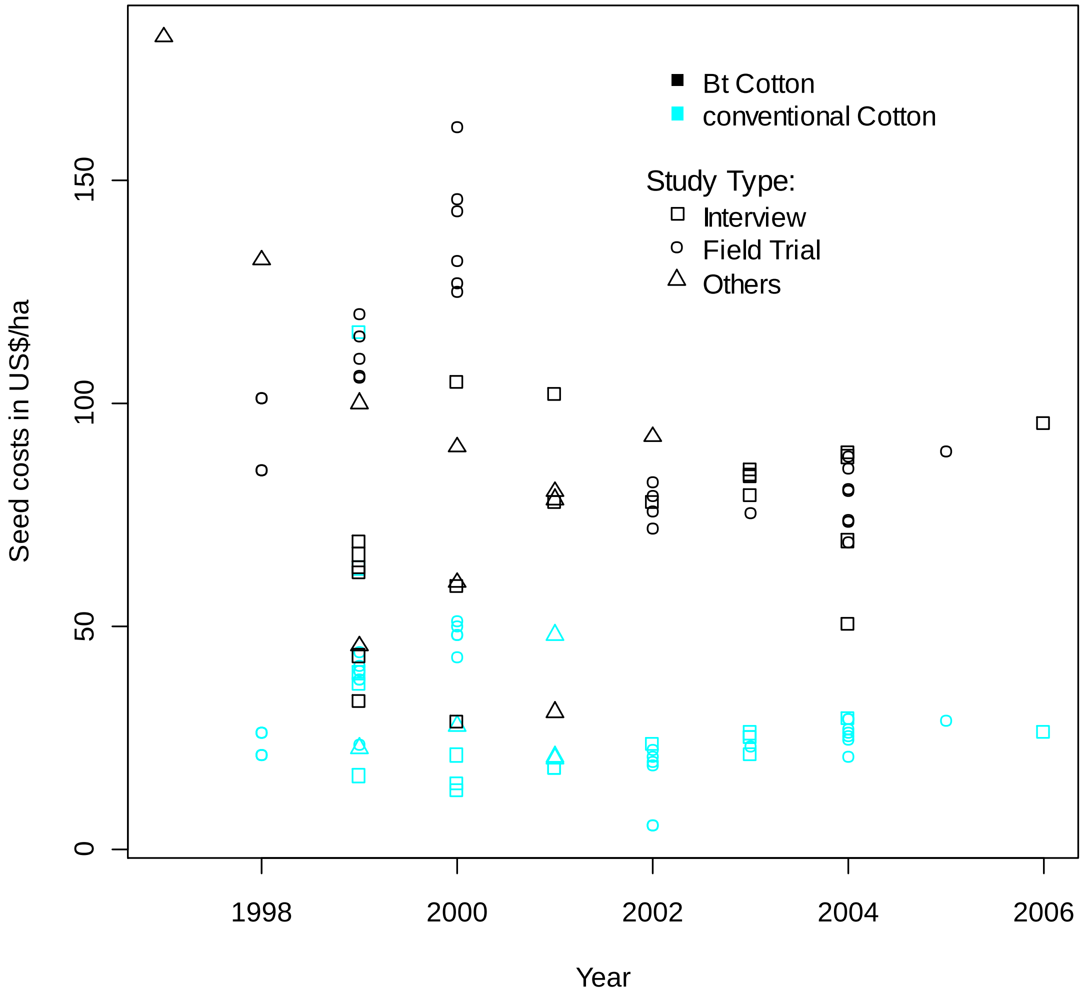


Figure 23. Pesticide costs data and study type

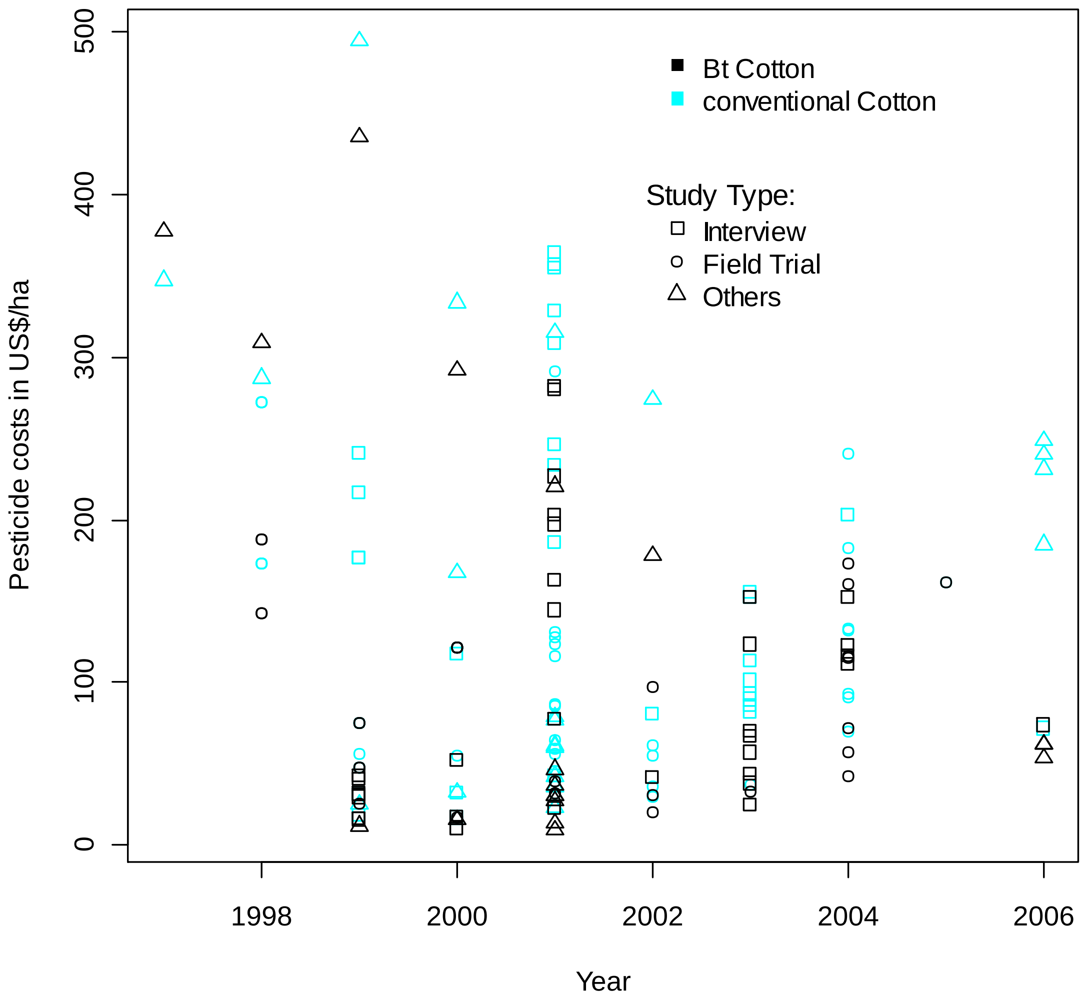


Figure 24. Management and labour cost data and study type

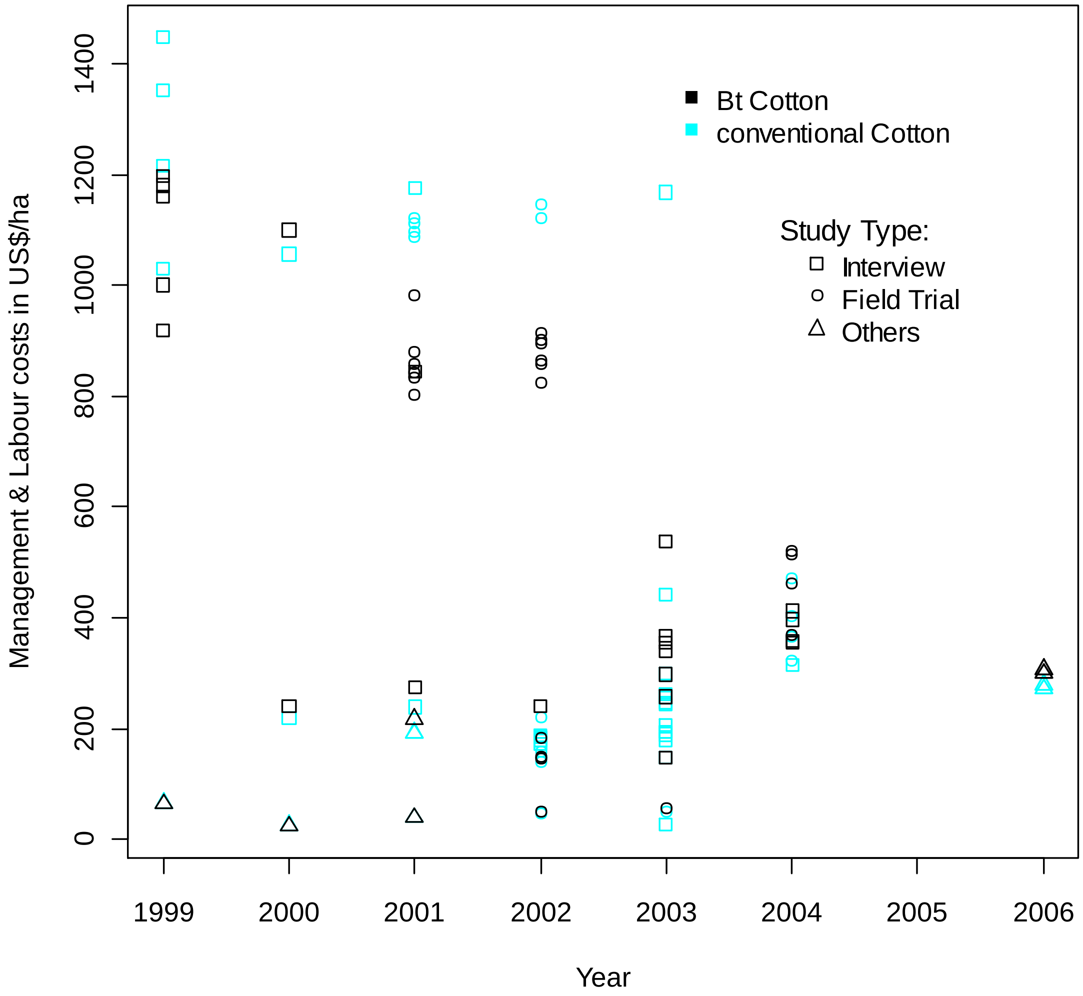


Figure 25. Yield data and study conductor

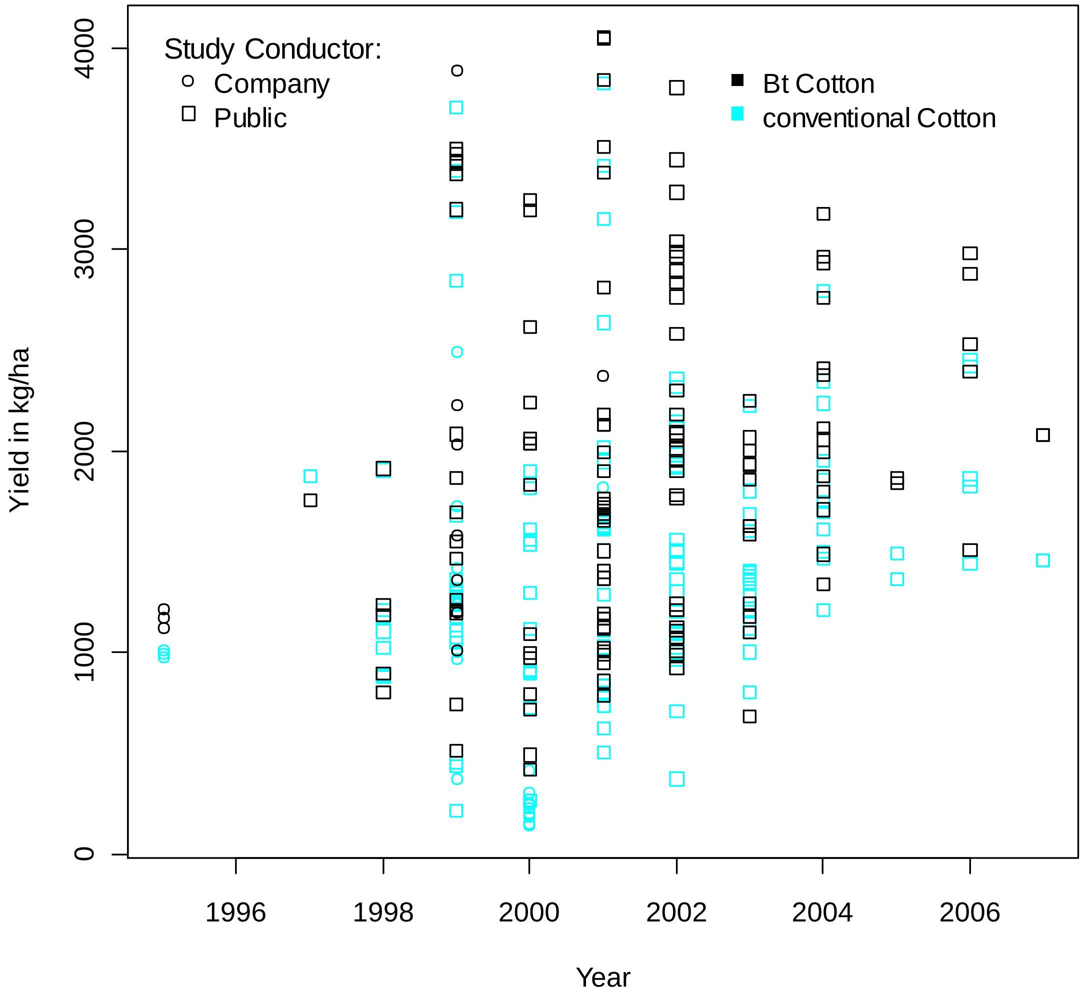
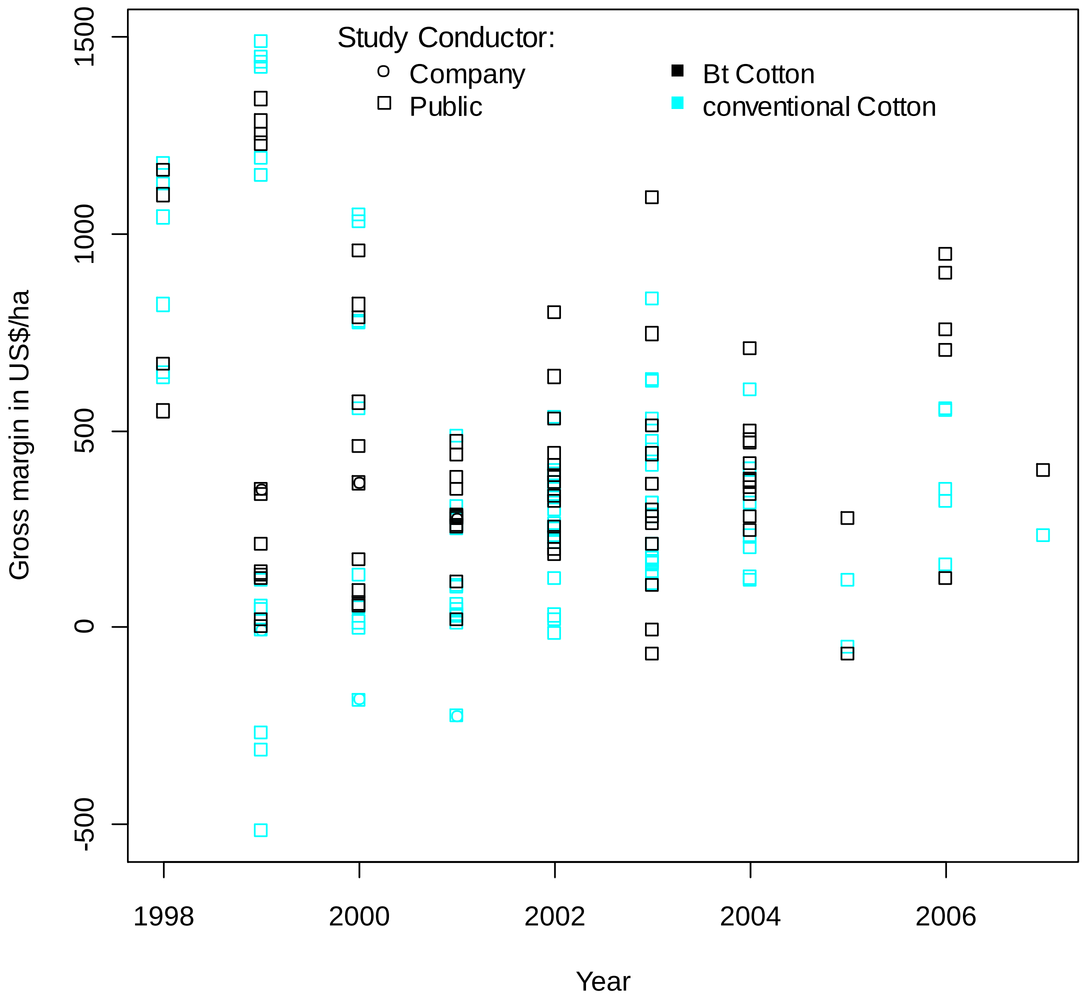


Figure 26. Gross margin data and study conductor



Annex G. List of reviewed literature [35]

Author	Year	Title	Source	Publication in database	Studies from publication in database	Peer-reviewed
Acworth et al	2008	Economic impacts of GM crops in Australia	Australian Bureau of Agricultural and Resource Economics	yes	no	no
AfricaBio	2008	Overview of the Socio-Economic Benefits of Agricultural Biotechnology in South Africa	Conference of the Parties to the Convention on Biological Diversity Serving as the Meeting of the Parties to the Catagena Protocol on Biosafety, 4th meeting, Bomnn, 12-14 May 2008	no	no	no
Ahuja	2007	Indian GM cotton experience in 2005	International NGO Journal Vol. 2 (4), pp. 078 - 081	yes	no	yes
Alderman	2008	Managing risk to increase efficiency and reduce poverty	World Bank BACKGROUND PAPER FOR THE WORLD DEVELOPMENT REPORT 2008	yes	no	no
All India Crop Biotechnology Association	2008	Socio-Economic Impact of Biotechnology in India: Overview of Empirical Studies	All India Crop Biotechnology Association	yes	no	no
Altieri	2000	Ten reasons why biotechnology will not ensure food security, protect the environment and reduce poverty in the developing world	AgBioForum 2(3&4), pp. 155-162	yes	no	yes
Amendola et al	2006	Who Benefits from GM Crops? Monsanto and the Corporate-Driven Genetically Modified Crop Revolution	Friends of the Earth International, Issue 110	no	no	no
Amman	2008	In defense of GM crops	Science 322 (5907): 1465-1466	no	no	yes
Andersen et al	2007	Agricultural studies of GM maize and the field experimental infrastructure of ECOGEN	Pedobiologia-International Journal of Soil Biology 51(3): 175-184	yes	no	yes

[35] (including both references that have been included in the database and other sources, see Section 2.3.)

Author	Year	Title	Source	Publication in database	Studies from publication in database	Peer-reviewed
Andersen et al	2008	Recent and prospective adoption of genetically modified cotton: A global computable general equilibrium analysis of economic impacts	Economic Development and Cultural Change 56(2): 265-296	yes	no	yes
Arshad et al	2009	Farmers' perceptions of insect pests and pest management practices in Bt cotton in the Punjab, Pakistan	International Journal of Pest Management 55(1): 1-10	yes	no	yes
Aulakh et al	2004	Direct and residual effects of green manure and fertilizer nitrogen in a rice-rapeseed production system in the semiarid subtropics	Journal of Sustainable Agriculture 25(1): 97-115	no	no	yes
Bambawale et al.	2004	Performance of Bt cotton (MECH-162) under Integrated Pest Management in farmers' participatory field trial in Nanded district, Central India	CURRENT SCIENCE, VOL. 86, NO. 12, pp. 1628-1633	yes	yes	yes
Barker	2007	What's the impact of a decade of herbicide resistant crops?	Top Crop Manager, pp. 6-7	yes	no	no
Barnett, Gibson	1999	Economic Challenges of Transgenic Crops: The Case of Bt Cotton	Journal of Economic Issues 33(3), pp. 647-659)	yes	no	yes
Barwale et al	2004	Prospects for Bt Cotton Technology in India	AgBioForum 7(1&2)	yes	yes	yes
Bellon, Risopoulos	2001	Small-Scale Farmers Expand the Benefits of Improved maize Germplasm: A Case Study from Chiapas Mexico	World Development 29(5), pp. 799-811	no	no	yes
Benbrook	2001	Do GM Crops Mean Less Pesticide Use?	Pesticide Outlook: 204-207	yes	no	yes
Benbrook	2003	Impact of Genetically Engineered Crops on Pesticide Use in the United States: The First Eight Years	BioTech InfoNet, Technical paper No. 6	yes	no	no
Benbrook	2001	The farm-level economic impact of Bt cotton from 1996 through 2001: An independent National Assessment	Benbrook Consulting Services	yes	no	no
Benbrook	1999	World Food System Challenges and Opportunities: GMOs, Biodiversity and Lessons from America's Heartland	Paper presented January 27, 1999 as part of the University of Illinois World Food and Sustainable Agriculture Program	yes	yes	no

Author	Year	Title	Source	Publication in database	Studies from publication in database	Peer-reviewed
Bennett et al	2003	Bt cotton, pesticides, labour and health - A case study of smallholder farmers in the Makhathini Flats, Republic of South Africa	Outlook on Agriculture 32(2): 123-128	yes	no	yes
Bennett et al	2004	Economic Impact of Genetically Modified Cotton in India	AgBioForum, 7(3): 96-100	yes	no	yes
Bennett et al	2005	Explaining contradictory evidence regarding impacts of genetically modified crops in developing countries. Varietal performance of transgenic cotton in India	Varietal performance of transgenic cotton in India. Journal of Agricultural Science 143 (1): 35-41	yes	yes	yes
Bennett et al	2006	Farm-Level Economic Performance of Genetically Modified Cotton in Maharashtra, India	Review of Agricultural Econommics, Vol. 28 No.1: 59-71	yes	yes	yes
Bennett et al	2007	Inequality and GM Crops: A Case-Study of Bt Cotton in India	AgBioForum 10(1): 44-50	yes	yes	yes
Bennett et al	2004	Reductions in insecticide use from adoption of Bt cotton in South Africa: impacts on economic performance and toxic load to the environment	Journal of Agricultural Science 142: 665-674	yes	yes	yes
Bennett et al	2006	The economic impact of genetically modified cotton on South African smallholders: Yield, profit and health effects	Journal of Development Studies 42(4): 662-677	yes	yes	yes
Bhatti et al	2005	Effect of organic manure and chemical amendments on soil properties and crop yield on a salt affected Entisol	Pedosphere 15(1): 46-51	no	no	yes
Birol et al	2009	Farmer Preferences for Milpa Diversity and Genetically Modified Maize in Mexico: A Latent Class Approach	Environment and Development Economics 14 (4): 521-540	yes	no	yes
Bohanec et al	2008	A qualitative multi-attribute model for economic and ecological assessment of genetically modified crops	Ecological Modelling 215 (1-3): 247-261	yes	no	yes
Bohm et al	2009	Glyphosate- and Imazethapyr-Induced Effects on Yield, Nodule Mass and Biological Nitrogen Fixation in Field-Grown Glyphosate-Resistant Soybean	Soil Biology and Biochemistry 41(2): 420-422	no	no	yes

Author	Year	Title	Source	Publication in database	Studies from publication in database	Peer-reviewed
Bond et al	2005	Economic and Environmental Impacts of Adoption of Genetically Modified Rice in California	University of California Agriculture and Natural Resources publication 350	no	no	no
Boros	2007	Practical experiences Bt Corn Planting in Slovakia	www.innoplanta.de	yes	yes	no
Brookes	2007	The benefits of adopting genetically modified, insect resistant (Bt) maize in the European Union (EU): first results from 1998-2006 plantings	PG Economics Limited	no	no	no
Brookes	2009	The Existing and Potential Impacts of Using GM Insect Resistans (GM IR) Maize in the European Union	PG Economics Limited	yes	yes	no
Brookes	2005	The farm level impact of Herbicide-Tolerant Soybeans in Romania	AgBioForum 8: 235-241	yes	yes	yes
Brookes	2002	The farm level impact of using Bt maize in Spain	PG Economics Limited	yes	yes	no
Brookes	2003	The farm level impact of using Roundup Ready soybeans in Romania	PG Economics Limited	yes	yes	no
Brookes	2008	The impact of using GM insect resistant maize in Europe since 1998	International Journal of Biotechnology 10 (2-3): 148-166	no	no	yes
Brookes	2006	The potential role of GM cost reducing technology in helping the Slovak arable cropping sector remain competitive	PG Economics Limited	no	no	no
Brookes & Barfoot	2008	Global Impact of Biotech Crops: Socio-Economic and Environmental Effects, 1996-2006	PG Economics Limited	no	no	no
Brookes & Barfoot	2009	GM crops: global socio-economic and environmental impacts 1996-2007	PG Economics Limited	yes	yes	no
Brookes & Barfoot	2006	GM Crops: The First Ten Years – Global Socio-Economic and Environmental Impacts	ISAAA Briefs, 36	yes	yes	no

Author	Year	Title	Source	Publication in database	Studies from publication in database	Peer-reviewed
Brush & Chauvet	2004	Maize and Biodiversity: The Effects of Transgenic Maize in Mexico - Chapter 6 Assessment of Social and Cultural Effects Associated with Transgenic Maize Production	Commission for Environmental Cooperation Secretariat Report	yes	yes	no
Bryant et al	2000	Economic evaluation of transgenic cotton systems in Arkansas	Proceedings of the 2000 Cotton Research Meeting	yes	yes	no
Carew & Smith	2006	Assessing the Contribution of Genetic Enhancements and Fertilizer Application Regimes on Canola Yield and Production Risk in Manitoba	Canadian Journal of Agricultural Economics 54 (2): 215-226	yes	no	yes
Carpenter & Gianessi	2001	Agricultural Biotechnology: Updated Benefits estimates	National Centre for Food and Agricultural Policy, NCFAP Report, Washington DC (USA)	yes	no	no
Carpenter & Gianessi	1999	Herbicide Tolerant Soybeans: why growers are adopting Roundup Ready varieties?	AgBioForum 2: 65-72	yes	no	yes
Carpenter et al	2002	Comparative Environmental Impacts of Biotechnology-derived and Traditional Soybean, Corn, and Cotton Crops	Council for Agricultural Science and Technology (Ames, Iowa)	yes	no	no
Carriere et al	2001	Large-Scale Management of Insect Resistance to Transgenic Cotton in Arizona: Can Transgenic Insecticidal Crops be Sustained?	Journal of Economic Entomology 94 (2): 315-25	yes	no	yes
Cattaneo et al	2006	Farm-scale evaluation of the impacts of transgenic cotton on biodiversity, pesticide use, and yield	Proceedings of the National Academy of Sciences of the United State of Americ 103(20): 7571-7576	no	no	yes
Ceddia et al	2008	An ex-ante evaluation of the economic impact of Bt cotton adoption by Spanish farmers facing the EU cotton sector reform	AgBioForum, 11(2): 82-92	yes	yes	yes
Chen et al	2006	Effects of insect-resistance transgenes on fecundity in rice (Oryza sativa, Poaceae): A test for underlying costs	Americal Journal of Botany 93(1): 94-101	no	no	yes
Cotton South Africa	2003	Cotton Market Report as at 1 December 2003	Cotton South Africa	yes	no	no

Author	Year	Title	Source	Publication in database	Studies from publication in database	Peer-reviewed
Cotton South Africa	2004	Cotton Market Report as at 1 December 2004	Cotton South Africa	yes	no	no
Cotton South Africa	2005	Cotton Market Report as at 1 December 2005	Cotton South Africa	yes	no	no
Cotton South Africa	2006	Cotton Market Report as at 1 December 2006	Cotton South Africa	yes	no	no
Cotton South Africa	2007	Cotton Market Report as at 1 December 2007	Cotton South Africa	yes	no	no
Couvillion et al	2000	A preliminary Economic Assessment of Roundup Ready Soybeans in Mississippi	Research report, Mississippi State University, Department of Agricultural Economics	yes	no	no
CropLife Australia	2007	Socio-Economic Benefits of Agricultural Biotechnology Canola and Australian Farming Systems	CropLife Australia	yes	no	no
Crost et al	2007	Bias from Farmer Self-Selection in Genetically Modified Crop Productivity Estimates: Evidence from Indian data	Journal of Agricultural Economics 58(1): 24-36	yes	yes	yes
Darr et al	2000	Estimating Adoption of GMO Soybeans and Corn: A Case Study of Ohio, U.S.A	Working paper			no
de Bianconi et al	2003	Two Years of Insect Protected Bt Transgenic Cotton in Argentina: Regional Field Level Analysis of Financial Returns and Insecticide Use	Journal of New Seeds 5 (2&3): 223-235	yes	no	yes
De Groote et al	2004	Debunking the myths of GM crops for Africa: The case of Bt maize in Kenya	American Agricultural Economics Association Annual Meetings	yes	no	no
Degenhardt et al	2003	Bt maize in Germany: experience with cultivation from 1998 to 2002	Mais 2/2003	yes	yes	no
Demont et al	2008	Herbicide tolerant sugar beet: The most promising first-generation GM crop?	International Sugar Journal 110(1318): 613-617	no	no	yes
Devos at al	2009	Coexistence of Genetically Modified (GM) and non-GM Crops in the European Union. A Review	Agronomy for Sustainable Development 29(1): 11-30	no	no	yes

Author	Year	Title	Source	Publication in database	Studies from publication in database	Peer-reviewed
Diamond & Price	2009	Agrofuels and the Use of Genetic Modification. Report	GeneWatch UK	yes	no	no
Dong et al	2004	Development of hybrid Bt cotton in China – A successful integration of transgenic technology and conventional techniques	Current Science 86(6): 778-782	yes	yes	yes
Doyle et al	2002	The performance of Ingard Cotton in Australia during the 2000/2001 Season	Cotton Research and Development Corporation	yes	yes	no
Dwivedi et al	2005	Effect of green manures of Sesbania rostrata and Vigna radiata and biofertilizers on soil sustainability and crop productivity in rice-wheat cropping system	Physiology and Molecular Biology of Plants 11(1): 141-147	no	no	yes
Edgerton	2009	Increasing Crop Productivity to Meet Global Needs for Feed, Food, and Fuel	Plant Physiology 149: 7-13	yes	no	yes
Egziabher et al	2003	The use of genetically modified crops in agriculture and food production, and their impacts on the environment - A developing world perspective	Acta Agriculturae Scandinavica, Section B – Soil and Plant Science 53: 9-13	no	no	yes
Eicher et al	2006	Crop biotechnology and the African farmer	Food Policy 31(6): 504-527	yes	no	yes
Elbehri & Macdonald	2004	Estimating the Impact of Transgenic Bt Cotton on West and Central Africa: A General Equilibrium Approach	World Development 32(12): 2049-2064	yes	no	yes
Erkossa et al	2006	Tillage effects on sediment enrichment, soil quality, and crop productivity in Ethiopian Highlands	Australian Journal of Soil Research 44(8): 753-758	no	no	yes
Espinoza-Esquivel et al	2007	A multidisciplinary approach directed towards the commercial release of transgenic herbicide-tolerant rice in Costa Rica	Transgenic Research 16(5): 541-555	no	no	yes
European Commission	2002	Economic Impacts of Genetically Modified Crops on the Agri-Food Sector. Working Document Rev. 2	EC, DG Agriculture	no	no	no

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European Commission	2009	Report from the Commission to the Council and the European Parliament on the coexistence of genetically modifed crops with conventional and organic farming, SEK(2009) 408	http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0153:FIN:en:PDF	yes	no	no
European Commission, DG Agriculture	2000	Economic Impact of Genetically Modified Crops on the Agri-Food Sector. A synthesis	European Commission, DG Agriculture	yes	no	no
FAO	2004	Economic Impacts of Transgenic Crops	FAO	yes	no	no
FAO	2004	The State of Food and Agriculture 2003-04 - Agricultural Biotechnology: Meeting the needs of the poor? Section B: The evidence so far. Chapter 4: Economic impacts of transgenic crops.	FAO	yes	yes	no
Feil et al	2003	Controlling the release of pollen from genetically modified maize and increasing its grain yield by growing mixtures of male-sterile and male-fertile plants	Euphytica 130(2): 163-165	no	no	yes
Fernandez-Cornejo & Caswell	2006	The First Decade of Genetically Engineered Crops in the United States. Electronic Report	United States Department of Agriculture, Economic Research Service, Economic Information Bulletin No. 11	yes	no	no
Fernandez-Cornejo & McBride	2002	Adoption of bioengineered Crops	USDA Economic Research Service, Agricultural Economics Report 810, Washington DC (USA)	yes	no	no
Fernandez-Cornejo & McBride	2000	Genetically engineered crops for pest management in US agriculture: farm-level effects	USDA-Agricultural Economic Service, Agricultural Economics Report 786, Washington DC (USA)	yes	yes	no
Fernandez-Cornejo et al	2002	Farm-Level Effects of Adopting Herbicide-Tolerant Soybeans in the USA	Journal of Agricultural and Applied Economics 24(1): 149-163	yes	no	yes
Fitt	2003	Implementation and Impact of Transgenic Bt Cottons in Australia	Cotton Production for the New Millenium. Proceedings Third World Cotton Research Conference, 9-13 March 2003, Cape Town, South Africa: pp. 371-381	yes	yes	no

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Flannery et al	2004	An Economic Cost-Benefit Analysis of GM Crop Cultivation: An Irish Case Study	AgBioForum, 7(4): 149-157	no	no	yes
Fok et al	2006	Cotton production by family farms in China: Strengths and weaknesses of its integration into a market economy	Cahiers Agricultures 15(1): 42-53	no	no	yes
Freese & Vilar	2008	Who Benefits from GM Crops? The Rise in Pesticide Use	Friends of the Earth International	no	no	no
Friswold et al	2006	Bt Cotton Adoption in The United States and China: International Trade and Welfare Effects	AgBioForum 9(2): 69-78	yes	no	yes
Fulton & Keyowski	1999	The Producer Benefits Of Herbicide-Resistant Canola	AgBioForum 2(2): 85-93	yes	yes	yes
Furlaneto et al	2007	Análise comparative de estimativas de custo de producao e de rentabilidade entre as cultural de soja conventional e transgênica na regiao de assis, estado de Sao Paulo, Safra 2006/07	Informações Econômicas vol.37, n.12	yes	yes	yes
Gandhi & Namboodiri	2006	The Adoption and Economics of Bt Cotton in India: Preliminary Results from a Study	IIMA Working Paper 206-09-04	yes	yes	no
Gardener et al	2009	Genetically Modified Crops and Household Labor Savings in US Crop Production	AgBioForum 12(3&4): 303-312	yes	yes	yes
GeneWatch UK	2000	Genetically Modified Crops in the UK - the Current Situation	Farmers Information Series, Briefing 1 – September 2000	no	no	no
GeneWatch UK	2008	GeneWatch UK response to: Biological approaches to enhance food-crop production: a call for evidence by the Royal Society	GeneWatch UK	yes	no	no
GeneWatch UK	2000	Growing Genetically Modified Crops - Financial and Farm Management Implications	Farmers Information Series, Briefing 2 – September 2000	yes	no	no
GeneWatch UK	2000	The Market for Genetically Modified Crops	Farmers Information Series, Briefing 3 – September 2000	no	no	no
Gianessi	2005	Economic and herbicide use impacts of glyphosate-resistant crops	Pest Management Science 61: 241-245	yes	no	yes

Author	Year	Title	Source	Publication in database	Studies from publication in database	Peer-reviewed
Gianessi & Carpenter	2000	Agricultural Biotechnology: Benefits of Transgenic Soybeans	National Center for Food and Agricultural Policy	yes	no	no
Gianessi & Carpenter	1999	Agricultural Biotechnology: Insect Control Benefits	National Center for Food and Agricultural Policy: 1-78	yes	no	no
Gianessi et al	2003	Plant Biotechnology: Potential Impact for Improving Pest Management in European Agriculture	Report, The National Center for Food and Agricultural Policy	yes	no	no
Glenna et al	2007	Organic and conventional Washington State farmers' opinions on GM crops and marketing strategies	Renewable Agriculture and Food Systems 22(2): 118-124	no	no	yes
Glick	2001	Herbicide tolerant crops: a review of agronomic, economic and environmental impacts	BCPC Conference - Weeds 2001, Vols 1and 2: 359-366	no	no	no
Gomez-Barbero & Rodriguez-Cerezo	2006	Economic Impact of Dominant GM Crops Worldwide: A Review	Technical Report Series. European Commission Directorate-General Joint Research Centre (DG JRC) and Institute for Prospective Technological Studies (IPTS)	yes	no	no
Gomez-Barbero & Rodriguez-Cerezo	2006	GM Crops in EU Agriculture: Case Study for the BIO4EU Project	European Commission Directorate-General Joint Research Centre (DG JRC)	yes	yes	no
Gomez-Barbero et al	2008	Adoption and performance of the first GM crop introduced in EU agriculture: Bt maize in Spain	JRC Schientific and Technical report	yes	yes	no
Gouse et al	2005	A GM subsistence crop in Africa: the case of Bt white maize in South Africa	AgBioForum 9(1): 84-94	yes	yes	yes
Gouse et al	2005	Bt Cotton in KwaZulu Natal: Technological Triumph but Institutional Failure	AgBiotechNet	yes	no	no
Gouse et al	2003	BT Cotton in South Africa: Adoption and the Impact on Farm Incomes amongst Small-Scale and Large Scale Farmers	Working paper: 2002-15 Department of Agricultural Economics, Extension and Rural Development University of Pretoria,South Africa	yes	yes	no
Gouse et al	2006	Monsanto's Adventures in Zulu Land: Output and Labour Effects of GM Maize and Minimum Tillage	International Association of Agricultural Economists 2006 Annual Meeting, August 12-18, 2006, Queensland, Australia	yes	no	no

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Gouse et al	2006	Output and Labour Effects of GM Maize and Minimum Tillage in a Communal Area of Kwazulu-Natal	Journal of Development Perspectives 2(2): 71-86	yes	no	yes
Gouse et al	2004	The Distribution of Benefits from Bt Cotton Adoption in South Africa	AgBioForum, 7(4): 187-194	yes	yes	yes
Gouse et al	2006	Three Seasons of Subsistence Insect-Resistant Maize in South Africa: Have Smallholders Benefited?	AgBioForum 9(1): 15-22	yes	yes	yes
GRAIN	2008	Lessons from Green Revolution in South Africa	GRAIN	no	no	no
GRAIN	2009	Twelve Years of GM Soya in Argentina: A Disaster for People and the Environment	GRAIN	no	no	no
Greenpeace	2004	GE Contamination, the Ticking Time-Bomb	Greenpeace	yes	no	no
Grueve et al	2008	Bt Cotton and Farmer Suicides in India. Reviewing the Evidence	IFPRI Discussion Paper 808	yes	no	no
Guehlstorf	2008	Understanding the Scope of Farmer Perceptions of Risk: Considering Farmer Opinions on the Use of Genetically Modified (GM) Crops as a Stakeholder Voice in Policy	Journal of Agricultural and Environmental Ethics 21(6): 541-558	yes	no	yes
Gupta & Chandak	2005	Agricultural biotechnology in India: ethics, business and politics	Esocialsciences Working Paper 884	yes	yes	no
Gurian-Sherman	2009	Failure to Yield: Evaluating the Performance of Genetically Engineered Crops	Union of Concerned Scientists	no	no	no
Hareau et al	2005	The potential benefits of herbicide-resistant transgenic rice in Uruguay: Lessons for small developing countries	Food Policy 31(2): 162-179	no	no	yes
Herring	2009	Persistent Narratives: Why is the “Failure of Bt Cotton in India” Story Still with Us?	AgBioForum, 12(1): 14-22	yes	no	yes
Herring	2008	Whose numbers count? Probing discrepant evidence on transgenic cotton in the Warangal district of India	International Journal of Multiple Research Approaches (2008) 2: 145–159	yes	no	yes

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Herring	2006	Why did "Operation Cremate Monsanto" fail?	Critical Asian Studies 38(4): 467-493	yes	no	yes
Hilocks	2005	Is there a role for Bt cotton in IPM for smallholders in Africa?	International Journal of Pest Management 51(2): 131-141	yes	no	yes
Ho et al	2009	Access and control of agro-biotechnology: Bt cotton, ecological change and risk in China	Journal of Peasant Studies 36(2): 345-364	yes	yes	yes
Hofs et al	2006	Gnetically modified cotton (Gossypium hirsutum L. Bt.): what future for small family farms in French-speaking Africa?	Biotechnologie Agronomie Societe et Environnement 10(4): 335-343	no	no	yes
Hofs et al	2006	Impact of Bt cotton adoption on pesticide use by smallholders: A 2-year survey in Makhatini Flats (South Africa)	Crop Protection 2525(9): 984-988	no	no	yes
Hofs et al	2006	Impact of Bt cotton adoption on pesticide use by smallholders: A 2-year survey in Makhatini Flats (South Africa)	Crop Protection 25: 984–988	yes	no	yes
Horna et al	2009	Cotton Production in Uganda: Would GM technologies be the Solution?	Contributed Paper prepared for presentation at the International Association of Agricultural Economists Conference, Beijing, China, August 16-22, 2009	yes	no	no
Huang	2002	Transgenic varieties and productivity of smallholder cotton farmers in China	The Australian Journal of Agricultural and Resource Economics 46(3): 367-387	yes	yes	yes
Huang et al	2003	Biotechnology as an alternative to chemical pesticides: a case study of Bt cotton in China	Agricultural Economics 29(1): 55-67	yes	yes	yes
Huang et al	2004	Biotechnology boosts to crop productivity in China: trade and welfare implications	Journal of Development Economics 75(1): 27-54	yes	no	yes
Huang et al	2002	Bt Cotton Benefits, Costs, and Impacts in China	AgBioForum, 5(4): 153-166	yes	yes	yes

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Huang et al	2003	Economic Impacts of Genetically Modified Crops in China	Proceedings of the 25th International Conference of Agricultural Economists (IAAE) 16 – 22 August 2003: 1075-1083	yes	no	no
Huang et al	2002	Five years of Bt cotton in China - the benefits continue	The Plant Journal 31(4): 423-430	yes	yes	yes
Huang et al	2005	Insect-resistant GM rice in farmers' fields: Assessing productivity and health effects in China	Science 308(5722): 688-690	yes	no	yes
Huang et al	2006	Plant Biotechnology in China: public investments and impacts on farmers	Science 295(5555): 674 - 676	yes	yes	yes
IFOAM	2008	Annual Report 2008	International Federation of Organic Agriculture Movements (IFOAM) – EU Regional Group			no
ISAAA	2009	Biotech Crops in India: The Dawn of a New Era	ISAAA South Asia office	yes	no	no
Ismael et al	2003	Benefits from Bt cotton use by smallholder farmers in South Africa	AgBioForum 5(1): 1-5	yes	yes	yes
Ismael et al	2002	Farm level impact of Bt cotton in South Africa	Biotechnology and Development Monitor 48: 15-19	yes	yes	yes
Ismael et al	2002	Farm-level economic impact of biotechnology: smallholder Bt cotton farmers in South Africa	Outlook on Agriculture 31(2): 107-111	yes	no	yes
James	2002	Global Review of Commercialized Transgenic Crops: 2001 Feature: Bt Cotton	ISAAA Briefs, 26	yes	yes	no
James	2003	Global Review of Commercialized Transgenic Crops: 2003	ISAAA Briefs, 30	yes	no	no
James	2006	Global Staus of Commercialized Biotech/GM Crops: 2006	ISAAA Briefs, 35	yes	no	no
James	2007	Global Staus of Commercialized Biotech/GM Crops: 2007	ISAAA Briefs, 37	yes	no	no
James	2008	Global Staus of Commercialized Biotech/GM Crops: 2008	ISAAA Briefs, 39	yes	no	no

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Johnson et al	2008	Quantification of the Impacts on US Agriculture of Biotechnology-Derived Crops Planted in 2006. Executive Summary	National Center for Food and Agricultural Policy. US	yes	yes	no
Jost et al	2008	Economic Comparison of Transgenic and Nontransgenic Cotton Production Systems in Georgia	Agronomy Journal 100: 42-51	yes	no	yes
Kambhampati et al	2006	Farm-level performance of genetically modified cotton - A frontier analysis of cotton production in Maharashtra	Outlook on Agriculture 35(4): 291-297	yes	yes	yes
Kambhampati et al	2005	Perceptions of the Impacts of Genetically Modified Cotton Varieties: A Case Study of the Cotton Industry in Gujarat, India	AgBioForum 8(2-3): 161-171	yes	yes	yes
Karembu et al	2009	Biotech Crops in Africa: The Final Frontier. Report	ISAAA	no	no	no
Karihaloo & Kumar	2009	Bt Cotton in India: A Status Report (Second Edition)	Asia-Pacific Consortium on Agricultural Biotechnology (APCoAB), Asia-Pacifis Association of Agricultural Reserch Institutions (APAARI)	yes	yes	no
Keetch et al	2005	Bt maize for small scale farmers: a case study	African Journal of Biotechnology 4 (13): 1505-1509	yes	yes	yes
Khan et al	2009	Water management and crop production for food security in China: A review	Agricultural Water Management 96(3): 349-360	no	no	yes
Klotz-Ingram et al	1999	Farm-Level Production Effects Related to the Adoption of Genetically Modified Cotton for Pest Management	AgBioForum 2(2): 73-84	yes	no	yes
Knox	2006	Environmental impact of conventional and Bt insecticidal cotton expressing one and two Cry genes in Australia	Australian journal of agricultural research 57(5): 501-509	yes	no	yes
Koch	2007	Liability and Compensation Schemes for Damage resulting from the presence of genetically modified organisms in non-gm crops	European Commission External Study, European Centre of Tort and Insurance Law	yes	no	no
Krishna et al	2007	Estimating the adoption of Bt eggplant in India: Who Benefits from public-private partnership?	Food Policy 32(5-6): 523-543	no	no	yes

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Krishna et al	2008	Potential impacts of Bt eggplant on economic surplus and farmers' health in India	Agricultural Economics 38(2): 167-180	no	no	yes
Kruger et al	2009	Perspective on the development of stem borer resistance to Bt maize and refuge compliance at the Vaalharts irrigation scheme in South Africa	Crop Protection 28(8): 684-689	no	no	yes
Kuruganti	2009	Bt Cotton and the Myth of Enhanced Yields	Economic and Political Weekly 44(22)	yes	no	yes
Landesamt für Verbraucherschutz, Landwirtschaft und Flurneuordnung	2005	Bericht des Landesamtes für Verbraucherschutz, Landwirtschaft und Flurneuordnung zur Begleitung des Erprobungsanbaus mit Bt-Mais MON810 im Jahr 2005	Landesamt für Verbraucherschutz, Landwirtschaft und Flurneuordnung	yes	yes	no
Lemarie	2001	The spread of GM foods and how it affects farmers: what are the connections?	Ocl-Oleagineux Corps Gras Lipides 8(3): 204-210	no	no	yes
Lemaux	2009	Genetically Engineered Plants and Foods: A Scientist's Analysis of the Issues (Part II)	Annu. Rev. Plant Biol. 2009. 60:511–59	no	no	yes
Lima et al	2008	Interação genótipo-ambiente de soja convencional e transgênica resistente a glifosato, no Estado do Paraná	Pesq. agropec. bras., Brasília43(6): 729-736	yes	no	yes
Lipton	2007	Plant breeding and poverty: Can transgenic seeds replicate the 'Green Revolution' as a source of gains for the poor?	Journal of Development Studies 43(1): 31-62	yes	no	yes
Ma & Subedi	2005	Development, yield, grain moisture and nitrogen uptake of Bt corn hybrids and their conventional near-isolines	Field Crop Research 93(2&3): 199-211	yes	no	yes
Majumder	2008	Organic amendments influence soil organic carbon pools and rice-wheat productivity	Soil Science Society of America Journal 72(3): 775-785	no	no	yes
Makinde et al	2007	Role of Agricultural Biotechnology in Hunger and Poverty Alleviation for Developing Countries	South African Report, http://www.europabio.org/GreenManifesto/South%20African%20REPORT%20-%20FINAL.pdf	yes	no	no

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Manjunath	2008	Bt-Cotton in India: Remarkable Adoption and Benefits. Position Paper on Indian Bt cotton	Foundation for Biotechnology Awareness and Education	yes	no	no
Manzoor et al	2008	Effects of Split Application of Potash on Yield Relaited Traits of Basmati Rice	Journal of Animal and Plant Sciences 18(4): 120-124	no	no	yes
Marra et al	2002	The payoffs to Transgenic Field Crops: An Assessment of the Evidence	AgBioForum, 5(2): 43-50	yes	no	yes
Mauro et al	2008	Farmer knowledge and risk analysis: Postrelease evaluation of herbicide-tolerant canola in western Canada	Risk Analysis 28(2): 463-476	yes	no	yes
Mayer	2004	Non-Food GM Crops: New Dawn or False Hope? Part 2: Grasses, Flowers, Trees, Fibre Crops and Industrial Uses. Report	GeneWatch UK	yes	no	no
Mayer, Furtan	1999	Economics of transgenic herbicide-tolerant canola The case of western Canada	Food Policy 24(4): 431-442	yes	no	yes
Meade et al	2005	GM crop cultivation in Ireland: Ecological and economic considerations	Biology and Environment 105B(1): 33-52	no	no	yes
Menegattil, Mendonça de Barros	2007	Análise comparativa dos custos de produção entre soja transgênica e convencional: um estudo de caso para o Estado do Mato Grosso do Sul	Revista de Economia e Sociologia Rural 45(1): 163-183	yes	no	yes
Moccia et al	2006	Yield and quality of sequentially grown cherry tomato and lettuce under long-term conventional, low-input and organic soil management systems	European Journal of Horticultural Science 71(4): 183-191	no	no	yes
Monjardino et al	2005	The economic value of glyphosate-resistant canola in the management of two widespread crop weeds in a Western Australian farming system	Agricultural Systems 84(3): 297-315	yes	no	yes
Morse & Bennett	2008	Impact of Bt cotton on farmer livelihoods in South Africa	International Journal of Biotechnology 10(2-3): 224-239	no	no	yes
Morse et al	2005	Bt-cotton boosts the gross margin of small-scale cotton producers in South Africa	International Journal of Biotechnology 7(1,2&3): 72-83	yes	yes	yes

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Morse et al	2009	Can genetically modified cotton contribute to sustainable development in Africa?	Progress in Development Studies 9(3): 225-247	yes	no	yes
Morse et al	2005	Comparing the Performance of Official and Unofficial Genetically Modified Cotton in India	AgBioForum 8(1): 1-6	yes	yes	yes
Morse et al	2006	Environmental impact of genetically modified cotton in South Africa	Ecosystems and Environment 117: 277-289	yes	yes	yes
Morse et al	2005	Genetically modified insect resistance in cotton: some farm level economic impacts in India	Crop Protection 24: 433-440	yes	yes	yes
Morse et al	2007	Isolating the 'farmer' effect as a component of the advantage of growing genetically modified varieties in developing countries: a Bt cotton case study from Jalgaon, India	Journal of Agricultural Science 145: 491-500	yes	no	yes
Mutuc et al	2007	Farm Level Impacts of Bt Corn Adoption in a Developing Country: Evidence from the Philippines	Paper 9891, American Agricultural Economics Association 2007 Annual Meeting, July 29-August 1, 2007, Portland, Oregon TN	yes	no	no
Nalley et al	2009	Photothermal Quotient Specifications to Improve Wheat Cultivar Yield Component Models	Agronomy Journal 101(3): 556-563	no	no	yes
Newnham	2007	Australian Cotton Comparative Analysis 2006 Crop	Report, Australian Cotton Comparative Analysis	yes	no	no
Norton	2003	Conservation farming systems and canola	University of Melbourne	yes	yes	no
ORAMA	2006	Mais OGM en plein champ: des resultats probants	Zoom Biotech 4	yes	no	no
Paarlberg	2006	genetically modified (GM) crops a commercial risk for Africa?	International Journal Technology and Globalisation 2(1-2): 81-92	no	no	yes
Palaudelmas et al	2009	Effect of volunteers on maize gene flow	Transgenic Research 18(4): 583-594	no	no	yes
Paredes et al	2006	Adoption of Transgenic Crops by Smallholder Farmers in Entre Rios, Argentina	Paper 9996, Amerial Agricultural Economics 2007 Annual Meeting	yes	yes	no

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Patel et al	2008	Impact assessment of climate change on maize cultivars in middle Gujarat agro-climatic region using CERES-maize model	Journal of Agrometeorology 10: 292-295	no	no	yes
Patil et al	2007	Insect Pest Status and Economics of Bt Cotton Cultivation under Irrigated Ecosystem	Paper presented at The World Cotton Research Conference-4, Lubbock, TX. Available on the World Wide Web: http://wcrc.confex.com/wcrc/2007/ techprogram/P1229.HTM	yes	yes	no
Pelaez et al	2004	Soja transgênica versus soja convencional: uma análise comparativa de custos e benefícios	Cadernos de Ciências & Tecnologia, Brasília 21(2): 279-309	no	no	yes
Pemsl et al	2004	A methodology to assess the profitability of Bt-cotton: case study results from the state of Karnataka, India	Crop Protection 23(12): 1249-1257	yes	yes	yes
Pemsl et al	2007	Assessing the profitability of different crop protection strategies in cotton: Case study results from Shandong Province, China	Agricultural Systems 95(1-3): 28-36	yes	yes	yes
Pemsl et al	2008	The economics of biotechnology under ecosystem disruption	Ecological Economics 66(1): 177-183	no	no	yes
Penna& Lema	2002	Adoption of herbicide resitant soybeans in Argentina: An economic analysis	http://www.inta.gov.ar/ies/docs/doctrab/adoption_dt_18.PDF	yes	yes	no
Perlak et al	2001	Development and commercial use of Bollgard cotton in the USA - early promises versus today's reality	Plant Journal 27(6): 489-501	yes	no	yes
PG Economics Limited	2006	Biotech Crops: The Real Impacts 1996-2006-yields. Summary	PG Economics Limited	no	no	no
PG Economics Limited	2003	Consultancy support for the analysis of the impact of GM crops on UK farm profitability. Final report	PG Economics Limited	no	no	no
PG Economics Limited	2008	Focus on Yield. Biotech Crops: Evidence, Outcomes and Impacts 1996-2006	Brief August 2008, PG Economics Limited	no	no	no

Author	Year	Title	Source	Publication in database	Studies from publication in database	Peer-reviewed
Pidgeon et al	2004	Can GMHT beet contribute to sustainable crop production in Europe?	Proceedings of the 67th IIRB Congress, February 2004. 107-111	no	no	no
Piesse et al	2008	Genetically modified crops, factor endowments, biased technological change, wages and poverty reduction	International Journal of Biotechnology 10(2-3): 184-206	no	no	yes
Porch et al	2009	Evaluation of Common Bean for Drought Tolerance in Juana Diaz, Puerto Rico	Journal of Agronomy and Crop Science 195(5): 328-334	no	no	yes
Prasad et al	2009	Area Wide Implementation of Insecticide Resistance Management Strategies on Bt Cotton – A Case Study in India	Journal of Plant Protection Research 49(2): 162-166	no	no	yes
Pray et al	2002	Five years of Bt cotton in China ± the benefits continue	The Plant Journal 31(4): 423-430	no	no	yes
Pray et al	2001	Impact of Bt cotton in China	Worlds Development 29(5): 813-825	yes	yes	yes
Pray et al	2007	Supplying crop biotechnology to the poor: Opportunities and constraints	Journal of Development Studies 43(1): 192-217	yes	no	yes
Prey & Naseem	2003	The Economics of Agricultural Biotechnology Research. ESA Working Paper No. 03-07	Agriculture and Economic Development Analysis Division, FAO UN	no	no	no
Pschorn-Strauss	2005	Bt cotton in South Africa the case of the Makhathini farmers	Seedling 2005: 13-24	yes	no	no
Purcell & Perlak	2004	Global Impact of Insect-Resistant (Bt) Cotton	AgBioForum, 7(1&2): 27-30	yes	no	yes
Qaim	2003	Bt Cotton in India: Field Trial Results and Economic Projections	World Development 31(12): 2115-2127	yes	yes	yes
Qaim & Zilberman	2003	Yield effects of genetically modified crops in developing countries	Science 5608: 900-902	yes	no	yes
Qaim & de Janvry	2002	Bt Cotton in Argentina: Analyzing Adoption and Farmers' Willingness to Pay	Paper 19710, American Agricultural Economics Association 2002 Annual meeting, July 28-31, Long Beach	yes	yes	no

Author	Year	Title	Source	Publication in database	Studies from publication in database	Peer-reviewed
Qaim & Subramanian	2009	Village-wide Effects of Agricultural Biotechnology: The Case of Bt Cotton in India	World Development 37(1): 256-267	yes	no	yes
Qaim et al	2006	Adoption of Bt cotton and impact variability: Insights from India	Review of Agricultural Economics 28(1): 48-58	yes	yes	yes
Qaim et al	2003	Agronomics and Sustainability of Transgenic Cotton in Argentina	AgBioForum, 6(1&2): 41-47	yes	yes	yes
Qaim et al	2005	Bt cotton and pesticide use in Argentina: economic and environmental effects	Environment and Development Economics 10: 179-200	yes	yes	yes
Qaim et al	2003	Genetically Modified Crops, Corporate Pricing Strategies, and Farmers' adoption: The case study of Bt Cotton in Argentina	American Journal of Agricultural Economics 85(4): 814-828	yes	yes	yes
Qaim et al	2005	Roundup Ready soybeans in Argentina: farm level and aggregate welfare effects	Agricultural Economics 32(1): 73-86	yes	yes	yes
Qayum & Sakkhari	2005	Bt Cotton in Andhra Pradesh: A three-year assessment	Report, Deccan Development Society, http://www.grain.org/research_files/BT_Cotton_-_A_three_year_report.pdf	yes	yes	no
Qayum & Sakkhari	2006	False hopes festering failures: Bt cotton in Andhra Pradesh 2005-2006	Report, Deccan Development Society, http://www.grain.org/research_files/APCIDD%20report-bt%20cotton%20in%20AP-2005-06.pdf	yes	yes	no
Qayum et al	2003	Did Bt Cotton Save Farmers in Warangal? A season long impact study of Bt Cotton - Kharif 2002 in Warangal District of Andhra Pradesh	AP Coalition in Defence of Diversity, Deccan Development Society, Hyderabad	yes	yes	no
Ramaswami et al	2008	The Limits of Intellectual Property Rights: Lessons from the Spread of Illegal Transgenic Cotton Seeds in India	Working Paper 2331, Esocialsciences	yes	no	no
Raney	2006	Economic impact of transgenic crops in developing countries	Current Opinion in Biotechnology 17(2): 174-178	yes	no	yes

Author	Year	Title	Source	Publication in database	Studies from publication in database	Peer-reviewed
Roca	2003	Impacto económico de la soja y el algodón transgénicos en Argentina. Asociación Semilleros Argentinos	Instituto de Economia y Sociologia, http://www.argenbio.org/h/biblioteca/pdf/impacto-economico.pdf	no	no	no
Roessing & Lizzarotto	2005	Soja Transgênica no Brasil: situação atual e perspectivas para os próximos anos	http://www.sober.org.br/palestra/2/186.pdf	yes	no	no
Ross-Larson et al	2002	Harnessing Technologies for Sustainable Development. ECA Policy Research Report	Economic Commission for Africa	no	no	no
Russell	2007	GMOs and their contexts: A comparison of potential and actual performance of GM crops in a local agricultural setting	Geoforum 39(1): 213-222	yes	no	yes
Russell et al	2006	Sustainability of Bt cotton in China and India	Cahiers Agricultures 15(1): 54-59	no	no	yes
Sadashivappa & Qaim	2009	Bt Cotton in India: Development of Benefits and the Role of Government Seed Price Interventions	AgBioForum, 12(2): 172-183	yes	yes	yes
Sahai, Rahman	2003	Performance of Bt Cotton in India: Data from the First Commercial Crop	Economic and Political Weekly 38(30): 3139-3141	yes	no	yes
Schiefer et al	2008	Untersuchungen zum Anbau von GVO in Sachsen	Schriftenreihe der Sächsischen Landesanstalt für Landwirtschaft Heft 15/2008	yes	yes	no
Schwember	2008	An update on genetically modified crops	Ciencie e Investigacion Agraria 35(3): 231-250	no	no	yes
Serecon Management Consulting Inc. and Koch Paul Associates	2001	An Agronomic and Economic Assessment of GMO Canola	Serecon Management Consulting Inc. and Koch Paul Associates	yes	yes	no
Shankar & Thirtle	2005	Pesticide Productivity and Transgenic Cotton Technology: The South African Smallholder Case	Journal of Agricultural Economics 56(1): 97-116	yes	yes	yes
Shankar et al	2008	Production risk, pesticide use and GM crop technology in South Africa	Applied Economics 40(19): 2489-2500	yes	yes	yes

Author	Year	Title	Source	Publication in database	Studies from publication in database	Peer-reviewed
Skevas et al	2009	Coping with Ex-ante Regulations for Planting Bt Maize: The Portuguese Experience	AgBioForum, 12(1): 60-69	yes	no	yes
Smale et al	2006	Bales and Balance: A Review of the Methods Used to Assess the Economic Impact of Bt Cotton on Farmers in Developing Economies	AgBioForum 9(3): 195-212	yes	no	yes
Subramanian & Qaim	2010	The Impact of Bt Cotton on Poor Households in Rural India	Journal of Development Studies 46(2): 295-311	yes	yes	yes
Surekha et al	2006	Effect of straw on yield components of rice (Oryza sativa L.) under rice-rice cropping system	Journal of Agronomy and Crop Science 192(2): 92-101	no	no	yes
Teklay et al	2006	Effect of organic inputs from agroforestry species and urea on crop yield and soil properties at Wondo Genet, Ethiopia	Nutrient Cycling in Agroecosystems 75(1-3): 163-173	no	no	yes
Thirtle et al	2003	Can GM-Technologies Help the Poor? The Impact of Bt Cotton in Makhathini Flats, KwaZulu-Natal	World Development 31(4): 717-732	yes	yes	yes
Thompson	2008	The role of biotechnology for agricultural sustainability in Africa	Philosophical transactions of the Royal Society of London 363(1492): 905-13	yes	yes	yes
Tiwari et al	2003	Effect of drip irrigation on yield of cabbage (Brassica oleracea L. var. capitata) under mulch and non-mulch conditions	Agricultural Water Management 58(1): 19-28	no	no	yes
Traore et al	2000	Bt and Non-Bt Maize Growth and Development as Affected by Temperature and Drought Stress	Agronomy Journal 92:1027-1035	yes	no	yes
Traxler	2004	The Economic Impacts of Biotechnology-Based Technological Innovations. ESA Working Paper No. 04-08	Agriculture and Economic Development Analysis Division, FAO UN	yes	no	no
Traxler & Godoy-Avila	2004	Transgenic Cotton in Mexico	AgBioForum, 7(1&2): 57-62	yes	no	yes
Traxler et al	2003	Transgenic Cotton in Mexico: Economic and Environmental Impacts	Report, http://www.infoagro.net/shared/docs/a2/Traxler.pdf	yes	yes	no

Author	Year	Title	Source	Publication in database	Studies from publication in database	Peer-reviewed
Trigo et al	2003	The Impact of the Introduction of Transgenic Crops in Argentinean Agriculture	AgBioForum 6(3): 87-94	yes	no	yes
Ullah et al	2006	Genotypic variation for drought tolerance in cotton (Gossypium hirsutum L.): Seed cotton yield responses	Pakistan Journal of Botany 38(5): 1679-1687	no	no	yes
UNECA	2009	Global Impact of Biotech Crops: Income and Production Effects, 1996-2007	UNECA	yes	no	no
UNECA	2002	Harnessing Technologies for Sustainable Development: Realizing the Promise of Green Biotechnology for the Poor	UNECA	yes	no	no
UNEP-GEF Biosafety Unit	2006	A Comparative Analysis of Experiences and Lessons From the UNEP-GEF Biosafety Projects	UNEP-GEF Biosafety Unit	no	no	no
Van Beuzekom & Arundel	2009	OECD Biotechnology Statistics 2009	OECD	no	no	no
Vilar et al	2007	Who Benefits from GM Crops? An Analysis of the Glogal Performance of GM Crops (1995-2006)	Friends of the Earth International	no	no	no
Vilar et al	2009	Who Benefits from GM Crops? Feeding the Biotech Giants, not the World's Poor	Friends of the Earth International	no	no	no
Vitale et al	2008	Second-generation Bt cotton field trials in Burkina Faso: Analyzing the potential benefits to West African farmers	Crop Science 48(5): 1958-1966	no	no	yes
Wang et al	2009	Bt Cotton in China: Are Secondary Insect Infestations Offsetting the Benefits in Farmer Fields?	Agricultural Sciences in China 8(1): 83-90	yes	no	yes
Ward et al	2002	Efficiency of Alternative Technologies and Cultural Practices for Cotton in Georgia	AgBioForum 5(1): 10-13	yes	no	yes
Wilson et al	2003	Issues in Development and Adoption of Genetically Modified (GM) Wheats	AgBioForum, 6(3): 101-112	no	no	yes

Author	Year	Title	Source	Publication in database	Studies from publication in database	Peer-reviewed
Wolf	2009	Experiences in the economic use of herbicide tolerant crops	Agrarforschung 16(3): 52-57	no	no	yes
World Health Organisation, Food Safety Department	2005	Modern food biotechnology, human health and development: an evidence-based study	WHO study	yes	no	no
Wossink et al	2006	Environmental and cost efficiency of pesticide use in transgenic and conventional cotton production	Agricultural Systems 90 (1-3): 312-328	yes	yes	yes
Wu & Butz	2004	The Future of Genetically Modified Crops: Lessons from the Green Revolution	RAND Science and Technology	no	no	no
Yang et al	2005	Farmers' knowledge, perceptions and practices in transgenic Bt cotton in small producer systems in Northern China	Crop Protection 24(3): 229-239	yes	no	yes
Zika et al	2007	Consequences, Opportunities and Challenges of Modern Biotechnology for Europe. JRC Reference Reports. Synthesis Report, BIO4EU Study	European Commission, DG Joint Research Centre	no	no	no

Annex H. Interview details

Table 27. List of contacted experts and organisations

Name of Contact	Organisation or University
General contact	Actionaid
Ada Wossink	North Carolina State University
General contact	Agri South Africa
Alain de Janvry	University of California, Berkeley
Andres Schwember	University of California, Davis
Awudu Abdulai	University of Kiel
B L Ma	Agriculture and Agri-Food Canada
B Shankar	University of Reading
Basavarij V Patil	University of Agril. Sciences, College of Agriculture
Ben Crost	University of California
Bharat Ramaswami	Gujarat Institute of Development Research
General contact	Biowatch South Africa
Bruno J R Alves	Ministry of Agriculture Brazil
Colin Thirtle	Imperial College of Science, Technology and Medicine
General contact	Canola Council of Canada
Carl Pray	Rutgers, The State University of New Jersey
Catherine Joynson	Nuffield Council of Bioethics
Clare Hall	Scottish Agricultural College
General contact	Commission on Genetic Resources for Food and Agriculture
General contact	Consortium of Indian Farmers
Daniel Wolf	Forsch Anstalt Agroscope Reckenholz Tanikon ART
Daniela Soleri	University of California, Santa Barbara
Diemuth E Pemsl	Leibniz University Hannover
Dominic Glover	Wageningen University
Dr Anee Wargai	Bio-Earn
Dr Helen Ferrier	National Farmers Union (UK)
Ekin Birol	International Food Policy Research Institute
General contact	European Federation of Biotechnology
General contact	Federation of Farmers Association
Fernandez-Cornejo	USDA
Francesca Bignami	COPA-COGECA
G Traxler	University of Pretoria
Graham Brookes	PG Economics Ltd

Name of Contact	Organisation or University
Graham Moore	John Innes Centre
H Alderman	World Bank
Harold Witt	Saskatoon University
Hezhong Dong	Shandong Academy of Agricultural Sciences
Ian J Mauro	University of Manitoba
Ian Scoones	University of Sussex
General contact	IFAD
General contact	ISAAA
J Chataway	Open University
Janet Carpenter	Formerly of National Center for Food and Agricultural Policy
Jeffrey Vitale	Oklahoma State University
Ji-Kun Huang	Institute of Geographical Sciences and Natural Resource Research, Chinese Academy of Sciences
Jim Hershey	American Soybean Association
Joanne Green	CAFOD
K N Twari	Indian Institute of Technology
Kees Jamsen	Wageningen UR (University & Research centre)
Leonard Gianessi	Croplife Foundation
M Altieri	University of California, Berkley
M Kyotalimye	Association for Strengthening Agricultural Research in Eastern and Central Africa
Manuel Gomez Barbero	DG Agriculture and Rural Development
Maria Mutuc	Texas Tech University
Marko Bohanei	Institut "Jožef Stefan",
Marnus Gouse	University of Pretoria
Mathias N Andersen	Aarhus University
Matin Qaim	University of Goettingen
Megan Provost	American Farm Bureau Federation
Mehboob-ur-rehman	
Melinda Smale	Oxfam America
Michele Marra	North Carolina State University
Michele Sadler	Institute of Grocery Distribution
Mike Edgerton	Monsanto
Morven Mclean	AgBios
Muhammed Arshad	University of Agriculture, Faisalabad
Myvish Maredia	Dry Grain Pulse CRSP
N U U S D Prasad	Regional Agricultural Research Station, Lam
General contact	National Center for Food & Agricultural Policy

Name of Contact	Organisation or University
General contact	NFU America
General contact	NSW Farmers Association
O M Banbawale	National Centre for Integrated Pest Management
Oxfam	Oxfam
P K Viswanathan	Gujarat Institute of Development Research
Penny Garner	National Farmers Organization
Peter Ottesen	Department of Agriculture, Fisheries and Forestry, Australia
Prakash Sadashwappa	University of Hohenheim
Professor Zilberman	University of California, Berkeley
Puyin Yang	Ministry of Agriculture, Beijing
R B Barwale	Mahyco
Rafiq Chaudhry	International Cotton Advisory Committee
Ranaud Wilson	Defra
Richard Bennett	University of Reading
Richard Carew	Agriculture and Agri-food of Canada
Robert Norton	University of Melbourne
Robert Paarlberg	Wellesley College, Wellesley, MA
Ron Herring	Cornall University
General contact	Royal Agricultural Society of the Commonwealth
Rual Pitoro	Michigan State University
S L Ahuja	Central Institute for Cotton Research
General contact	Small Farms Association
General contact	South African Department of Agriculture
Steve E Naranjo	USDA
Subramanian Arjunan	University of Warwick
Suman Sahai	Genecampaign
Terri Raney	Food and Agriculture Organization of the United Nations
Tom Stallings	Funston Ginery
General contact	Uganda National Farmers Federation
General contact	United States Department of Agriculture
Vijesh Krishna	University of Hohenheim
W H Furtan	Furtan Ginery, South Africa
Wendy Russell	University of Wollongong

Table 28. Generic Questions posed and reasons

Question Number	Question	Reason
1	You have produced a number of reports and papers on GM crops? Why are you so interested in the subject?	This question aims to identify the expertise of the individual answering the question as well as how polarised their view is on the whole subject area.
2	During our research we have tried to find as many papers as possible examining the yield and economic effect of GM crops around the world. Whilst we have found some, they have not necessarily been up to date. Do you agree that this is a problem, what do you believe is causing this problem and how do you feel it should be resolved?	This question aims to establish whether or not the individual answering the question has been able to keep up to date
3	How do you view the research that has been carried out on GM crops. Do you feel there has been enough and has it been asking the right questions?	This question is designed to establish the individual's basic understanding of the literature.
4	What was your specific role in the research?	This question is to ensure that the individual selected has the right credentials to follow-up with further questions. If they only played a minor role in the production of a paper then it would be difficult to ask them further detailed questions.
5	What do you think are the important economic impacts of GM crops and what evidence do you have to support this?	This question aims to allow the individual to expand on what they feel are the important aspects of their research
6	Throughout your research have you noticed any variations, in either your results or evidence from elsewhere, in the yields or economic factors? Apart from production risks and other factors directly associated with the genetic modification, do you have any view on what else might be influencing these differences?	This allows the individual to expand on what they believe is causing variations within the data.
7	What evidence do you believe exists to support your views concerning these differences?	If the individual does have a view on variations identified, what are these views based on.
8	How do you view the overall direction of GM crop research?	This allows the individual to identify where they feel future research should be directed, either to answer identified problems or gaps in understanding.

Table 29. Hypothesised groups of answer for a few of the stakeholder types

	Question	GM companies	Green pressure groups	Producer groups	Food industry	Academic experts
1	What is your position and responsibilities					
2	Are you aware of the scientific literature on the economic impacts of GM crops?	Combination of white and grey literatures. Also likely to be well aware of sources employed by the green pressure groups.	Emphasis on grey literature. May be an acknowledgement of the white literature but this may be selective.	Emphasis on grey literature and websites. More open to influence from the GM companies.	Probably more reliant on the grey literature and websites. More open to influence from the 'green' pressure groups	Emphasis on white literature but with awareness of grey literature
3	What do you think are the economic impacts of GM crops?	Positive benefits with figures quoted to show the scale of gain	Negative impacts – probably stressing enhancement of inequality and/or no difference and/or dependency	Probably aware more of the claims for a positive economic impact May not be aware of issues such as an enhancement of farmer inequality		Mixed. Will probably be a more nuanced awareness of the evidence
4	Why do you think there is variation with regard to the evidence of economic impact?	Environmental conditions Pest population pressure Use of other inputs such as irrigation, fertilizer and labour Inappropriate varieties or use of farmer-saved seed	Wealth of farmers Availability of credit Use of inputs (perhaps linked to above) Bias on the part of what is perceived to be evidence generated at the behest of the GM industry and its supporters	Mixture of factors in the 2 columns to the left.		Probably more in common with answers supplied by GM company respondents than the 'green' pressure groups

Table 30. Details of people interviewed, telephone conversations held or email answers received

Code		Organisation
A1	Academic	University of California, Davis
A2	Academic	University of Reading
A3	Academic	Anonymous
A4	Academic	Formerly of the Leibniz University, Hanover
A5	Academic	Wageningen UR (University & Research centre)
A6	Academic	University of Pretoria
A7	Academic	University of Goettingen
A8	Academic	University of Reading
A9	Academic	University of Warwick
A10	Academic	North Carolina State University
A11	Academic	Open University and Consultant
A12	Academic	University of Reading
G1	Government Researcher	USDA
G2	Government Officer	Defra
G3	Government Researcher	Agriculture and Agri-food of Canada
I1	Industry Researcher	Monsanto
N1	Scientific Analyst	NFU
R1	Researcher	University of California
R2	Researcher	Wageningen University
R3	Researcher	IFPRI
R4	Researcher	Consultant
R5	Researcher	Consultant
R6	Researcher	Oxfam
R7	Researcher	Consultant