A META-ANALYSIS STUDY OF WELFARES OF GENETICALLY MODIFIED CROPS

by

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ABSTRACT OF THE THESIS

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Due to the controversial debates, skepticism and speculations around Genetic Modified (GM) crops, substantial research has been done on the allocation of welfare implications of GM crops. However, different procedures, various data sources and economic models are used to study commercialized GM crops around the world. Therefore mixed conclusions were conducted. Some papers mentioned benefits from farm producer side; some focused on research of willingness to pay among consumers; while others were asmore interested in market prospect. As a result, is has become difficult to effectively summarize the benefit of adopting GM crops and explain the large study-to-study variations of surplus estimation. This thesis presents a meta-analysis of 58 primary studies with a total of 119 GM crops evaluations, aiming to summarize previous studies on economic surplus of GM crops which are not conditional from a single research study and to identify the determinants of the farmer surplus, GM seed company surplus and consumer surplus of GM crops, from analysis and comparison those broad range data set. This thesis finds that GM seed companies and farmers gained different surplus based on geographic locations. On the other hand, research methods might affect farmer surplus estimation but not GM seed company surplus.

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I want to thank my parents for their unconditional support during my graduate research. Undoubtedly, I would not have been able to get this Master degree without the support of my husband Yijie Gao. Thank you.

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Chapter 1

Introduction

Almost 20 years passed, since the first Genetic Modified (GM) food crop (*Flavr Savr* tomato) was commercialized in 1994. From 7.1 million acres of GM crops in 1996 to 420 million acres in 2012, the adoption rates of GM crops exceeds for any new technology by agricultural industry standards. In 2013, about 17.3 million farmers planted about 25 different kinds of GM crops in 28 countries around the world (James 2012). In the USA, roughly 85% of corn, 91% of soybean, and 88% of cotton are genetically modified. Many foods in US markets are either GM whole foods, or contain ingredients derived from GM crops. Productivity and yields of crops were significantly enhanced through introducing GM traits. GM technology has an impressive impact on farm income and GM seed companies' profit. In 2009, famers gained about $10.8 billion from adopting GM crops, globally. Since 1996, farm incomes have increased by $64.7 billion (Brookes. and Barfoot 2011). Innovating companies also captured enormous surplus from selling GM seeds and technologies. In the late 1990s, Bt cotton generated a total annual economics surplus gain of about $164 million in the USA, of which 45% was captured mostly by GM seed companies, 37% by farmers, while only 18% by consumers (Falck-Zepeda, Traxler, and Nelson 2000b). For Bt maize, a total surplus gain of $334 million was reported in 2001 and approximately half of the gain accrued to farmers, followed by GM seed companies (31%) (Wu 2002). The total consumer surplus was relatively small. This number would be even smaller if calculated by per capita, especially considering that there are many more consumers than producers in the market.

As GM crops expanded significantly in the past 17 years, the controversy over genetic engineering techniques and the use of GM crops also gets more and more heated. On one hand, it is believed that GM crops could contribute to global food, feed and fiber security; a safer environment; a more sustainable agriculture; and the alleviation of poverty and hunger in developing countries. Farmers gained huge benefits through increased yields and lower chemical cost, by adopting GM crops. On the other hand, consumers worried about the safety issue of GM crops while their benefits barely increased through purchasing GM food. Consumers concerned about environmental pollution, unintentional gene transfer to wild plants, possible creation of new viruses and toxins, limited access to seeds due to patenting of GM crops, threat to crop genetic diversity, religious cultural and ethical issues, as well as fear of the unknown.

Because of the controversial debates, skepticism and speculations around GM crops, there are substantial research in different countries focused on economic and policy aspects of GM crops. However, most of these studies either report the surplus of a certain GM crop in some countries, or present the data of some GM crop during several years in one country. Some studies only discussed about the farmer surplus, while others analyzed the survey data for consumer willingness to pay. Besides, different procedures, different versions of the basic models and different subject pools were used. Therefore, a wide range of valuation estimates was generated. Even though more and more studies investigated surplus of adopting GM crops, there is barely consensus on these reports. As a result, it has become difficult to effectively summarize the benefit of adopting GM crops and explain the large study-to-study variations of surplus estimation.

This thesis presented a meta-analysis of 58 previous literature studies, which estimated farmer surplus, GM seed company surplus or consumer surplus for GM food. The goal is to summarize previous findings on economic surplus of GM crops which are not conditional from a single research study and to indentify the determinants of the farmer surplus, GM seed company surplus and consumer surplus of GM crops, from analysis and comparison those broad range data set.

Chapter 2

Background

Almost thirty years passed, since the first genetically modified plant was produced in 1982. Agricultural history has been re-written by the increased planting area of GM crops and the increased yield of crops. In this chapter, I would like to briefly discuss about the background of GM traits and global markets of GM crops.

2.1 History of GM crops

Genetically modified cops are plants, the DNA of which have been modified using genetic engineering techniques, in order to introduce resistance to certain pests, diseases, environmental conditions, resistance to chemical treatments or the production of a certain nutrient or pharmaceutical agent. These introduced functions do not occur naturally in species and could significantly increase the yield or nutrient of the crops. Generally there are three categories of GM traits: First-generation GM crops involve improvements in agronomic traits, such as insect resistance traits (based on different genes from the soil bacterium Bacillus thuringiensis (Bt)) and herbicide resistance (HT) traits. Second-generation GM crops involve enhanced quality traits, such as higher nutrient contents of food products like Golden Rice. Third-generation GM crops involve traits that are designed to produce special substances for pharmaceutical or industrial purposes.

The basic techniques of plant genetic engineering were developed in the early 1980s. Antibiotic-resistant tobacco, produced in 1982, was the first genetically modified crop (Fraley et al. 1983). The first field trial of herbicide resistant tobacco was introduced in 1986 in France and the USA. The *Flavr Savr* tomato, which had a longer shelf life, was the first commercialized GM crop and it was approved for sales in the USA in 1994. Because the negative research results of Flavr Savr tomatoes on rats, which were proved incorrect later, it was pushed out of the market in 1998 (Bruening and Lyons 2000). Later in 1995, Bt Potato, canola with modified oil composition, HT cotton, Bt corn/maize, and HT soybean received safety and marketing approvals. 35 GM crops with 8 different traits were approved for commercialization in 6 countries by 1996 (James and Krattiger 1996). 1996 was a milestone year for GM crops; after that the growing rate and adoption rate of GM technology has increased rapidly.

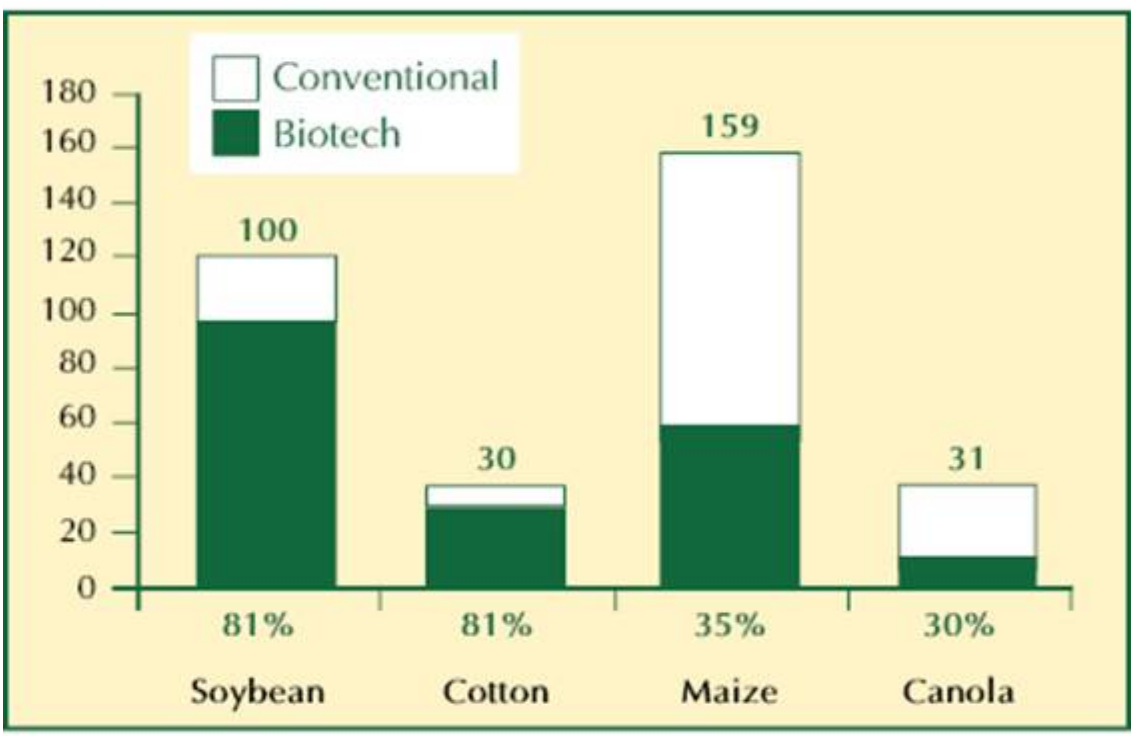


Figure 1. Biotech crop area as % of global area of principal crops in 2012 (Million Hectares) Source: (James 2012)

In 2012, the total area cultivated with GM crops reached 420 million acres, at a sustained growth rate of 6% or 25 million acres per year (James 2012). Most of the commercialized GM crops are the products of first-generation gene-engineer techniques. The most common and widely planted GM crops are soybean, maize, cotton and canola. The dominant technology is herbicide tolerance (HT) in soybeans. Currently, most of the HT soybeans are planted in the USA, Argentina, Brazil and other South American countries. About 81% of the global soybeans, around 200 million acres, are GM soybeans in 2012. GM maize, including HT maize as well as Bt and HT stacked maize, is the second-most dominant crop, covering 35% of maize globally.

2.2 Global Adoption of GM crops

Since the first commercial GM crops were planted in 1994 (tomatoes), GM crops were commercially adapted in 28 countries in all six continents of the world by 2012. In these 28 countries, 18 are developing countries and 10 are industrial countries. The top ten countries each grew more than 3 million acres of GM crops. Those mega-countries include the USA (171.7 million acres), Brazil (90.4 million acres), Argentina (59 million acres), Canada (28.6 million acres), India (26.7 million acres), China (9.9 million acres), Paraguay (8.4 million acres), South Africa (7.2 million acres), Pakistan (6.9 million acres), and Uruguay (3.5 million acres). There are more developing counties than industrial countries in those mega-countries. Most of the top ten GM crops adoption countries are North and South America countries. In spite of rapid spread in other continents, the development and use of GM crops have aroused significant opposition in Europe. The strong public reservations are also spilled over to other countries and regions through trade regulations, public media, and outreach efforts of anti-biotech lobbying groups (Pinstrup Andersen and Schiøler 2001). Among European Union countries (EU), GM crops are only grew on a significant scale and commercialized in Spain; although individual GM technologies have been approved in a few other EU countries.

The global adoption area of GM crops has been growing impressively every single year with almost a remarkable 100-fold increase since 1996. GM crops are considered as the fastest adopted technology in the history of modern agriculture. By 2012, about 17.3 million farmers planted 420 million acres GM crops (James 2012). Most of these farmers, over 90 %, are small and resource-poor farmers from developing countries.

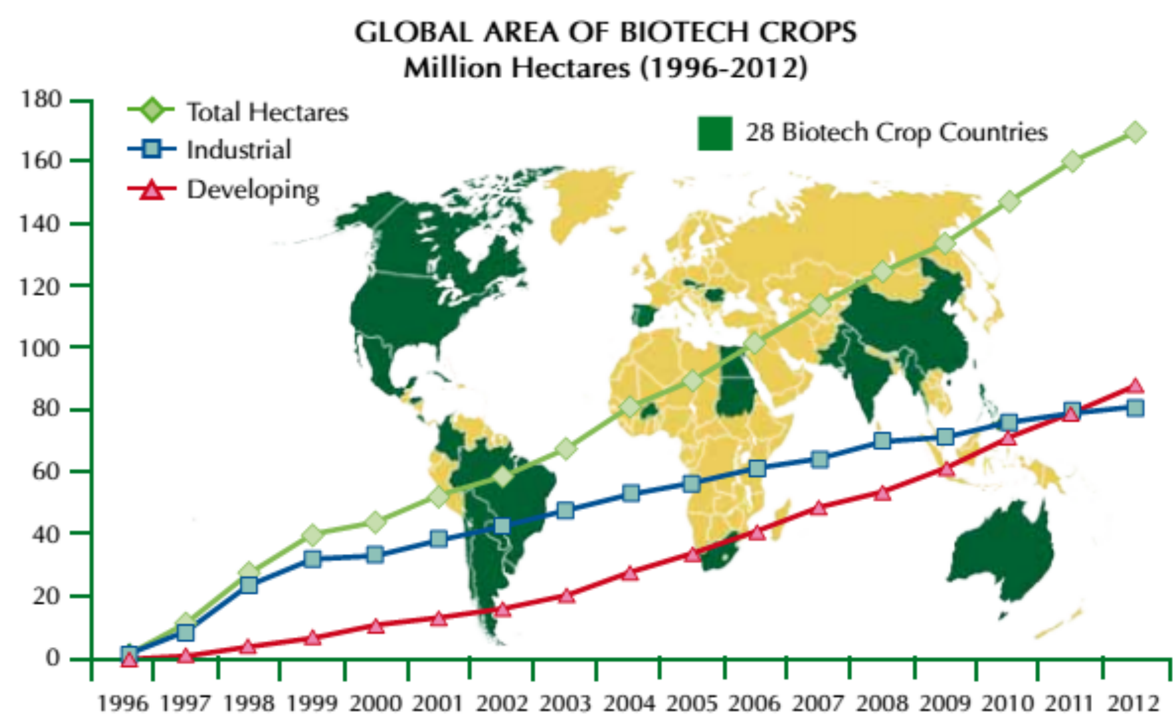


Figure 2. Global area of biotech crops from 1996 to 2012 (Million Hectares) Source:(James 2012)

Since GM techniques were first developed in industrial countries, GM crops were mostly planted in these countries in the first ten years, 1996 to 2006. In 1996, around 4.1 million acres of GM crops were planted (Brookes. and Barfoot 2011). After almost 17 years development of GM biotech, GM crops were gradually adapted in developing countries and reached up to 52% of the global GM crop area in 2012. The adoption of GM crops in Burkina Faso, Egypt and South Africa is very promising and it is believed that these three countries might become role models in their respective regions. Africa is so far recognized as the continent that encountered the biggest challenge in terms of acceptance and adoption, which is also the continent with the greatest and most urgent need for GM crops to solve poverty and hunger.

At first, most of the adopted GM traits were single traits in one variety or hybrid; as the technique develops stacked traits become a very important feature of GM crops. In 2008, 85% of maize in the USA was GM maize and 78% of the GM maize was hybrids with either double or triple stacked traits. Only 22% was hybrids with a single trait. About 75% of GM cotton was occupied by double-stacked traits and this percentage was even higher in Australia, around 81%.

2.3 GM seeds markets

As the development of genetic technologies, more and more companies started to provide innovative crops with valuable new traits. There are hundreds of GM seed companies around the world. Most of the GM firms developed out of the chemical industry and they remain the world's biggest manufactures of agrochemicals. Those leading GM corporations together control nearly 75% of the global pesticide market.

Monsanto, the world's biggest seed company, was a pioneer in biotechnology and among the first to create GM seeds and conduct field trials of GM corps. As of 2012, the GM seed lineup of Monsanto included Roundup Ready (resistance to herbicide, HT) alfalfa; Roundup Ready canola; cotton with Bt, Roundup Ready or stacked traits; Roundup Ready soybeans; Roundup Ready sugar beet; and a wide range of wheat products. Since Monsanto is also the world's fifth largest agrochemical company, most of Monsanto's traits are HT traits, creating a near-monopoly for Monsanto's Roundup herbicide.

DuPont is the second-biggest seed company, and the world's third largest chemical company. Its GM seed products include the LibertyLink gene, that provides resistance to Bayer's Ignite/Liberty herbicides; the Herculex I Insect Protection gene that provides protection against various insects; the Herculex RW insect protection trait that provides protection against other insects; the YieldGard Corn Borer gene, that provides resistance to another set of insects; and the Roundup Ready Corn 2 trait that provides crop resistance against glyphosate herbicides. Recently, DuPont also developed a nutrition enhanced Plenish soybeans.

Syngenta is the third largest seed company, and the world's second largest agrochemical manufacturer. Its GM seeds include the triple stack corn seeds, and VMAX soybean that is resistant to glyphosate herbicide and other insect resistance traits. Besides these large GM seed companies in North America, there are also some corporations, which collaborate with Monsanto and develop their own region special GM seeds, such as Mahyco Monsanto Biotech (MMB) in India and China Academy of Agricultural Sciences (CAAS) in China.

2.4 Consumer attitudes

While seed industries and commercial farmers take GM crops as an opportunity to increase profits, consumer attitudes toward GM crops and GM food appear to differ greatly across different regions. North American consumers seem to be more willing to accept GM food. However, the public in many other countries, especially in European countries, distrusts GM crops, often seeing them as part of globalization and privatization. Previous literatures found that consumers normally value non-GM foods higher than GM foods and this valuation strongly varies by countries or regions, product and type of genetic modification (Bugbee, Loureiro, and Hine 2004; James and Burton 2003). The aversion to GM foods is higher if animal genes are involved.

Even though there is broad scientific consensus that food derived from GM crops poses no greater risk to human health than conventional food, opponents are more concerned about whether GM crops have negative impacts on biodiversity, whether food produced from GM crops is safe, whether GM crops are needed to address the world's food needs. Consumers are also worried about the ethics of genetic engineering, feeling it to be in some way "unnatural" and fearing the unknown consequences. Since it is impossible to predict the impact of biotechnology and the cumulative effects of consuming GM foods over time; there are concerns about unknown long-term effects on health (Hobbs and Plunkett 1999). Some consumers are afraid that the use of anti-biotic resistant marker genes might cause the growth of antibiotic resistance in humans and animals. On the other hand, governments lack coherent policies on GM products and have not yet developed and implemented adequate regulatory instruments and infrastructures. As a result, there is no consensus in most countries on how biotechnology and GM crops could address the key challenges in the food and agricultural sector.

There are continuous conflicting reports showing that GM food is not different from traditional food in flavor and nutrition; and that GM food has potential health risk. The controversy never stops and become more aggravated. In the history of GM food, there are some scientific results showing that GM crops could damage vital organs and weaken the immune system of experiments animals, such as the negative reports on *Flavr Savr* tomatoes and GM potatoes from British scientist Dr. Arpad Pusztai. Although, it was approved later that those negative results was irrelevant and was flawed in its design, execution and analysis; the impact on consumer through media was permanent and these two GM crops failed to return to the market. The consumers' attitude toward GM foods has an important impact on welfare implications of adopting GM crops (Fulton and Giannakas 2004). Consumers are easily affected by media and commercials. The reason European consumers are resistance to GM food is because activist and lobby groups are more prevalent; while in North America, government and industry are more influential and therefore acceptance is generally higher.

2.5 GM crops and environment

The impact of GM crops on environment is also controversial and the debate is growing increasingly complex, intense, and extremely emotional. On one hand, adaption of GM corps could reduce pesticide use and increase yields of crops; on the other hand, the public worries that GM crops might cause undesirable gen flow or impacts on non-target organisms and create new weeds through outcrossing with wild relatives or simply by persisting in the wild themselves.

For HT crops, it could reduce the usage of selective herbicides and fuel, therefore less soil erosion and greenhouse gas emissions. For Bt crops, especially for Bt cotton, the main environmental benefits are the reductions in chemical insecticide applications, pest-related crop losses, and the lower pesticide residues in food and water to farmers (Pray et al. 2001). Previous research data showed that GM technology has reduced pesticide application by 443 million kilogram (kg) and has reduced environmental footprint associated with pesticide use by 17.9% (Brookes and Barfoot 2005). In 2003, 46.4 million pounds of pesticide was reduced due to adoption of GM crops in the USA (Sankula and Blumenthal 2004). Besides, it was reported that GM crops might have a positive effect on agro-biodiversity. Compared to conventional breeding at a long a costly process, GM crops could be backcrossed at moderate costs into numerous varieties.

While the public is concerned about the potential environmental risks of GM crops, such as new weedy species, negative impact on non-target organisms, emergence of secondary pests and development of insect resistance, scientists point out the most of those concerns are not specific to GM crops but would be present for any conventionally produced crops with the same heritable traits. Although there were some reports that pollen from Bt corn might affect survival rate of Monarch butterfly larvae; it was proved later that those studies only reflected a different situation than that in the environment and that the impact of Bt corn pollen on Monarch butterfly populations was negligible (Sears et al. 2001). As for insect resistance, scientists argued that no direct evidence has been observed under field conditions by now. On the other side, advocacy groups such as Greenpeace, The Non-GMO Project and Organic Consumers Association keep providing scientific evidences regarding the environmental and health risks of GM crops. The debate about the impacts on environment grows as GM crops expand.

Chapter 3

Literature Review

Since the first commercialized GM crop was approved 17 years ago, a lot of studies have used macro-level economic surplus models to analyze the broader welfare effects of GM crops. There were many original literatures focusing on welfare effects of single GM crops using partial equilibrium models. The partial equilibrium model is mainly based on the works developed by Moschini, Lapan (Moschini and Lapan 1997) and Falck-Zepeda (Falck - Zepeda, Traxler, and Nelson 2000) for assessing the welfare impacts of an innovation. The innovator is considered as a monopolist under the protection of intellectual property rights (IPR) in an input market. Marshallian surplus is the sum of producer and consumer welfare and the monopoly profit is captured by the innovator. Then the benefits for adopters and non adopters are estimated thought using a mathematical programming model, which accounts for the impacts of commodity price changes and government price support programs on the stakeholders' welfare (Frisvold et al. 2000).

Price et al. (2003) analyzed the total benefit arising from the adoption of Bt cotton, HT cotton and HT soybeans in 1997 in the USA, finding that almost half of the surplus was earned by innovating companies. Similar results were concluded later in other literatures, indicating that the surplus distribution did not change in the USA, even after the adoption area kept increasing (Falck-Zepeda, Traxler, and Nelson 2000b). There are also numerous literatures using the partial equilibrium models to estimate welfare impacts of Bt cotton in India or China. Pray et al. estimated economic surplus of Bt cotton in China and found that around 98% of surplus was captured by the farmers and only 1.5% going to GM seed companies, due to weak IPR protection in China (Pray et al. 2002). Similar situations happened in India, where nearly 85-90% of the total profits earned by the Bt cotton industry went to farm profits (Pray et al. 2001). Though the distribution of the surplus among farmers, consumers and seed companies were similar in these developing studies; the absolute values were different.

The partial equilibrium model has been employed to estimate the welfares for Bt corn and HT soybeans. Wu et al. reported Bt corn surplus in the USA (Wu 2004); Yorobe et al. analyzed the gains in Philippines (Jose M. Yorobe and Quico 2006); and Demont et al. studied the welfare of Bt corn in Spain (Demont and Tollens 2004). the USA gained millions of dollars from adoption of Bt corn, half of which was captured by farmers. The absolute surplus value of Bt corn in Philippine and Spain are relatively small, around several million dollars. However, the distribution of surplus among farmers, seed companies and consumers is similar as that in the USA. For HT soybeans, more than half of the total surplus was gained by seed companies in developed countries (Falck-Zepeda, Traxler, and Nelson 2000a); while 90% was captured by farmer in developing countries such as in Argentina (Qaim and Traxler 2005).

Some researchers analyzed the economic gains of multi-GM crops in multi-regions around several years. Brookes and Barfoot published their data set since 2006 and updated each year (Brookes. and Barfoot 2011). Some of their data sources came from peer literatures and some were their original estimation. Their studies presented the farm level economic effects, the production effects, and the environmental impact resulting from adoption of GM crops, and the contribution towards reducing greenhouse gas emissions. Their data set broadly covered almost all the adopting countries and provided information for all the commercialized GM crops since 1996. James also updates his documents every year and reports the global database on the adoption and distribution of GM crops (James 2012).

Besides plenty of Ex-post studies which using exiting data sets to estimate economic effects of GM crops, there are also some Ex-ante studies evaluating the surplus of non-commercialized GM crops such Bt eggplant or the commercialized GM crops in non-adopting countries such as Ireland. Fannery et al. assessed the costs and benefits of hypothetical GM winter wheat, GM spring barley and GM potatoes in Ireland. They predicted that specific GM crops would economically outperform conventional crops (Flannery et al. 2004). Krishna and Qaim analyzed the potential impacts of Bt eggplant on economic surplus in India (Krishna and Qaim 2008); and Mishra expanded the estimation of Bt eggplant to Philippine and Bangladesh in his master thesis (Mishra 2003). Besides, Alston et al. predicted the likely economic impacts of introducing a new corn rootworm resistant transgenic corn in the USA (Alston and et al. 2002).

Since there are various literatures using different models to estimate the risk, benefits and consumer willingness to pay of GM crops in different countries, different estimations are reported. Some researcher started to use the meta-analysis method to re-analyze the published estimation, trying to avoid the condition limits from the particulars of a single study and provide policy makers with a concise summary of the extant work. Lusk et al. conducted a meta-analysis of 25 studies, including 57 valuations for consumer willingness to pay of GM crops, in 2006 (Lusk et al. 2005). This thesis summarized the previous literatures on consumer demand for GM food and examined the influence of the method of value elicitation on estimated premiums for non-GM food. Hall et al. published their meta-analysis in the book Environmental Valuation in Developed Countries: Case Studies, using 22 primary studies with a total of 56 valuation values. They derived mean estimates for consumer preferences and determined the explanatory variables that influence these values (Hall, Moran, and Allcroft 2006). Then in 2009, Astrid re-analyzed 51 primary studies with a total of 114 data points reporting the valuation for consumer preference for GM food relative to the non-GM counterpart or vice versa, finding that elicitation methods and formats used in the primary studies affect valuation estimations much more than do sample characteristics (Dannenberg 2009). Recently Demont and Stein published a review paper, analyzing all the Ex Ante studies about economic value of GM rice globally (Demont and Stein 2013). Since GM rice is not commercialized yet, no impact assessments from Ex Post studies are available and all the studies reviewed in this paper either using field data or farm trials. Various methods are used to estimate the benefit of GM rice. Despite the broad range of estimation, Demont concluded that GM rice could bring around $64 billion benefit each year globally, as well as the nutrition and environment effects which were neglected normally. Although several meta-analysis papers have been published, they mainly focused on consumer preference for GM food. There have not been any studies summarizing the economic surplus of GM crops though the meta-analysis method.

Chapter 4

Data Description and Methods

The extensive research for published articles relating to economical benefit of GM food was conducted using all economic databases and websites commonly used, including Econlist, Google Scholoar and Agricola databases. The article and data collection strategy involved conducting keyword searches in search engines using GM-crop names and checking the Genetically Engineered Crops database in USDA Economic Research Service website. Studies with estimations of annual economic surplus of GM crops for farmers, seed companies or consumers from a single country were considered. There are some papers reporting the global benefits of GM crops but failed to meet the criterion. Because analyzing the regional effect on economic surplus of GM crops is one the main goals for this thesis, those papers reporting global surplus are not included here. The analysis includes studies reporting GM food welfare from consumer side, producer side or seed industry side. In cases where multiple papers cited the same estimation results, only the original research paper was taken into account to avoid redundancy. Our primary data set included 58 primary publications, including 50 journal papers, 4 book chapters, 1 meeting report and 3 thesiss. Table 1 in the appendix showed detailed information about those recourses. Data collection in all primary studies took place between 1995 and 2011. Estimations from the same paper or book chapters on one GM trait in different years in each country were averaged and counted as one observation. The total observation number is 119. About 88% of the observations came from Ex-Post studies, only 11% were Ex-Ante studies. The values of producer surplus, consumer surplus, seed company surplus and the savings of herbicides and insecticides from international countries were changed to US dollars based on that year's currency. Then all the surplus values were adjusted to value of 2013 by consumer price index (from U.S. Department of Labor, Bureau of Labor Statistics), to avoid the effect of inflation.

Besides the primary data of annual yields and surplus for farmers, seed companies and consumers, we also record the study location—country, GM traits and the economic level of the country as dummy variables. The data set of annual crop prices was collected from FAOSTAT website (http://faostat.fao.org/) and the annual average crop yields data was taken from the World Bank data source (http://data.worldbank.org/).

We also introduced region as a dummy variable to indicate the geographic location. the USA and Canada were considered as North America, while other counties in South America and Mexico were counted as Latin America. Other region groups such as Asia, Europe, Africa and Australia were created based on the geographic division method for continents. There are 101 observations for seed company surplus, about 58% reporting surplus in North America and Latin America, as shown in Figure 3. This might be because North America and Latin America have positive attitude and are more open to GM product. About 30% of the studies focused on Bt cotton and 23% on Bt corn. For farmer surplus, we have 115 observations, half of them estimated on Bt traits and mostly focused on North and Latin Americans, similar as seed company surplus. Only a few papers talked about consumer surplus, about 21 observations in total, mostly reporting on North American consumers, as shown in Figure 3.

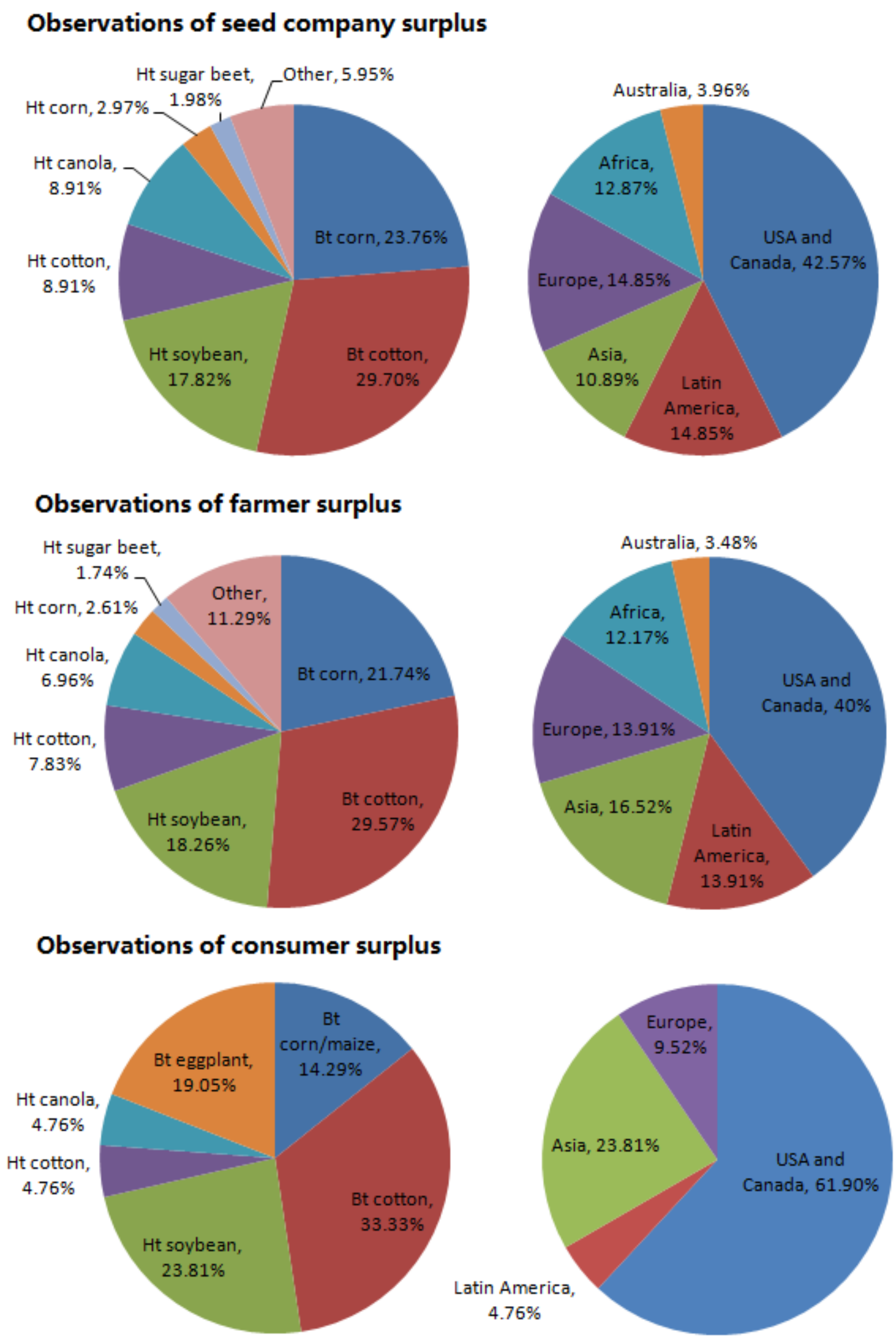


Figure 3. Distribution of observations.

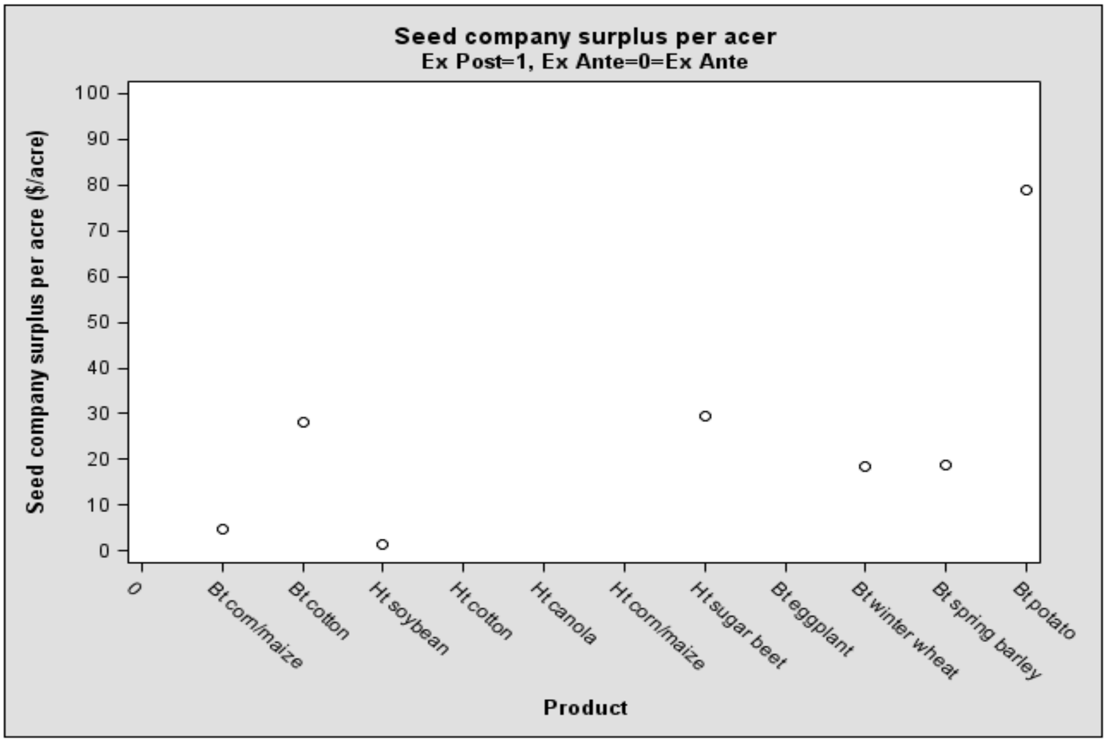
Chapter 5

Seed Company Surplus

5.1 Seed companies earn different surplus for different GM crops

For the seed company surplus ($/acre), first we plot the benefit by different GM crops. As shown in Figure 4, seed company surplus distribution from ex-ante studies is slightly different from ex-post studies. For ex-ante studies, seed companies earn more from Bt-potato crop, compared to ex-post studies. While in ex-ante studies, Bt-cotton provide more surplus for seed companies. Most of the research is focused on ex-post studies and observations from ex-ante studies are less. For seed company surplus, there are 93 observations from ex-post studies, while only 8 observations from ex-ante studies. That is might be the main reason that results from ax-ante studies are different from ex-post studies. The most frequently mentioned Seed Company in those recourses is Monsanto. Monsanto also collaborates with seed companies in other countries, such as Mahyco Monsanto Biotech in India.

1. Seed company surplus from Ex Ante studies



2. Seed company surplus from Ex Post studies

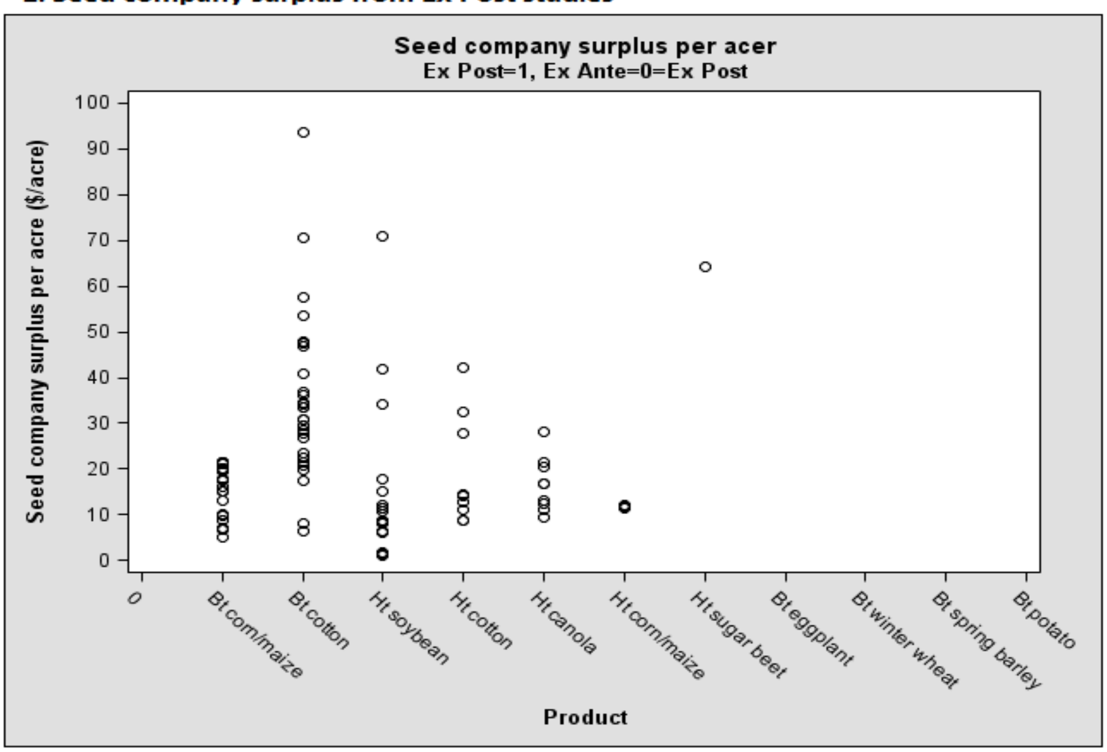


Figure 4. Seed company surplus plot by GM crops.

We also plot the mean value of seed company surplus of different types of GM crops and compared them between Ex-ante and Ex-post studies, as shown in the Figure 5 below. Seed companies have higher profit for some type of GM crops such as Ht suger beet and Bt cotton, while lower profit for other GM crops like Ht soybean and Bt corn. Among all of the GM Crops, Ht sugar beet has the highest surplus for seed companies, about 4 times higher than the lowest seed company surplus for Ht soybean. It also shows from the figure that for each type of GM crops, seed company surplus in Ex ante studies is lower than Ex post studies, indicating that the Ex-ante studies turned to under-estimate the seed company surplus.

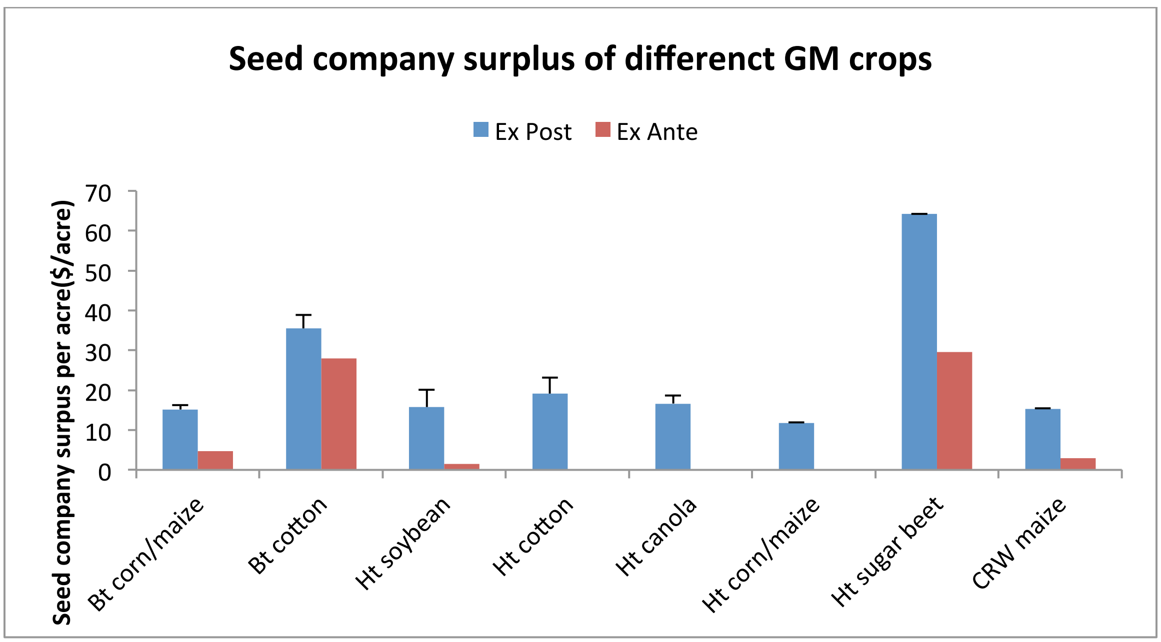


Figure 5. Seed company surplus for different GM crops.

We only have 8 observations from Ex-ante studies and some of the observations estimated the seed company surplus of non-commercialized GM crops, such as Bt eggplant and Bt winter wheat. We only found a few observations which cover the same type of GM crop in the same region as Ex-post studies and compared their estimation, as show in Figure 6. Generally, the estimated surplus from Ex-post studies is higher than Ex-ante studies, except Bt cotton in Africa. The average seed company surplus of Bt corn in Africa from Ex-post studies is $6.39, about $1.72 higher than Ex-ante studies per acre. Similar for Ht soybean in Latin America, the average estimation from Ex-post studies is about $3.62 higher than Ex-ante studies. For CRW corn in the USA and Canada, the difference is even larger, about $12.47 per acre.

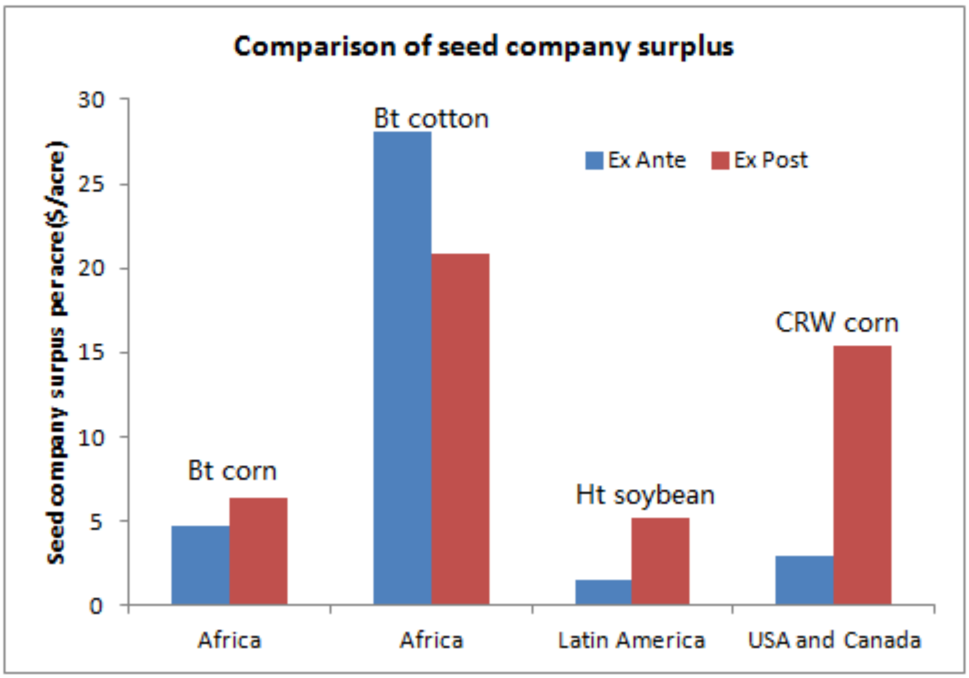
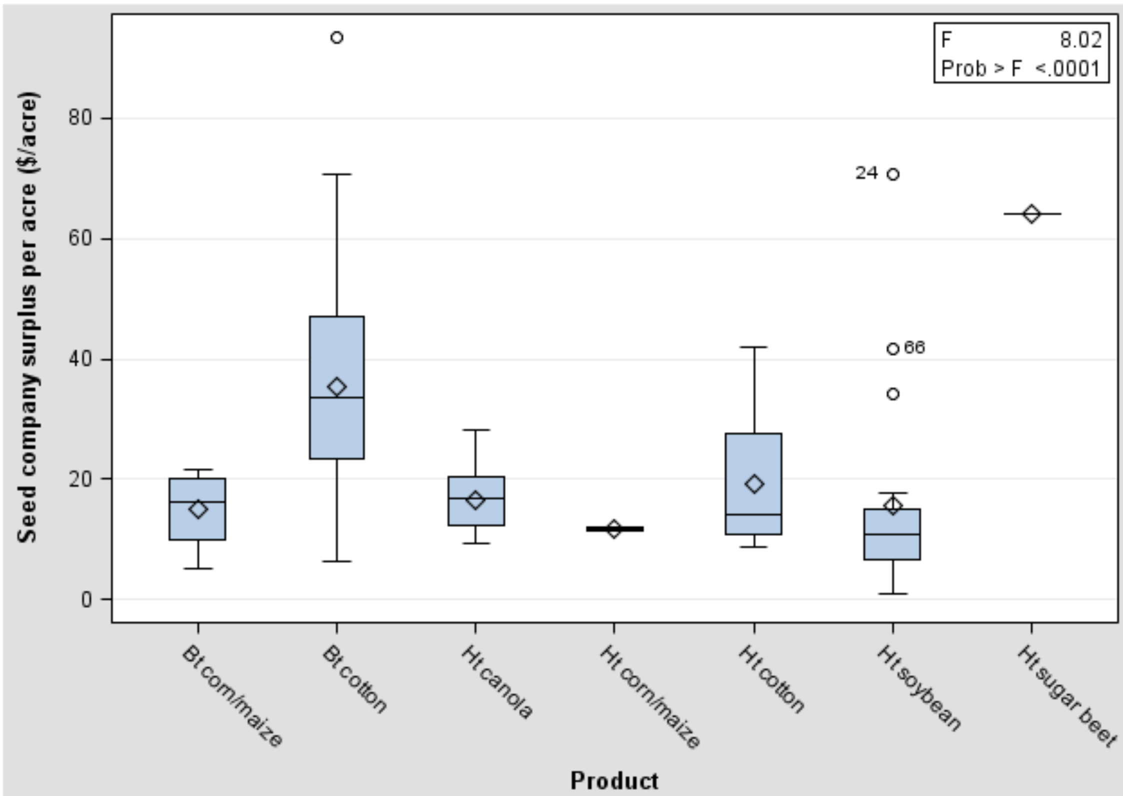


Figure 6. Comparison of seed company surplus between Ex-ante and Ex-post studies.

Furthermore, seed company surplus was compared between different types of GM crops and the comparison is analyzed only based on Ex-post studies. The one-way ANOVA analysis shows that P<0.001, indicating that the mean of seed company surplus differs significantly among different types of GM crops. However, we do not know if the difference is between all of the GM crops or only two of the GM crops. The results are shown in Figure 7. To find out which two GM crops have different seed surplus, t-test screen is needed between different GM crops.

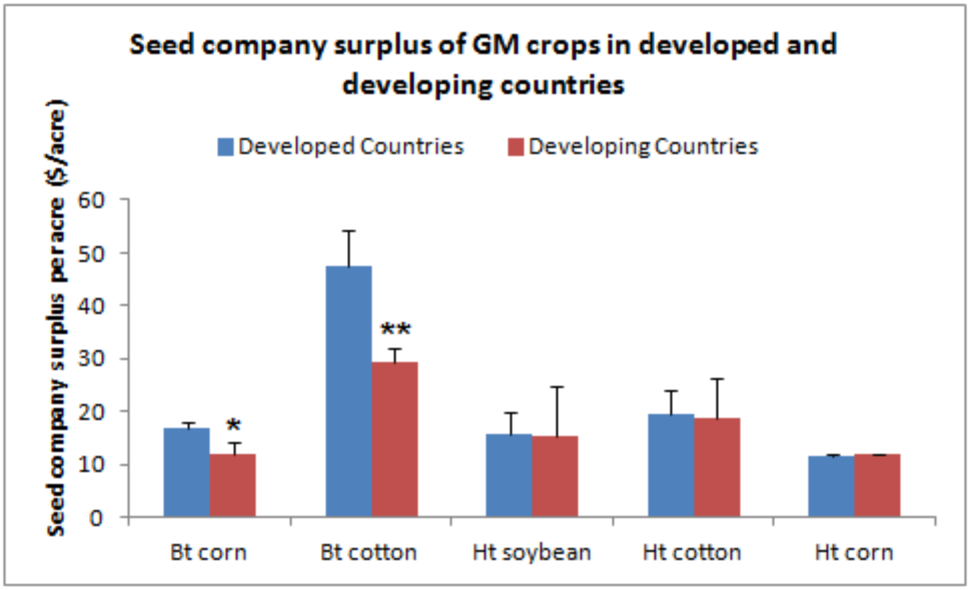


Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	9400.54036	1566.75673	8.02	<.0001
Error	84	16407.81102	195.33108		
Corrected Total	90	25808.35138			

Figure 7. ANOVA results for seed company surplus by GM crops

5.2 Seed company surplus is different between developed and developing countries

We also compared the seed company surplus of different GM corps between developed and developing countries. Since there were only 8 observations coming from Ex ante studies and they could not form comparison groups for t-test, only observations from Ex post studies are considered here. We found that, for Bt corn ($P<0.05$) and Bt cotton ($P<0.01$), seed companies have more profit in developed countries, as shown in Figure 8. Especially for Bt cotton, seed companies earn about \$47 per acre more than traditional seed companies in developed countries such as the USA and Australia, while about \$29 in developing countries such as China and India. Generally, seed companies have the most benefit from selling Bt cotton seeds in developed countries than other GM crops in other countries. For Ht cotton and Ht corn, no difference was observed based on current research data sources, with about \$15 surplus per acre for GM seed companies. For Ht sugar beet, due to lack of data in developing countries, we did not compare their surplus. More data about the seed company's surplus in developing countries was reported than developed countries for Bt cotton. For other crops, more studies were done in developed countries than developing countries.



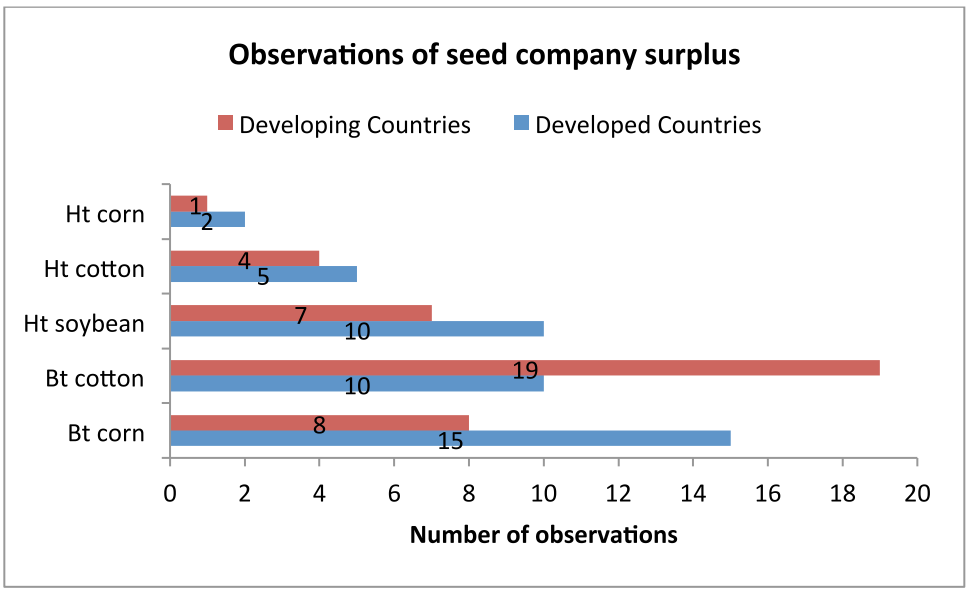


Figure 8. Differences of seed company surplus between GM crops.

5.3 Region differences in seed company surplus

The observations of our data set came from different countries, covering all the six continents. However, the numbers of the observations from the six continents are not even. Most of the studies focused on GM seed company surplus in the USA and Canada.

This might be because that the USA is one of those first countries to adopt GM crops, with the largest adoption area, and that most of GM seed companies locate in the USA. Figure 9 shows the number of seed company surplus observations in our sample categorized according geographical locations. In addition to the large number of observations for the USA and Canada, there are also a lot of Ex Post studies on seed company surplus in Latin America, Asia and Europe.

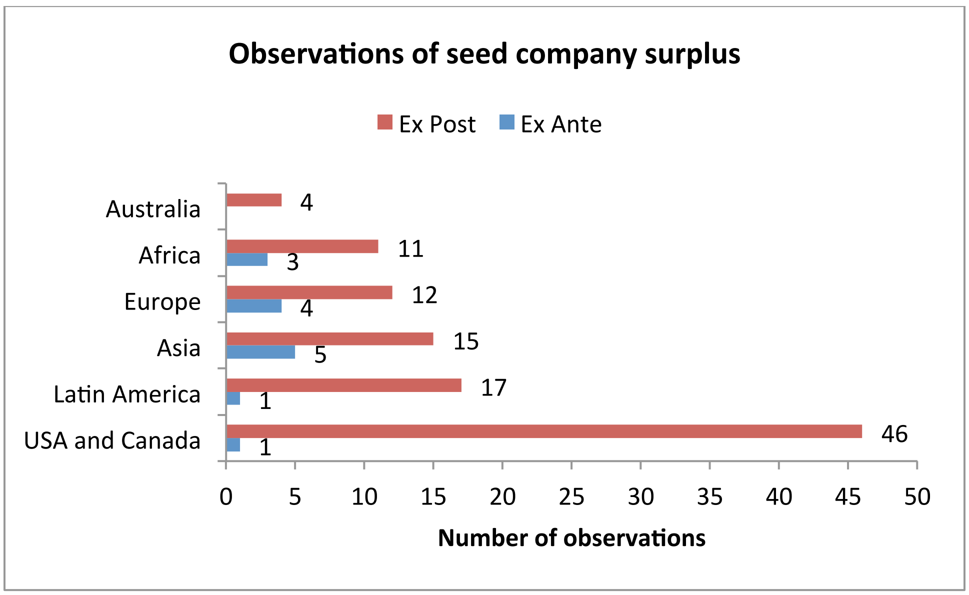
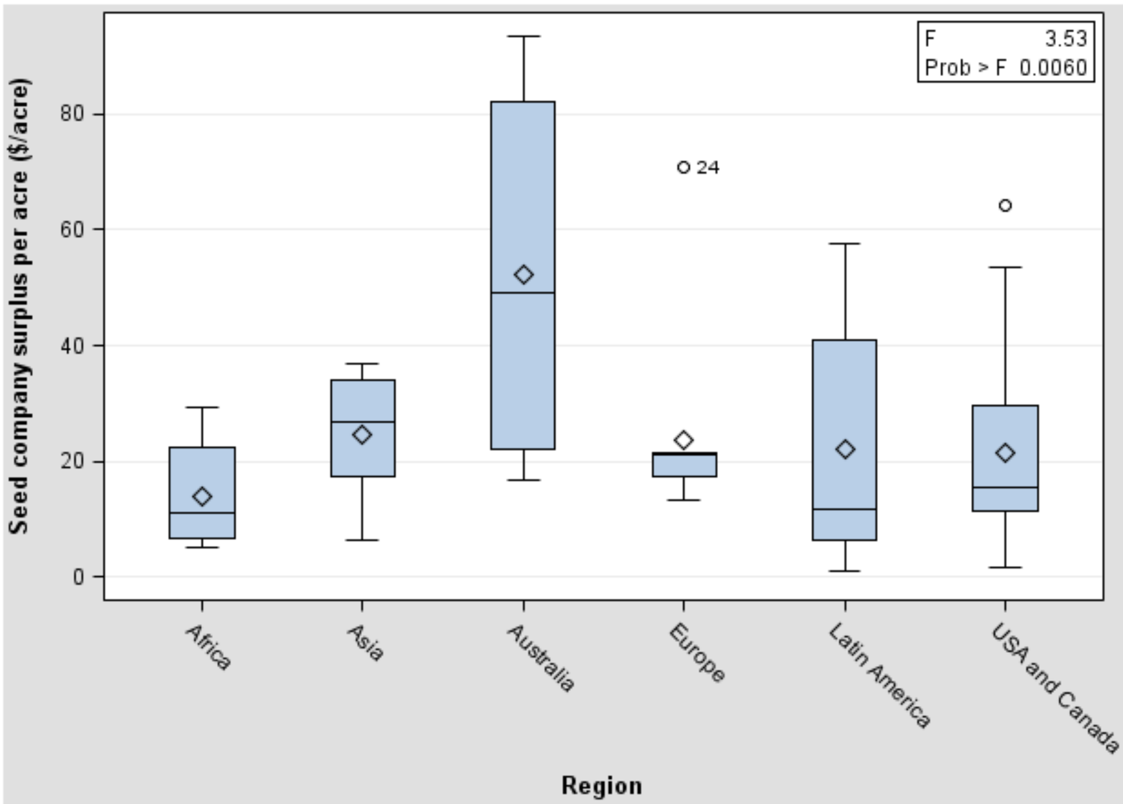


Figure 9. Observations of seed company surplus in different regions.

We also compared the regional difference of GM seed company surplus by one-way ANOVA. The results in Figure 10 show that seed companies earn the most in Australia, mostly from Bt cotton, while the least in Latin America and Africa. This might be mainly because the copy right protection. In most of Africa and Latin America countries, farmers could use their own saved farm seeds or sell their seeds at a lower price than GM seed companies without technology fee charges. The ANOVA results shows that $P<0.004$, indicating that GM seed companies earn differently per acre among different regions. Here we only compared the average surplus per acre. When the total profit is considered, the total adoption area of GM crops should also be included. Since the adoption rate and plant area is much larger in North America, seed companies generally gain the highest profit in the USA and Canada.



Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	4437.24645	887.44929	3.53	0.0060
Error	85	21371.10493	251.42476		
Corrected Total	90	25808.35138			

Figure 10. ANOVA results for seed company surplus in different regions

5.4 Econometrics results for seed company surplus

The above exploratory analysis of the available data did not explain interactions between the various explanatory variables. In order to attain marginal effects — given the interference of potentially relevant intervening characteristics — meta-regression analysis is used to estimate the relative importance of all potentially relevant factors simultaneously. Those original literatures used various methods to estimate the surplus of GM crops compared to non-GM crops. Some used basic statistic method to analyze farm survey data; and some literatures estimate through economic equilibrium models while others reported based on experienced data or published data of GM seed companies. Therefore, meta-regression is needed to analyze the impact of research methods and other relevant factors, such as GM traits and geographical locations, simultaneously. Different Ordinary Least Square models were employed to estimate the effect of GM traits and the degree of economic development on seed company surplus. It turns out the interaction model with region dummy variables works best, as shown in the Table 1 as below. In this model we used binary variables to indicate whether it is developing or developed countries and to distinguish Bt trait from other GM traits. Ex binary variable was created to indicate whether it is Ex Ante study or Ex Post study. We also included four dummy variables to estimate surplus differences between regions, as well as three dummy variables to distinguish data analysis methods. Crop prices in the producer market (data came from FAOSTAT) and average crop yields per acre (data came from the World Bank) were also used as independent variables. Besides, interaction terms were considered in this model. The model fit was considerably improved and the estimated model is shown as below, where $\alpha 0$ is the usual constant term, ε a vector of residuals (assuming well behaved underlying errors), and the vectors α1 to α12 indicate the estimated coefficients on the respective explanatory variables.

$$\begin{aligned} Y_{SSA} = {} & \alpha_0 + \alpha_1 EconLevel + \alpha_2 Bt + \alpha_3 Hybrid + \alpha_4 Ex + \alpha_5 Analysis \\ & + \alpha_6 Model + \alpha_7 Pprice + \alpha_8 TYield + \alpha_9 NorthAmerica \\ & + \alpha_{10} LatinAmerica + \alpha_{11} Asia + \alpha_{12} Europe + \varepsilon \end{aligned}$$

Table 1 presents the primary results of this study. A good model fit is evidenced by the F-statistics, which indicate the estimated models are statistically significant. The adjust R-square value (0.438) is strikingly high, considering the data point came from different literature articles, in which diverse research methods were studied at various geographic locations. About 43.8 % of the variation in the valuation of seed company surplus could be explained by the independent variable listed in Table 1. Among the research actives studies on GM food benefits, most of them focused on Bt traits. About 50% of our data points are Bt trait and the regression results showed that seed companies normally got more profit on Bt trait than other GM traits, about $16 per acre. The meta-regression results also showed that whether it is Ex Ante or Ex Post study did not affect the estimation of GM seed company surplus, when all the factors were considered simultaneously. Evaluations from different research methods tended to get similar results of seed company surplus. On the other hand, the seed company surplus was related to crop prices in producer markets and average crops yields. The more the farmers harvested from the crop and the higher price they sold on the market, the more the seed company earned from the crop. The effect of crops yields on seed company surplus is slightly related to Bt trait. The coefficients of the four region dummy variables show that seed companies earned different profit in different regions, with higher surplus per acre in Latin America. The GM traits are various and seed companies charge different seed prices in different counties, therefore their profit are affected.

Variable	Definition	Parameter
Intercept		-24.012 (9.480)
EconLevel	Developed=1, developing=0	-1.443 (9.433)
Bt	Bt trait=1, other trait=0	15.865*** (4.418)
Hyb	Hybrid=1, Non hybrid=0	0.564 (4.218)
Ex	Ex Post=1, Ex Ante=0	13.709 (8.209)
Analysis	Statistic analysis=1, other=0	4.053 (3.322)
Model	Economic model=1, other=0	3.250 (2.872)
Pprice	Crop Producer Prices($/kg)	8.583** (3.023)
TYield	Crop average yield (kg/acre)	0.001*** (0.0001)
bt_tyield	Interaction of Bt and Tyield	-0.002** (0.0008)
NorthAmerica	NorthAmerica=1, other=0	16.220 (9.781)
LatinAmerica	LatinAmerica=1, other=0	20.751*** (5.646)
Asia	Asia=1, other=0	6.745 (4.402)
Europe	Europe, other=0	17.284 (9.1408)
F-Statistic	9.96***	
Adjust R^2	0.439	

Note: Triple, double and single asterisks (*) denote statitical significance according to conventional OLS standard errors at the 0.001, 0.01 and 0.05 levels, respectively. Numbers in parentheses () are conventional standard errors obtained from the OLS variance-covariance matrix.

Table 1. Meta-regression results for seed company surplus.

Chapter 6

Farmer Surplus from GM Crops

6.1 Farmer surplus are slightly different between GM crops

Most of the farmer surplus observations were collected from Ex Post studies, about 104 data points; only 14 observations were collected from Ex Ante studies. There is a marked focus on Bt cotton and Ht soybean; while a few studies report farmer surplus of Ht corn. Besides, the observations are different among geographical locations, more literatures studied farmer surplus of GM products in the USA and Canada while less in Australia, as shown in Figure 11 and Figure 12.

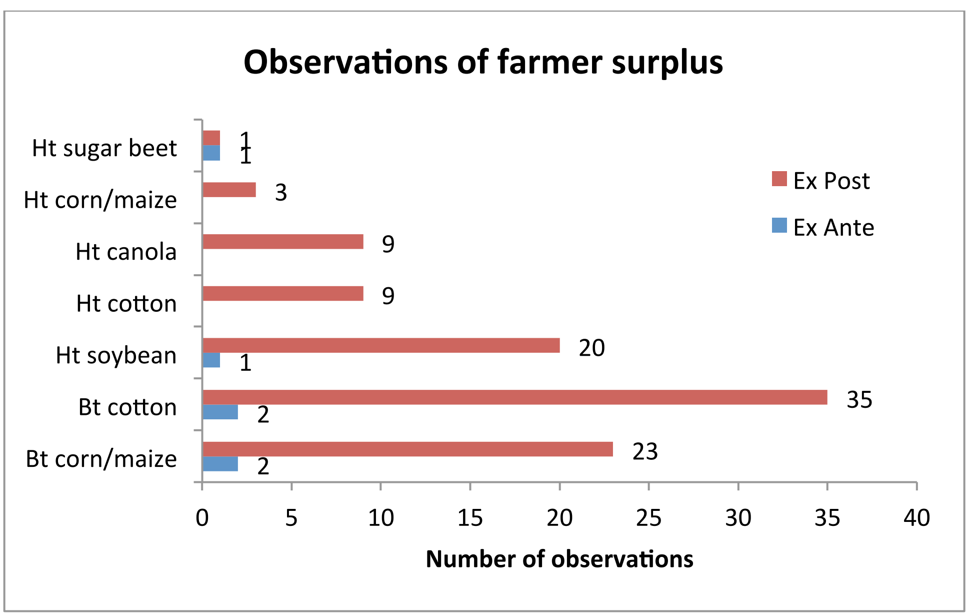


Figure 11. Number of farmer surplus observations for different GM crops.

In Figure 11, only those GM crops both studied by Ex Ante and Ex Post methods are showed here for comparison. Other GM crops, such as Bt eggplant which only reported by Ex Ante studies and Bt potato by Ex Post studies, are not showed in Figure 11 but included in our basic statistical analysis. More studies were focused on Bt cotton, compared to other GM crops. Bt cotton are broadly adapted in North America, Latin America, Asia and Australia and most of the data points were reported in those regions. There were also a lot of studies reporting farmer surplus of Ht soybean, mainly in North America and Latin America.

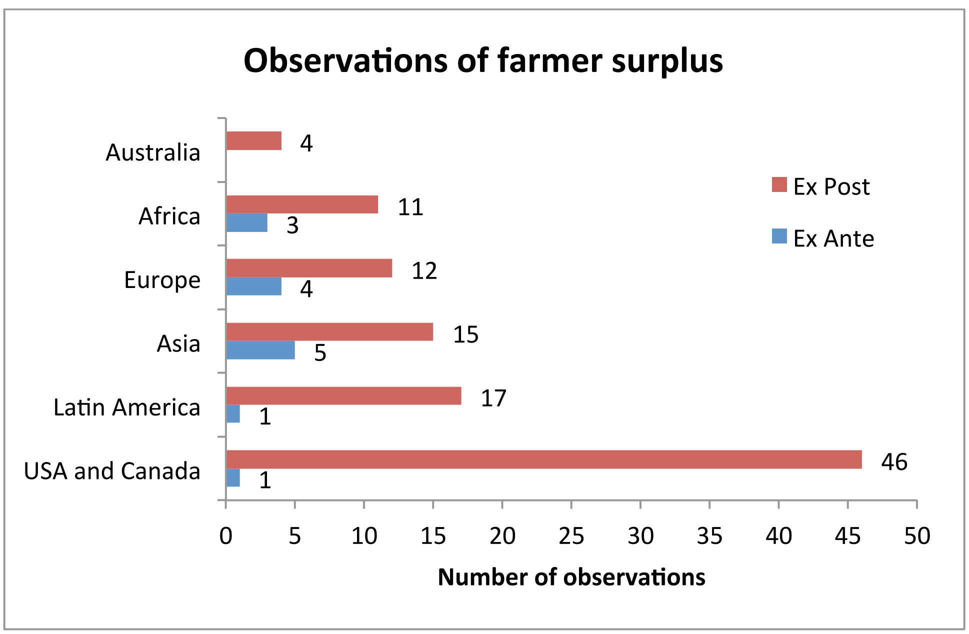
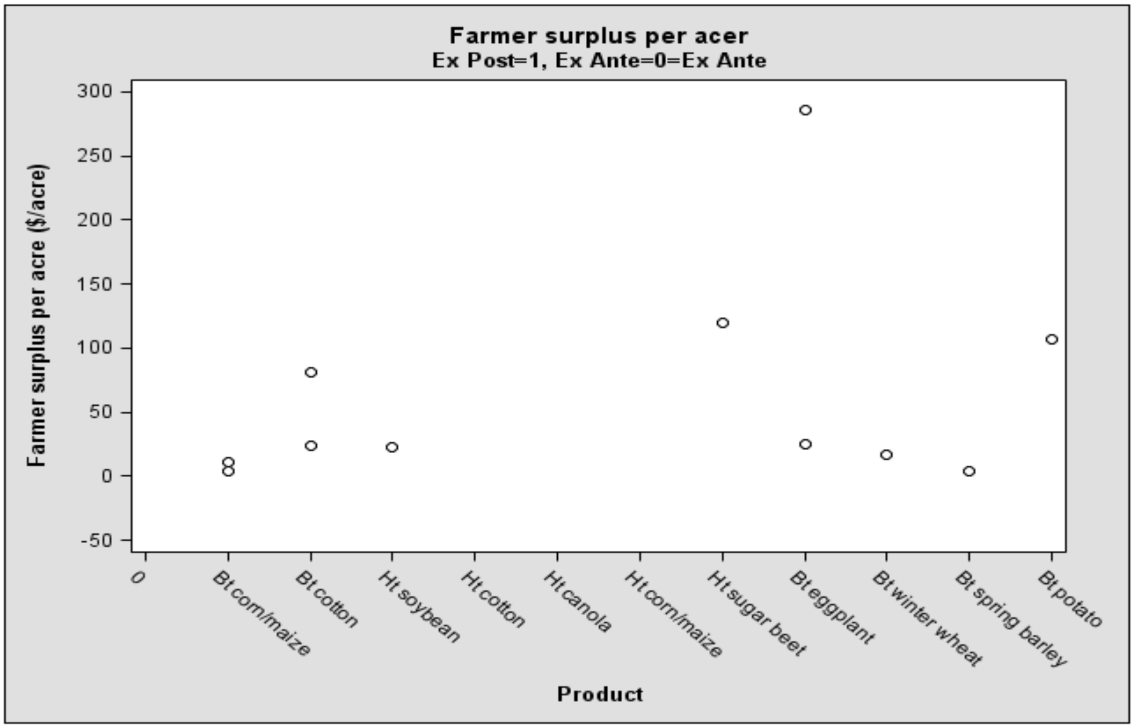


Figure 12. Number of farmer surplus observations in different regions.

From the distribution of the data points, grouped by types of GM crops, we could tell that farmer surplus is different between GM cops, as shown in Figure 13. For

Ex Ante studies, the Bt eggplant in India was reported to have higher farmer surplus around $300 per acre compared to traditional eggplant. However, among those commercialized GM crops, Asian farmer got higher pay off though adopting Bt cotton.

1. Farmer surplus from Ex Ante studies



2. Farmer surplus from Ex Post studies

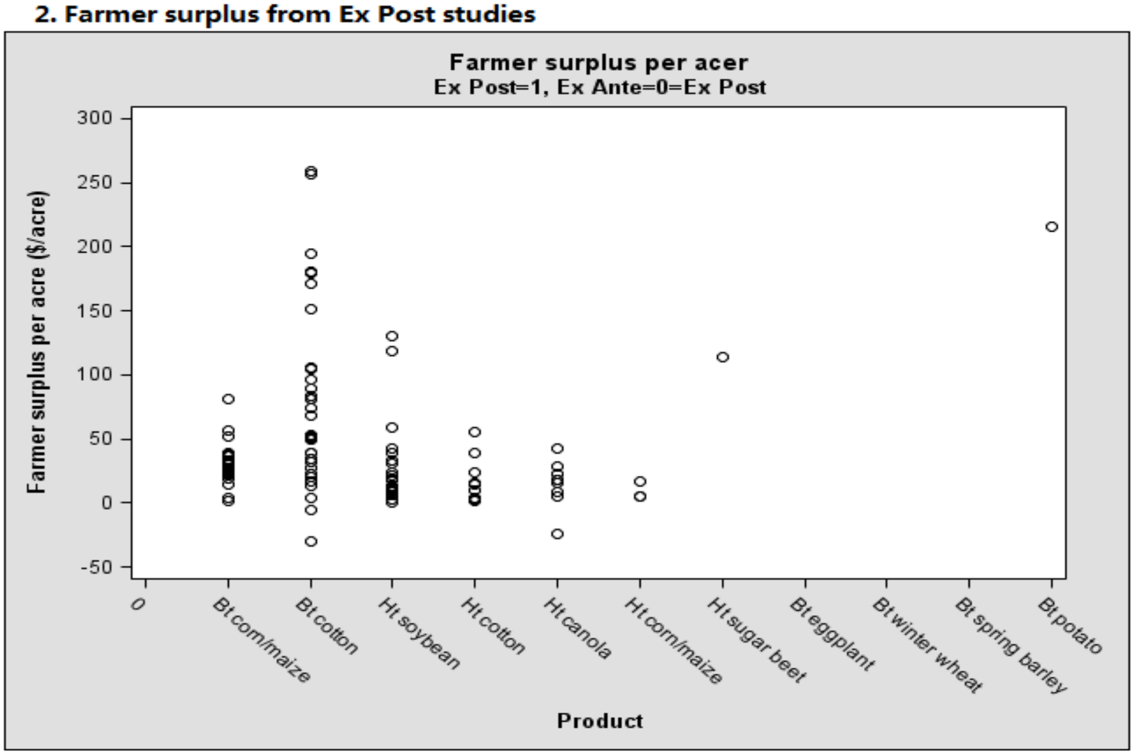
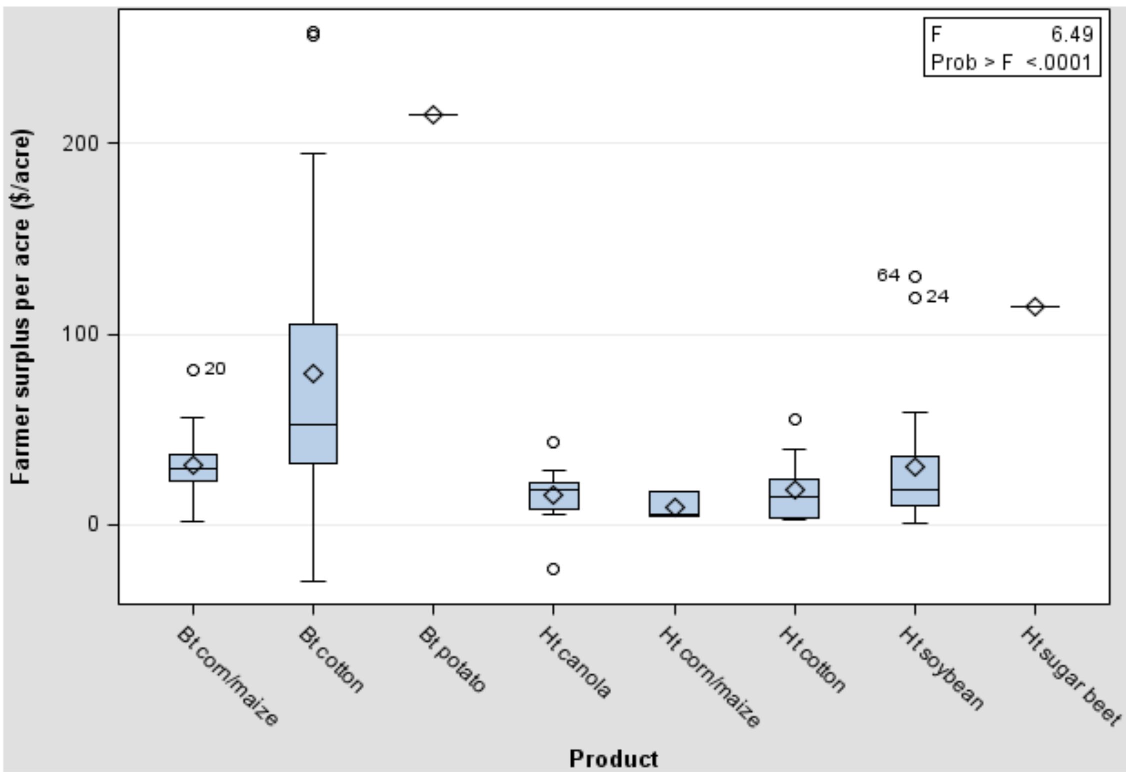


Figure 13. Distribution of farmer surplus for different GM crops.

Since famers might gain different profit from different GM traits, one way ANOVA was tested on the Ex Post observations. The ANOVA result, as shown in Figure 14, shows that P<0.0001, indicating there is significant difference between farmer surplus of different GM crops. It seems the farmer surplus of Bt cotton is much higher than other GM crops, such as Ht canola and Ht cotton which might have similar level of farm surplus. More solid statistical analysis is needed to distinguish the difference of farmer surplus.



Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	100186.6422	14312.3775	6.49	<.0001
Error	92	202877.6504	2205.1919		
Corrected Total	99	303064.2926			

Figure 14. ANOVA results for farmer surplus.

Bt cotton cultivars has been highly adopted in Asia, especially in China and India, due to agriculture history and the effective control on lepidopteran pests. Most of the observations of farmer surplus on Bt cotton in this thesis come from studies in India. Our meta-analysis results, in Figure 15, show that farmers in Asia gained higher benefits in average from adaption of Bt cotton, about $139 per acre. While in other place, farmers normally earn about $45 per acre more than planting traditional cotton. If we compare in the same region, we find that Bt cotton (around $45 per acre) brings a high benefit to farmers than other GM traits (around $25 per acre).

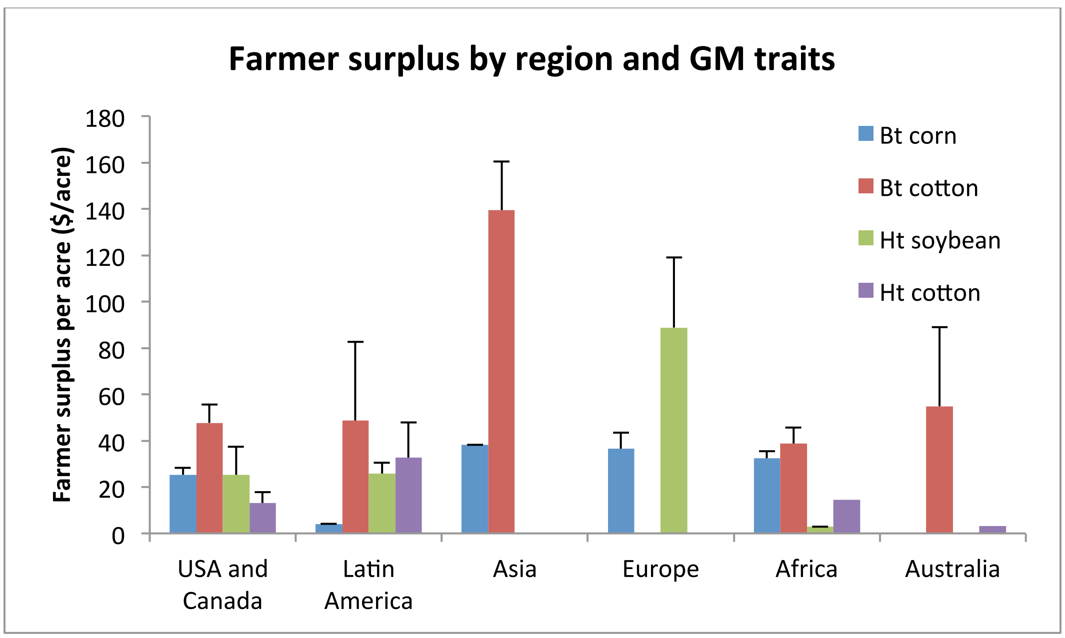


Figure 15. Farmer surplus of GM crops in different regions.

Farmer surplus is highly related to their geographical location and GM traits. For the same GM trait, farmers might have different surplus among countries. For example, farmer surplus of Ht soybean is higher (about $69 per acre) in Europe than in Africa (about \$2.9 per acre). In North America, farmers generally gain more profit from adaption of Bt cotton than other GM traits, such as Bt corn and Ht cotton. Those farmer surplus observations have been collected from various publication outlets, including journal articles, project reports, thesiss and book chapters. This study is very diverse in terms of the objectives of the research being presented. Besides, there is also a diversification in the valuation methodologies used and the geographic location of GM traits being adapted. Therefore the standard error of our analysis is large.

6.2 Econometrics results for farmer surplus

We also used the meta-regression model to estimate the marginal effects for farmer surplus. The dependent variable in this regression equation is a vector of values in US\$ per acre, indicating the extra earnings farmers gain per acre, compared to traditional non-GM crops. The explanatory variables are crop producer price, average yield in the according year, dummy variables for estimation methods, geographical location and the degree of economic development, as well as an interaction term. The estimated equation model is:

$$\begin{aligned} Y_{SSA} = {} & \alpha_0 + \alpha_1 EconLevel + \alpha_2 Bt + \alpha_3 Hybrid + \alpha_4 Ex + \alpha_5 Analysis \\ & + \alpha_6 Model + \alpha_7 Pprice + \alpha_8 TYield + \alpha_9 NorthAmerica \\ & + \alpha_{10} LatinAmerica + \alpha_{11} Asia + \alpha_{12} Europe + \varepsilon \end{aligned}$$

The regression results are presented in Table 2. The adjusted R-square value of 0.638 is reasonably high, and indicates that about half of the variation in farmer surplus is explained by variation in our explanatory variables. Besides, the F-statistic value (23.59) further proves that this meta-regression estimation on farmer surplus is statistically significant. Different from the meta-regression model for seed company surplus, the coefficients of dummy variables for Economic Level and GM traits are not significant in the farmer surplus model. This might show that the farmer surplus is not highly dependent on the degree of economic development and GM traits, as seed company surplus. Farmers in developed countries and developing countries might gain similar level of profit through introducing GM seeds, no matter whether the traits are Bt or not. However, the whether the crop is hybrid or not could affect farmer surplus. As shown in Table 2, farmers gained fewer surpluses if the GM trait was hybrid crop, about $34 less per acre.

On the other hand, estimation methods did affect evaluation of farmer surplus per acre. The meta-regression results showed that estimations from statistical analysis of farm survey data generally reported higher farmer surplus compared to other methods, about $35 higher per acre. While estimations from economic equilibrium models were about $19 lower than other methods per acre.

As we expected, farmer surplus is related to the total crop yield of that year; the more crops farmers produce, the more they can sell on market. Regarding the influence of geographical location on farmer surplus, differences in value associated with different locations are indicated by the coefficients on these four region dummy variables. One of these coefficients are significantly different from zero, indicating that Asian farmers gain about $94 more per acre from growing GM crops than farmers in other regions.

Variable	Definition	Parameter
Intercept		24.016 (29.335)
EconLevel	Developed=1, developing=0	16.063 (29.326)
Bt	Bt trait=1, other trait=0	20.566 (11.710)
Hyb	Hybrid=1, Non hybrid=0	-33.733** (10.535)
Ex	Ex Post=1, Ex Ante=0	-24.236 (26.205)
Analysis	Statistic analysis=1, other=0	35.035**** (9.735)
Model	Economic model=1, other=0	-18.766* (8.875)
Pprice	Crop Producer Prices($/kg)	10.364 (8.341)
TYield	Crop average yield (kg/acre)	0.003*** (0.0005)
bt_tyield	Interaction of Bt and Tyield	0.003** (0.001)
NorthAmerica	NorthAmerica=1, other=0	-16.795 (31.681)
LatinAmerica	LatinAmerica=1, other=0	-25.562 (17.604)
Asia	Asia=1, other=0	94.455*** (12.688)
Europe	Europe, other=0	-1.179 (29.889)
F-Statistic	23.59***	
Adjust R^2	0.639	

Note: Triple, double and single asterisks (*) denote statitical significance according to conventional OLS standard errors at the 0.001, 0.01 and 0.05 levels, respectively. Numbers in parentheses () are conventional standard errors obtained from the OLS variance-covariance matrix.

Table 2. Econometrics results for farmer surplus.

Chapter 7

Consumer Surplus

While a lot of previous studies focus on consumer wiliness to pay, like Timothy's study on GM rice in West Africa (Dalton 2004), we mainly focus on consumer surplus compared purchasing non-GM food. Among the 58 primary literatures, 15 provided estimations on consumer surplus of GM crops. Only 4 papers evaluated the consumer surplus through ex ante method while the other 11 literatures are ex post studies.

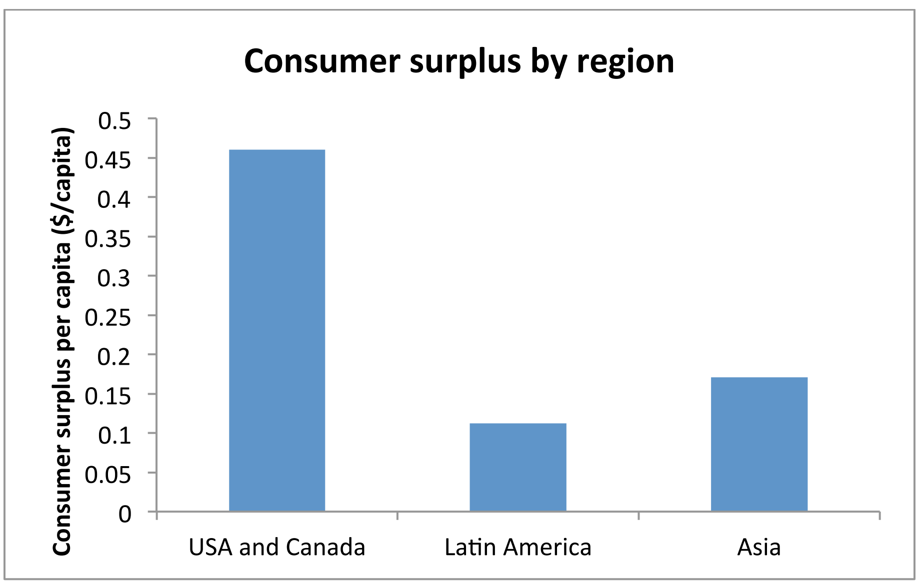


Figure 16. Consumer surplus ($/capita) in different regions.

One ex ante study assessed the potential benefit of Bt maize in Kenya, with a consumer surplus value of $1.59 per capita (De Groote et al. 2003). Qaim (Krishna and Qaim 2008) and Mishra (Mishra 2003) estimated consumer surplus of Bt eggplant in

India by Ex-Ante method and both reported around $0.2 per capita benefit for consumer. Then there is another Ex-Ante paper studied Bt cotton in Mali and conclude that consumers might gain $1.17 per capita from purchasing Bt cotton related products.

There are 15 observation data point for consumer surplus from ex post studies, including 13 reports for the USA and Canada, 1 for Latin American and 1 for Asia. The America continent is the largest market for GM crops, especially in the USA and Canada; therefore more surveys on consumer surplus have been done in North America. As shown in Figure 17, consumers in the USA and Canada captures more surplus than in other continents, such as Latin America and Asia. However, consumers generally receive a little surplus from purchasing GM crops or food; even the USA and Canadian consumers only got 0.3 dollars per capita. Consumers surplus are only 0.15 dollars per capita in Asia and around 0.1 dollars in Latin America. For consumer surplus, the estimation value from ex ante study is in the same range with ex post studies. Not too much benefit from consuming GM related products might play an important role in the consumer aversion toward GM crops.

When comparing the consumer surplus between GM crops, we found that Bt corn brought more benefits to consumers than other GM crops; although the absolute value is still not too much, about 2.23 dollars per capita. For Bt cotton, Ht soybean and Ht cotton, their consumers surplus are less than 1 dollar per capita, as shown in Figure 18.

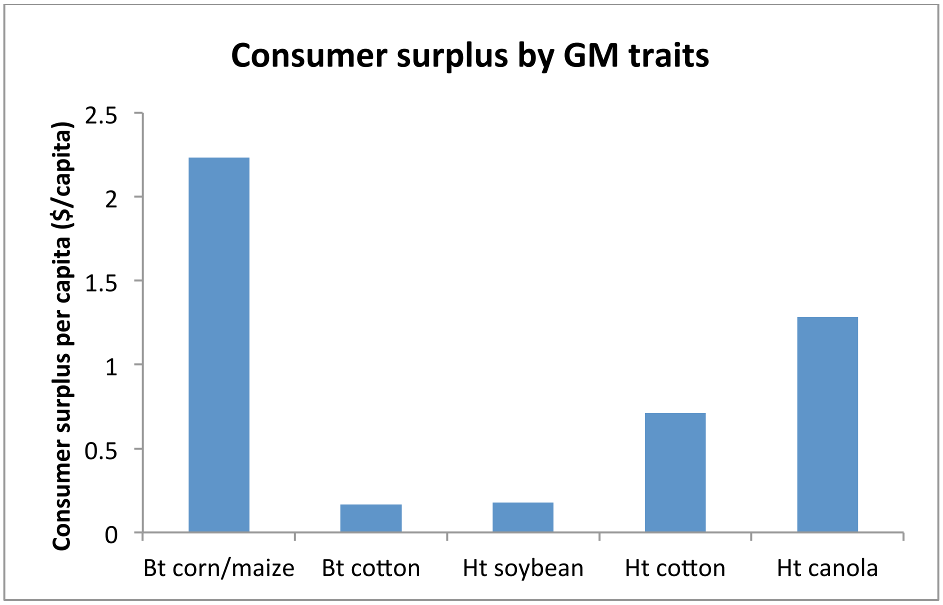


Figure 17. Consumer surplus of different GM crops ($/capita).

The meta-regression model was also used to estimate the marginal effects of consumer surplus. Data set comes from Ex-post literatures. The consumer surplus ($/capita), the extra earnings per consumer gains compared to non-GM crops, is the dependent variable. The explanatory variables are crop producer price, average yield in the according year, binary variables to indicate the degree of economic development and whether the GM crop is Bt trait or not. The estimation model is:

Variable	Definition	Parameter
Intercept		-0.052 (0.173)
EconLevel	Developed=1, developing=0	0.296* (0.067)
Bt	Bt trait=1, other trait=0	-0.407** (0.063)
Pprice	Crop Producer Prices($/kg)	-0.148 (0.098)
TYield	Crop average yield (kg/acre)	0.0002*** (0.00002)
F-Statistic	190.84***	
Adjust R^2	0.992	

Note: Triple, double and single asterisks (*) denote statitical significance according to conventional OLS standard errors at the 0.001, 0.01 and 0.05 levels, respectively. Numbers in parentheses () are conventional standard errors obtained from the OLS variance-covariance matrix.

Table 3. Econometrics results for consumer surplus.

The meta-regression results are shown in Table 3. Results are reported from un-weighted ordinary least squares regression. The F-statistics value is 190.84, indicating a good model fit and that the estimation is statistically significant. The adjusted R-square has a strikingly high value as 0.992, showing that the set of variables defined in Table 3 explain about 99% of the variation in the valuations for consumer surplus. The coefficient of GDP is positive and statistically significant, indicating that consumers in developed countries gain more profit from purchasing GM related products. From the result, it is also found that whether the GM crops are Bt trait have an impact on consumer surplus. Non-Bt trait GM crops, such as HT trait might bring more benefit to consumer. Besides, crop yield also affect consumer surplus, the more the total yield the more consumers benefit from the adoption of GM crops. On the other hand, the coefficient of crop market price is not significant, suggesting that the crop price might not affect consumer surplus.

Chapter 8

Cost savings of chemical sprays

6.1 Cost savings of insecticide

There are a few papers reported cost savings of insecticide. 3 of the observations came from Ex Ante studies and the other 31 observations were estimated by Ex Post studies. As shown in Figure 18, all the 3 observations of Ex Ante studies were done in developed countries and the insecticide cost savings varied from $28.43 per acre to $195.5 per acre. For the estimations in Ex Post studies, there is no difference between developing and developed countries, with average values around $25 per acre, indicating that insecticide chemical companies generally gain $25 less per acre if farmers adopt GM traits.

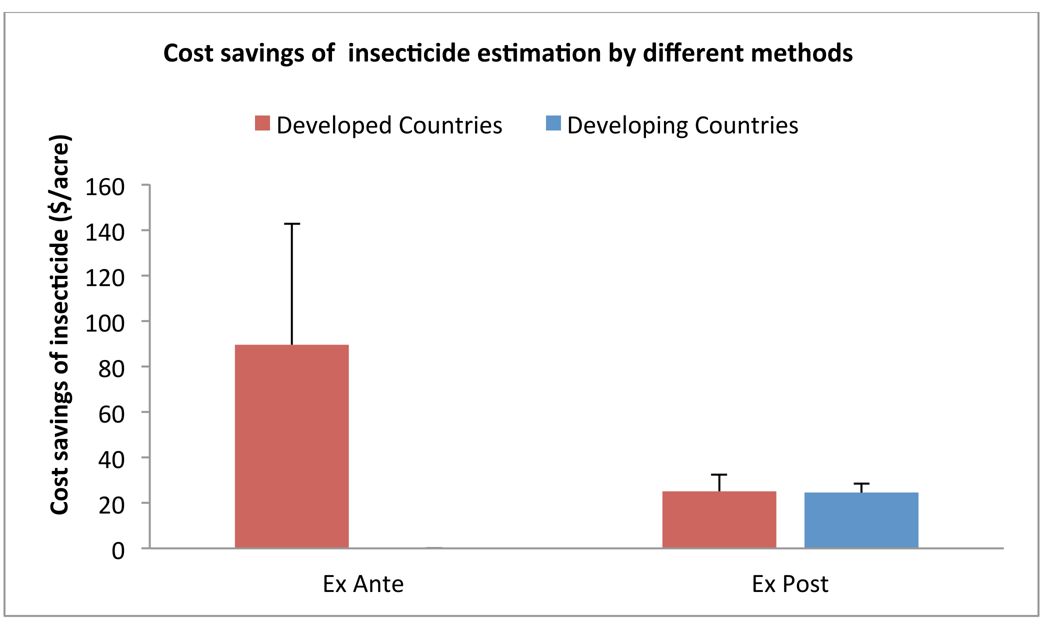


Figure 18. Cost savings of insecticide estimation by different methods.

Most of these available observations in Ex Post studies came from reports on Bt cotton and Bt corn. For Bt corn, only one observation was reported in developing countries, not enough for statistic analysis. It seems that farmers in developing countries save more on insecticide than in developed countries from adopting Bt corn, as shown in Figure 18, however, more studies are need to confirm the result. For Bt cotton, most of the insecticide data came from studies in India. It shows that no difference was observed for insecticide savings between developed countries and developing countries. Overall, farmers save about $18 to $20 dollars per acre through introducing GM seeds compared to traditional seeds.

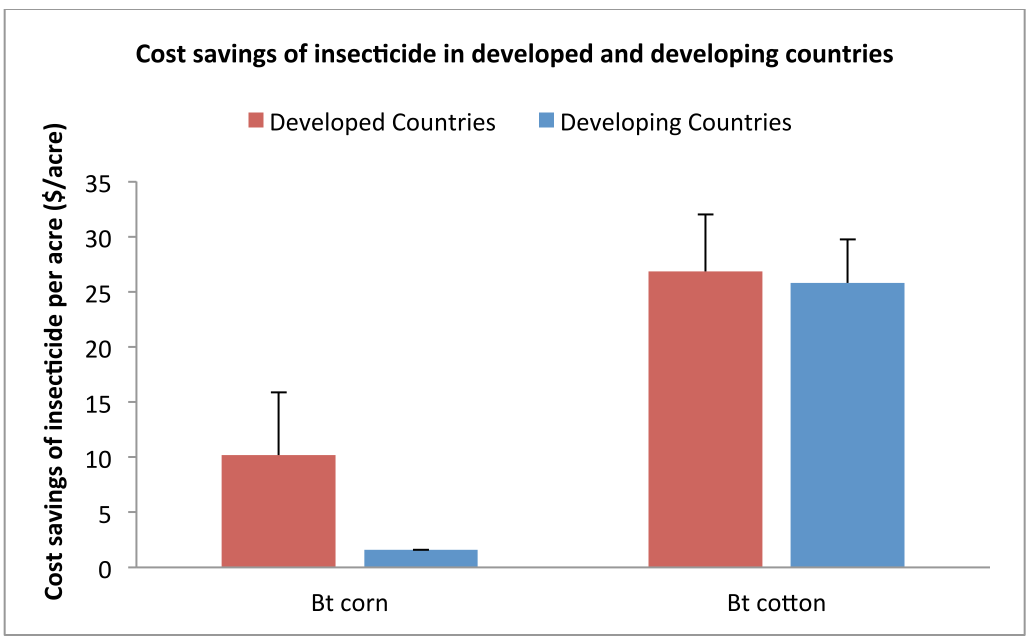


Figure 19. Cost savings of insecticide in developed and developing countries.

6.2 Cost savings of herbicide

Only one Ex Ante paper estimated herbicide cost savings from adopting Ht sugar beet in the USA, compared to traditional sugar beet. It reported that farmer could save about $75 per acre on herbicide from planting Ht sugar beet. There are 7 observations from Ex Post studies, 5 of which studied on Ht soybean, 1 on Ht cotton and 1 on Ht canola in Canada. As shown in Figure 20, plant Ht soybeans could save farmers about $20 per acre on herbicide and it seems that there is no significant difference between developed and developing countries. One paper reported that farmers could save as much as $80 per acre on herbicide cost while we need more observations to confirm this conclusion.

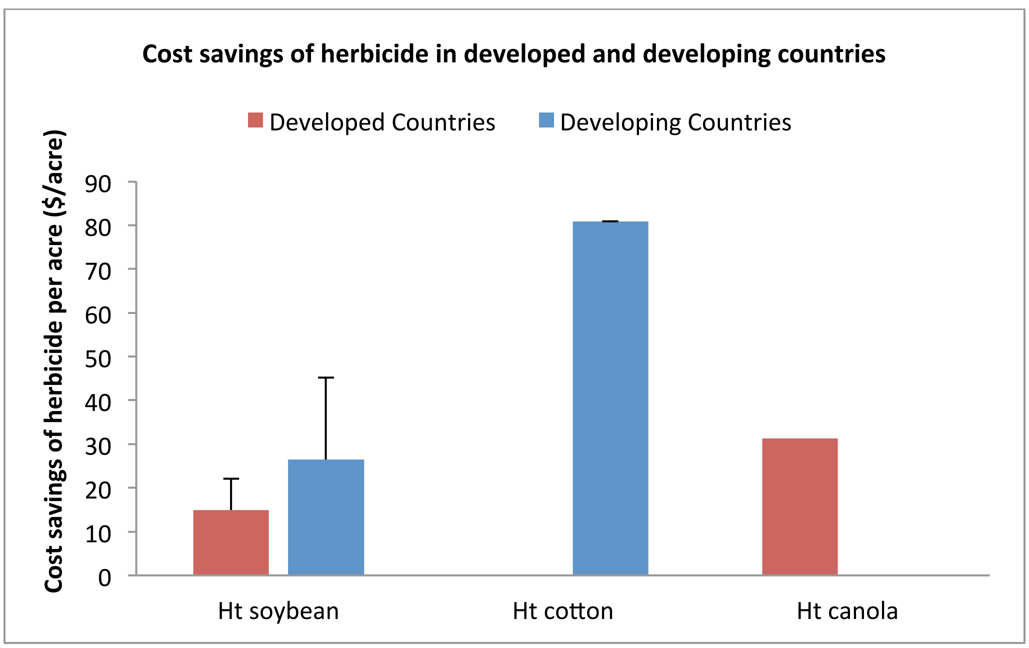


Figure 20. Cost savings of herbicide in developed and developing countries.

Chapter 9

Distribution of surplus on the supply chain

On the GM Agri-food market, different sectors are involved in, including GM seed companies, chemical corporations, the farmers, and consumers. They might gain or lose profit after GM traits were globally commercialized. In this chapter, we are going to discuss the distribution of GM crops' surplus throughout the supply chain. The estimation of surplus for each sector differs based on study methods, GM traits and the economic level of adopting countries. Since most of our observations came from Ex Post method, the discussion would focus on these studies. Bt corn, Bt cotton, Ht soybean and Ht cotton are the most adopted GM traits around world, almost covering all the continents, and so did the studies on them. Generally, farmers captured more benefits than other sectors, followed by the GM seed companies, across all the GM traits, as shown in Figure 21. Consumers barely gained surplus from purchasing GM related product. While farmers saved cost on chemical sprays after adopting GM traits, the surplus for insecticide and herbicide companies was decreased. Besides the insecticide and herbicide cost savings, normally around $20 per acre, farmer also gained from increased yields. After compensations on the technology fee and GM seeds, farmers could earn about $15 to $140 per acre depending the type of GM traits. Probably farmers in Asia captured the most from planting Bt cotton, about $139 per acre. North American farmers maintained a surplus around $20 per acre from Bt corn, Ht soybean and Ht cotton, while with a high payback on Bt cotton which is around $40 per acre. Adopting Bt cotton seems to be a correct choice for both farmers and GM seed companies globally. Since cotton is not a food related crop, less safety issue is concerned on Bt cotton. That is might be the reason that China is holding on a conservative attitude toward with other GM crops, but with a 13 million acre planting area for Bt cotton. Detailed information on the surplus distribution is showed in appendix Table 2.

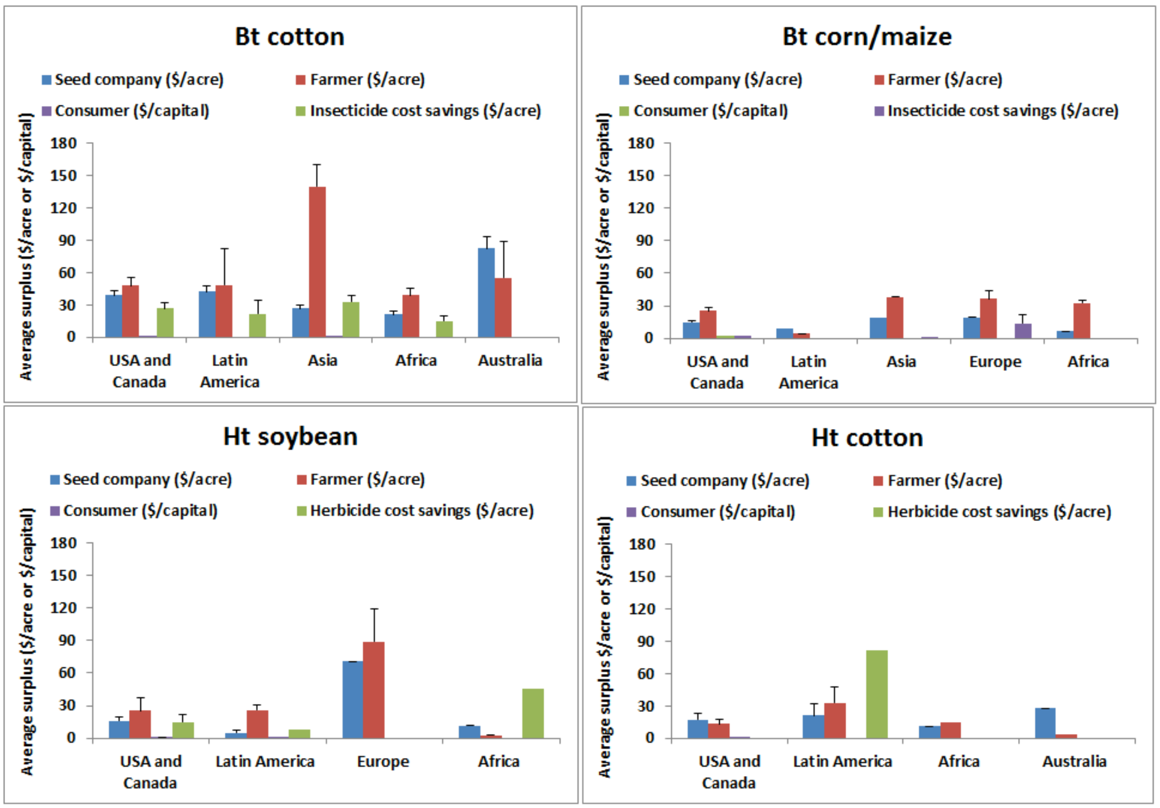


Figure 21. Distribution of GM crops' surplus on Agri-food sectors.

More studies were done in North America than other regions. The statistic results of other GM crops in North America are shown in Figure 22. Farmer gained more surpluses from planting Ht sugar beet than other crops including Bt cotton. Sugar plays an important role in American diet system and Americans consume much more sugar than other countries, creating a large market for sugar. Compared to other GM crops, GM seed companies and farmers capture less benefit from Ht corn, lower than $12 per acre. Besides Bt cotton, Ht sugar and Ht corn, the amount of surplus for all agri-sectors were maintained around the similar lever for Bt corn, Ht soybean, Ht cotton and Ht canola.

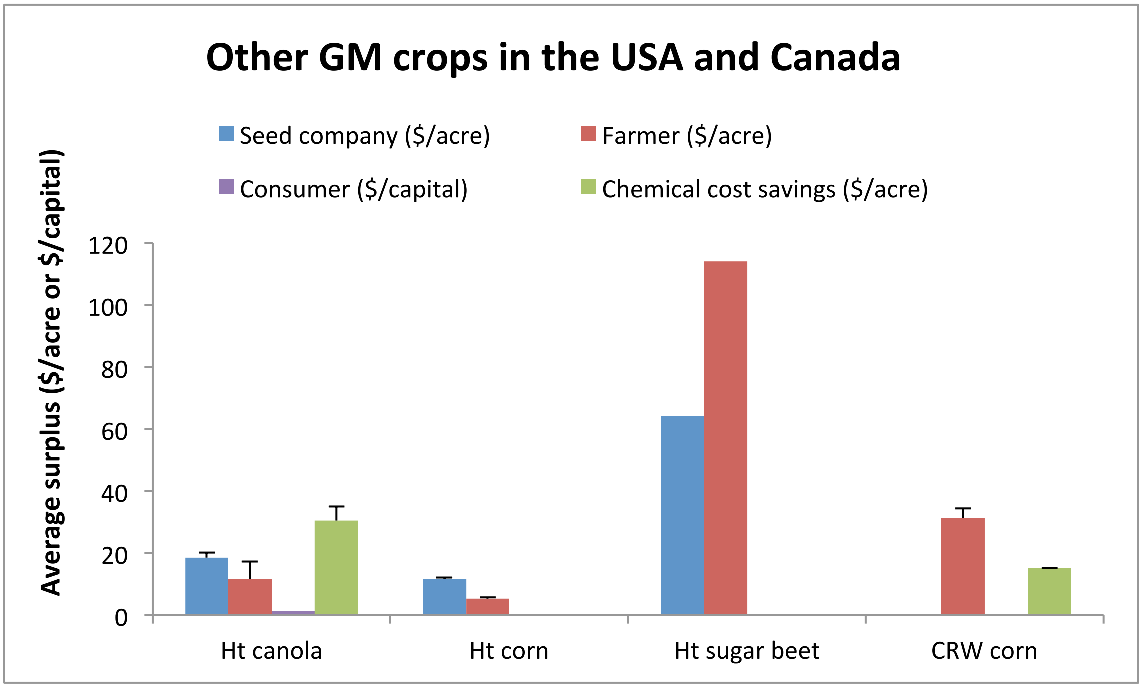


Figure 22. Surplus level for other GM crops in US and Canada.

In this thesis, we mainly focused on the averaged surplus per acre and all the results showed before used the $ per acre as the unit. It was showed in Figure 21 that GM seed companies gained higher surplus per acre in Australia through Bt cotton and in Europe through Ht soybean, compared to other regions. For the total GM seed company surplus, the total planting area need to be included in. Since the planting area increased rapidly every year, surplus was compared during certain year. Our data source comes from previous research literatures therefore our data failed to cover all the adopting countries in each year. For 2009, we have relatively more data points and could compare total surplus between different regions. As shown in Figure 23, GM seed companies and farmers gained significantly more total surplus in North America than other regions, although the average farmer surplus per acre is higher in Asia and Europe. This is mainly because the total Bt corn planting area is much larger in North America (around 55 million acre) than other regions.

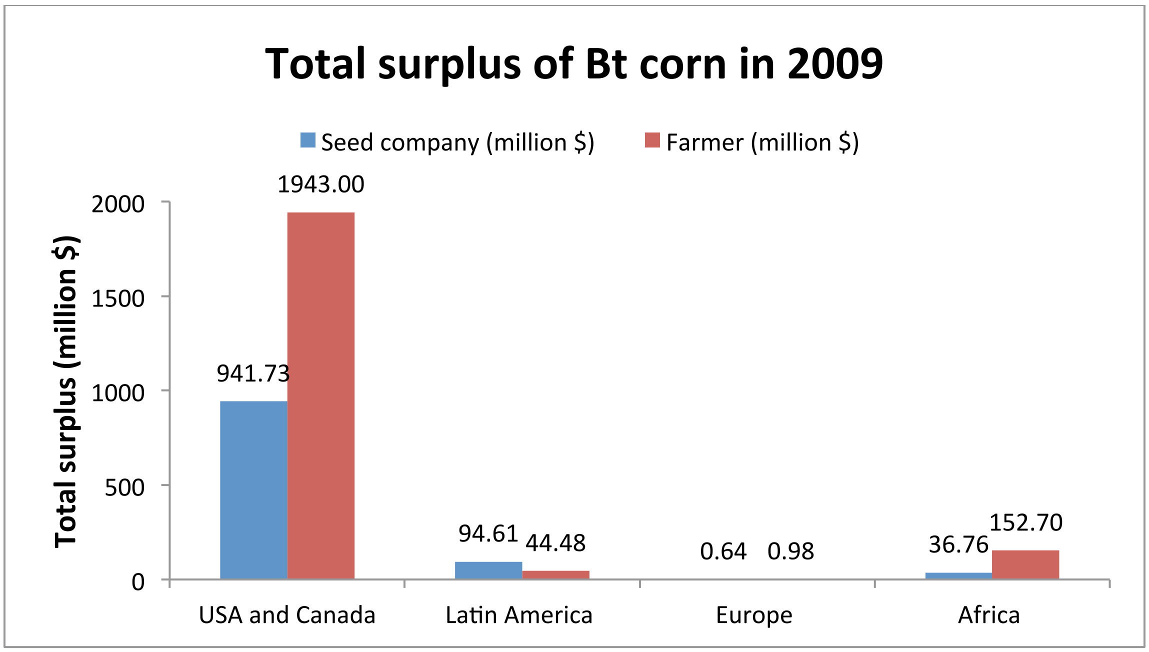


Figure 23. Total surplus of Bt corn in 2009

Different from Bt corn, GM seed companies and farmers earned highest surplus from Bt cotton in Asia, as the average surplus per acre and the planting area are both higher in Asia, as shown in Figure 24. The planting area of Bt cotton in 2009 in China is about 9 million acre and around 21 million acre in India, with the average farmer surplus of $139 per acre. While the USA has a total planting area of Bt cotton around 5.6 million acre and farmer surplus is about $47 per acre.

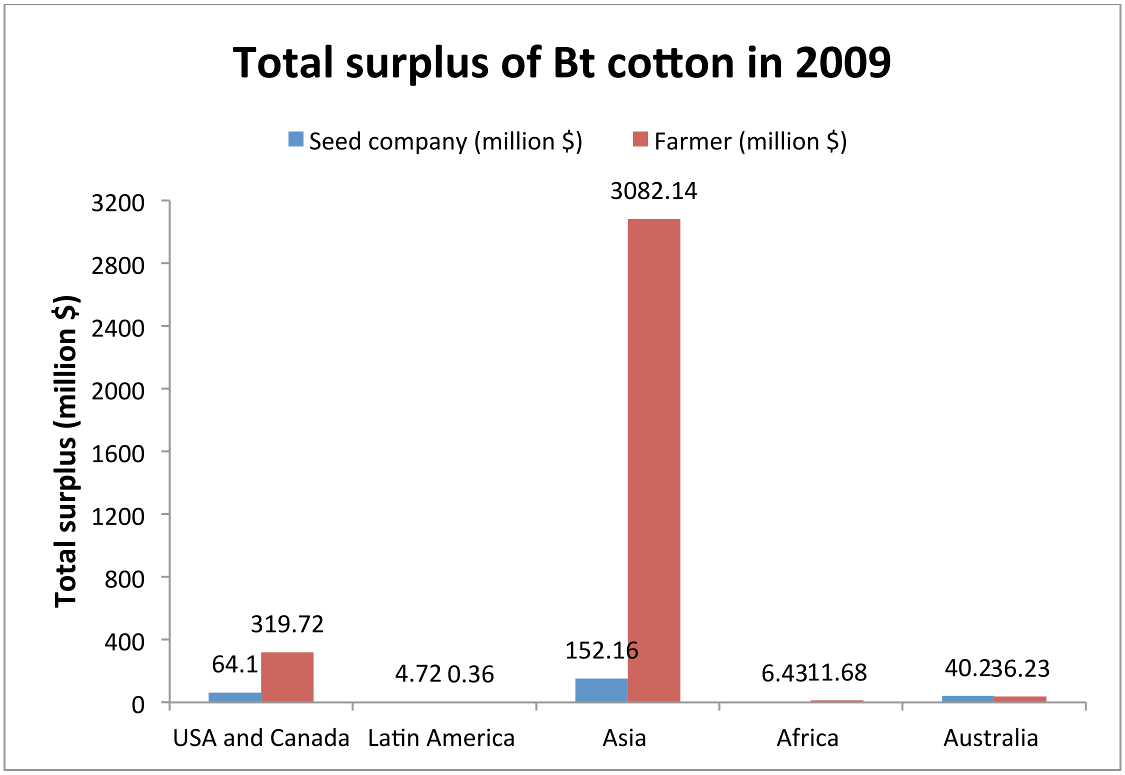


Figure 24. Total surplus of Bt cotton in 2009

We also recorded the planting area of Ht soybean in the USA and Latin America in 2001. When considering the total surplus, we find that GM seed companies gained more in the USA, while farmers had higher payback in Latin America, as shown in Figure 25. The Ht soybean planting area in the USA is about 50 million acres in 2001, while about 23 million acre in Argentina. The average surplus per acre for GM seed companies was higher in the USA than Argentina and timed by the larger planting area; therefore the total surplus of GM seed companies was much higher in the USA. On the other hand, average surplus for farmers were very high in Argentina and even compensate the less planting area, leading to a higher total surplus.

Both the analysis of average surplus and the total surplus showed regional differences. Each regional difference has its specific explanation. For the regional difference in average surplus of GM seed company surplus, the regional difference is more linked to the protection of IPR. If the government and the law could protect IPR of GM traits, seed companies could earn higher profit. On the other hand, the way that farmers use farm saved seed in Latin America and Asia greatly decreased GM seed companies' profit. For the regional difference in average farmer surplus, it is more related to the economic and technology development level of their country. In developing countries, the average surplus could be much higher than development countries, since the initial revenue was very low in developing countries. For the regional difference in consumer surplus, it is highly related to consumers' attitudes which could be affected by cultures, government policies, media and commercials. Therefore the USA consumers were more willing to purchase GM food and gained more surplus. When the total surplus was considered, the total planting areas were needed to be calculated in. However, the total planning areas are highly related to each country's geographical condition and government policy.

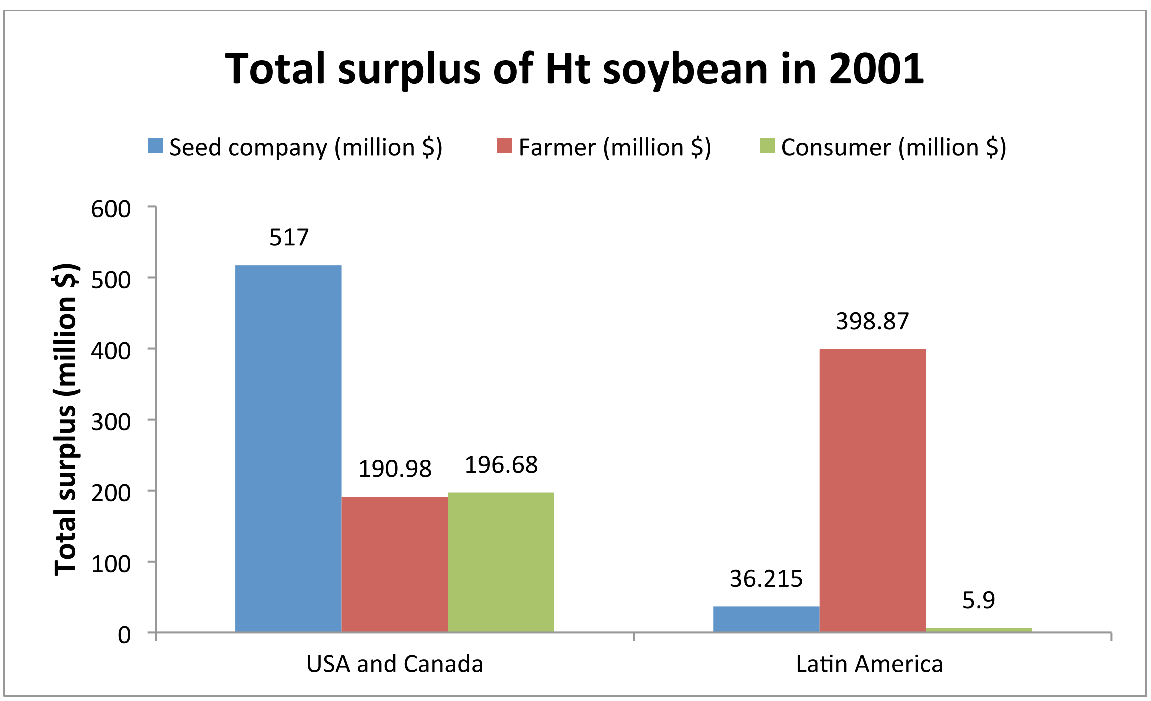


Figure 25. Total surplus of Ht soybean in 2001.

Chapter 10

Conclusions and Discussions

In this thesis, I reviewed previous literatures and re-analyzed the broad range of data, trying to assimilate the findings of the extant studies. This thesis conducted a meta-analysis of 58 studies that collectively report 119 valuations for the economic surplus of GM crops, and examined the factors, which might affect the farmer, seed company and consumer surplus. Through the meta-analysis, I found that the estimation results varied with the research methods, region locations, the economy development level and the type of traits. Generally, the evaluation values from Ex-ante studies are lower than Ex-post studies when the comparison is made between the same type of GM crop. The elicitation method could affect the estimation value and the Ex-ante method might have a tendency to under-estimate the economic effect of GM crops. It seems appropriate to suggest that non-hypothetical valuations should be preferred over hypothetical. Although both developed and developing countries adopted GM crops; the farmer, seed company and consumer surplus in developed countries are generally higher than developing countries. Basically, Bt traits bring more benefits to farmers and seed companies, but less to consumers, compared to other GM traits.

For seed company surplus, the most important impact factor is the type of the GM traits. Except for Ht sugar beet, which mainly are grew in North America and give the highest surplus to seed companies, the profits from Bt cotton are both higher in developed and developing countries. Especially, when the economic level and GM traits factors were both considered, seed companies gains more from Bt traits globally. This is consistent with the facts that Bt traits are the most commercialized traits in developing countries and seed companies put more effort and supports on its research and marketing in developing countries. On the other hand, seed companies earned less in some developing countries, such as China and India in Asia, due to the IPR issue and farmers use their farm saved seeds. There are only a few large GM seed companies on the global seed market, with a potential of monopolization. These large corporations earned most of the surplus from selling seeds and technology fee. With the expansion of GM crops and increasing surplus for seed companies, some researchers concerned about impact on traditional seed companies, the dependency on the extra-national GM seed corporations and the exploitation on smallholder farmers.

For the produce surplus, Asian farmer gains most from adopting Bt cotton. This further confirmed that Bt cotton is most successful commercialized GM crop since it brings both huge benefits to farmers and GM seed companies. When the geographic factor is considered, we found that farmers in Asia and Latin America capture more surplus than farmers in North America. This is consistent with the previous conclusion that GM seed companies earn more surpluses in the USA and Canada than in Asia. The government policies on IPR protection could significantly impact the surplus allocation and the market behavior.

Compared to the extent literatures on farmer surplus and GM seed company profit, less attention is focused on consumer side. Although there are some research papers report consumer preference and willingness to pay on GM food; even less effort was put on consumer benefit from purchasing GM food. There might be two reasons account for this circumstance. One reason is that almost all of the commercialized GM crops are not directly source for principal daily food and it is not straightly related to consumers. GM traits on main principal food related crops, such as wheat and rice, have been under strictly safety tests now and encountered strong opposition from consumers. Therefore, it is very difficult to estimate the consumer surplus of GM crops. The other reason is the labeling system. Without labeling, GM food could not be distinguished from Non-GM food and therefore it is hard to get real economical data for consumer surplus. Most of the consumer preference and willingness to pay data come from survey, which is highly dependent on survey method and format. Based on the limited number of literatures, we found that consumers generally captured very few surplus, less than 2 dollars per capita. Consumers in the USA and Canada turned to gain more surpluses from Bt corn, compared to other regions where consumers earn less than 1 dollars per capita. This result is consistent with previous findings that American consumers are more acceptable with GM food and European consumers are more conservative to GM food. On the other hand, Asian consumers seem to be polarized in their attitudes. Because of the lack of perceived benefits and uncertainty about the safety of GM products, consumer's aversion to GM food is gradually increasing.

While this thesis provides interesting information about farmer surplus, seed company surplus and consumer surplus, by using the meta-analysis method; there are a few more things we could do in future research. Most of the primary literatures in this meta-analysis estimated surplus of GM crops in North America, Latin America and Asia, only a few in Africa, Europe and Australia. Further research is needed to evaluate surplus in these regions. Besides, it is difficult to distinguish the surplus for single GM trait from the stacked traits. Stacked traits account for about 26% of global planting area of GM crops. More than half the GM cotton and GM corn in the USA are stacked traits. However, almost all the primary literatures did not distinguish the stacked traits with single Bt trait or Ht trait. Therefore, in this analysis we might include the surplus of stacked trait in the Bt trait and the Ht trait. The surplus estimation for GM cotton and GM corn might be higher than the actual value. Furthermore, the estimation method and economic model are not considered as a weighted factor the meta-analysis regression model. In future, it might be better to group the estimation method, include it as a dummy variable and analyze its impact on evaluation of economic surplus.

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Appendix

Table 4. Appendix table for data source.

Author	Bt trait	Country	Title
(Ali and Abdulai 2010)	Bt cotton	Pakistan	The Adoption of Genetically Modified Cotton and Poverty Reduction in Pakistan
(Alston and et al. 2002)	Rootworm Resistant corn	the USA	An Ex Ante Analysis of the Benefits from the Adoption of Corn Rootworm Resistant Transgenic Corn Technology
(Bennett et al. 2004)	Bt cotton	South Africa	Reductions in insecticide use from adoption of Bt cotton in South Africa: impacts on economic performance and toxic load to the environment
(Bennett et al. 2006)	Bt cotton	India	Farm-Level Economic Performance of Genetically Modified Cotton in Maharashtra, India
(Brethour et al. 2002)	Ht soybean	Canada	Agronomic, economic and environmental impacts of the commercial cultivation of glyphosate tolerant soybeans in Ontario
(Brookes 2005)	Ht soybean	Romania	The Farm-Level Impact of Herbicide-Tolerant Soybeans in Romania
(Brookes 2002)	Bt corn	Spain	The farm level impact of using Bt maize in Spain
(Brookes 2007)	Bt corn	Spain Romania Portugal Czech Republic Slovakia Poland	The benefits of adopting genetically modified, insect resistant (Bt) maize in the European Union (EU): first results from 1998-2006 plantings
(Brookes. and Barfoot 2011)	Ht soybean	Brazil Paraguay Uruguay South Africa Mexico	GM crops: global socio-economic and environmental impacts 1996-2009
	Bt corn	Canada Argentina	
	Ht corn	Canada	
	Ht cotton	Argentina South Africa Mexico Australia Colombia	
	Ht canola	Australia	
	Bt cotton	Argentina Australia Mexico South Africa Colombia	
(Carpenter and	Ht soybean	the USA	Herbicide Tolerant Soybeans: Why

Gianessi 1999)			Growers Are Adopting Roundup Ready Varieties
(Carpenter and Gianessi 2001)	Bt corn Bt cotton Ht corn Ht cotton Ht canola	the USA	Agricultural biotechnology: updated benefit estimates
(Consmuller, Beckmann, and Petrick 2010)	Bt corn	Germany	An Econometric Analysis of Regional Adoption Patterns of Bt Maize in Germany
(De Groote et al. 2003)	Bt corn	Kenya	Assessing the impact of Bt maize in Kenya using a GIS model
(Demont and Tollens 2004)	Bt corn	Spain	First impact of biotechnology in the EU: Bt maize adoption in Spain
(Falck-Zepeda, Traxler, and Nelson 2000a)	Ht soybean	the USA	Rent creation and distribution from biotechnology innovations: The case of bt cotton and Herbicide-Tolerant soybeans in 1997
(Falck-Zepeda, Traxler, and Nelson 1999)	Bt cotton	the USA	Rent creation and distribution from the first three years of planting Bt cotton
(Falck-Zepeda, Traxler, and Nelson 2000b)	Bt cotton	the USA	Surplus distribution from the introduction of a biotechnology innovation
(Fernandez 2009)	Ht soybean	Bolivia	GM soybeans in Bolivia
(Fernandez-Cornejo. and McBride 2000)	Ht soybean	the USA	Genetically Engineered Crops for Pest Management in U.S. Agriculture: Farm-Level Effects
(Fitt 2003)	Bt cotton	Australia	Deployment and impact of transgenic Bt cotton in Australia
(Flannery et al. 2004)	Ht sugar beet GM spring barley GM winter wheat GM potato	Ireland	An Economic Cost-Benefit Analysis of GM Crop Cultivation: An Irish Case Study
(Fulton and Keyowski 1999)	Ht canola	Canada	The Producer Benefits of Herbicide-Resistant Canola
(Frisvold and Mortensen 2000)	Bt cotton	the USA	Effects of Bt Cotton Adoption: Regional Differences and Commodity Program Effects
(Frisvold, Reeves, and Tronstad 2006)	Bt cotton	the USA China	Bt Cotton Adoption in the United States and China: International Trade and Welfare Effects
(Gandhi and Namboodiri 2006)	Bt cotton	India	The Adoption and Economics of Bt Cotton in India: Preliminary Results from a Study
(Gómez-Barbero., Berbel., and Rodríguez-Cerezo. 2008)	Bt corn	Spain	Adoption and performance of the first GM crop introduced in EU agriculture: Bt maize in Spain
(Gonsales 2009)	Ht corn	Philippines	Modern Biotechnology and Agriculture: a history of the commercialisation of biotechnology maize in the Philippines
(Gouse, Pray, and Schimmelpfennig	Bt cotton	South Africa	The Distribution of Benefits from Bt Cotton Adoption in South Africa

2004)			
(Gouse et al. 2005)	Bt corn	South Africa	A GM subsistence crop in Africa: the case of Bt white maize in South Africa
(Gouse et al. 2006)	Bt corn	South Africa	Three Seasons of Subsistence Insect-Resistant Maize in South Africa: Have Smallholders Benefited?
(Gusta et al. 2011)	Ht canola	Canada	Economic Benefits of Genetically-Modified Herbicide-Tolerant Canola for Producers
(Herring. and Rao. 2012)	Bt cotton	India	On the 'failure of Bt cotton' - Analyzing a decade of experience
(Huang 2002)	Bt cotton	China	Bt Cotton Benefits, Costs, and Impacts in China
(Jose M. Yorobe and Quico 2006)	Bt corn	Philippines	Economic impact of Bt corn in the Philippines
(Johnson, Strom, and Grillo 2007)	Bt corn Bt cotton Ht soybean Ht corn Ht cotton Ht canola	the USA	Quantification of the impacts on US agriculture of biotechnology-derived crops planted in 2006
(Kalaitzandonakes 2003)	Ht canola	Canada	The Economic and Environmental Impacts of Agbiotech: A Global Perspective
(Kaniewski and Thomas 2004)	Bt potato	the USA	The Potato Story
(Khan 2008)	Ht sugar	the USA	Roundup Ready sugar beet in America
(Kouser and Qaim 2011)	Bt cotton	India	Impact of Bt cotton on pesticide poisoning in smallholder agriculture: A panel data analysis
(Krishna and Qaim 2008)	Bt eggplant	India	Potential impacts of Bt eggplant on economic surplus and farmers' health in India
(Marra, Pardey, and Alston 2002)	Bt corn Ht soybean	the USA	The payoffs of agricultural biotechnology: an assessment of the evidence
(Matin 2003)	Bt cotton	India	Bt Cotton in India: Field Trial Results and Economic Projections
(Mishra 2003)	Bt eggplant	India Bangladesh Philippine	An Ex-Ante Economic Impact Assessment of Bt Eggplant in Bangladesh, the Philippines and India
(Moschini, Lapan, and Sobolevsky 2000)	Ht soybean	the USA	Roundup Ready Soybeans and Welfare Effects in the Soybean Complex
(Pray and Nagarajan 2010)	Bt cotton	India	Price Controls and Biotechnology Innovation: Are State Government Policies Reducing Research and Innovation by the Ag Biotech Industry in India?
(Pray et al. 2002)	Bt cotton	China	Five years of Bt cotton in China--the benefits continue
(Pray et al. 2001)	Bt cotton	China	Impact of Bt Cotton in China
(Price et al. 2003)	Ht soybean Ht cotton	the USA	Size and Distribution of Market Benefits From Adopting Biotech Crops
(Qaim and Traxler 2005)	Ht soybean	the USA Argentina	Roundup Ready soybeans in Argentina: farm level and aggregate welfare effects
(Qaim and de Janvry 2003)	Bt cotton	Argentina	Genetically Modified Crops, Corporate Pricing Strategies, and Farmers' Adoption: The Case of Bt Cotton in Argentina
(Sadashivappa and	Bt cotton	India	Bt Cotton in India: Development of

Qaim 2009)			Benefits and the Role of Government Seed Price Interventions
(Sankula and Blumenthal 2004)	Bt corn Bt cotton Ht soybean Ht cotton Ht canola	the USA	Impacts on US agriculture of biotechnology-derived crops planted in 2003: An update of eleven case studies
(Thirtle and et al. 2003)	Bt cotton	South Africa	Can GM-Technologies Help the Poor? The Impact of Bt Cotton in Makhathini Flats, KwaZulu-Natal
(Traxler and Godoy-Avila 2004)	Bt cotton	Mexico	Transgenic Cotton in Mexico
(Van der Weld 2009)	Bt corn	South Africa	Final report on the adoption of GM maize in South Africa for the 2008/09 season
(Vitale et al. 2007)	Bt cotton Bt corn	Mali	The Economic Impacts of Introducing Bt Technology in Smallholder Cotton Production Systems of West Africa: A Case Study from Mali
(Vitale et al. 2010)	Bt cotton	Burkina Faso	The Commercial Application of GMO Crops in Africa: Burkina Faso's Decade of Experience with Bt Cotton
(Wu 2004)	Bt corn	the USA	Explaining Public Resistance to Genetically Modified Corn: An Analysis of the Distribution of Benefits and Risks

Table 5. Appendix table for surplus distribution on the supply chain.

Bt cotton

Region	Seed company ($/acre)	Farmer ($/acre)	Consumer ($/capital)	Insecticide cost savings ($/acre)
Ex-Ante				
Asia		24.3		
Africa	28.04	81.75		
Ex-Post				
USA and Canada	38.74 (4.09)	47.67 (7.79)	0.16 (0.03)	26.84 (5.17)
Latin America	42.28 (4.81)	48.57 (33.93)		21.71 (12.08)
Asia	26.57 (3.43)	139.37 (20.94)	0.17	32.99 (5.15)
Africa	20.84 (3.49)	38.73 (7.06)		15.23 (4.41)
Australia	82.08 (11.40)	54.81 (34.19)		

Bt corn/maize

Region	Seed company ($/acre)	Farmer ($/acre)	Consumer ($/capital)	Insecticide cost savings ($/acre)
Ex-Ante				
Africa	4.68	7.49 (3.63)	1.38 (0.21)	
Ex-Post				
USA and Canada	14.9 (1.43)	25.28 (3.06)	2.23	2.45
Latin America	8.78	4.13		
Asia	19.38	38.22		1.59
Europe	19.07 (0.97)	36.43 (7.01)		14.03 (7.23)
Africa	6.39 (0.41)	32.42 (3.03)		

Ht soybean

Region	Seed company ($/acre)	Farmer ($/acre)	Consumer ($/capital)	Herbicide cost savings ($/acre)
Latin America	1.53	22.89		
Ex-Post				
USA and Canada	15.91 (3.95)	25.24 (12.01)	0.19 (0.07)	14.93 (7.08)
Latin America	5.15 (1.81)	25.76 (4.79)	0.11	7.74
Europe	70.77	88.77 (30.23)		
Africa	11.51	2.90		45.21

Ht cotton

Region	Seed company ($/acre)	Farmer ($/acre)	Consumer ($/capital)	Herbicide cost savings ($/acre)
Ex-Post				
USA and Canada	17.46 (5.21)	13.12 (4.54)	0.71	
Latin America	21.19 (10.52)	32.68 (15.24)		80.90
Africa	10.99	14.59		
Australia	27.69	3.07		

THE USA and Canada

Region	Seed company ($/acre)	Farmer ($/acre)	Consumer ($/capital)	Chemical cost savings ($/acre)
Ex-Post				
Ht canola	18.55 (1.54)	11.64 (5.63)	1.28	30.51 (4.40)
Ht corn	11.71 (0.39)	5.34 (0.42)		
Ht sugar beet	64.22	114.17		
CRW corn		31.23 (3.14)		15.14 (0.03)