Chapter 1

General introduction

Agriculture remains the most important sector for promoting economic growth in developing countries. In agriculture-based economies, the sector accounts for about 29% of the gross domestic product (GDP) and employs 65% of the labor force (World Bank, 2007). About 75% of the world's poor live in rural areas, where agriculture is the main economic activity. Cross-country comparison shows that GDP growth induced by agriculture is at least twice as effective in reducing poverty as GDP growth outside agriculture (World Bank, 2007). Agriculture is, therefore, imperative in reducing mass poverty and food insecurity in developing countries.

The prime focus of agricultural research in developing countries is to improve farm productivity to support the livelihood of the rural poor. For the last six decades various innovations have contributed to agricultural growth. High yielding varieties of the Green Revolution, which have been introduced since the late 1960s, have significantly changed the structure of agricultural production. While Green Revolution technologies increased food productivity and saved hundreds of millions of lives particularly in Asia, cultivation of high yielding varieties often requires heavy doses of pesticides, large quantities of fertilizers and irrigation water, which in many places cross the point of diminishing returns, thus, resulting in high cost of production (Byerlee, 1992; Sidhu and Byerlee, 2001; Murgai *et al.*, 2001). At the same time, this type of technical change has imposed an additional burden on natural resources, soil, water and the environment (Tilman, 2002; Singh, 2000). In the long run, Green Revolution technologies caused increased pesticide contaminations, depletion of groundwater tables, desertification, soil erosion, biodiversity loss and acute and chronic health problems (Theiling and Croft, 1988; Cheng, 1990; Crissman *et al.*, 1994; Pingali *et al.*, 1995; Pimentel, 2005; Travisi *et al.*, 2005; Arias-Estévez *et al.*, 2008). Since the Green Revolution started, global pesticide consumption has increased by about 30 times, from US$ 0.9 billion in 1960 to US$ 27.1 billion in 2000 (Zhang *et al.*, 2011). This high use of pesticides created multidimensional problems of health and the environment. The World Health Organization reported several million cases of acute pesticide poisoning each year in the world, with some 220,000 deaths (WHO, 1990). The United States alone consume one-fourth of total pesticides used in the world, facing human health and environmental costs valuing US$ 9.6 billion (Pimentel, 2005), implying that each dollar spend on pesticide generates external costs of the same amount. In developing countries, where pesticide regulations are laxer and spraying operations are usually carried out without due preventive measures, external costs are expected to be much higher. Such external effects are not duly considered, when designing pesticide policies, because of the lack of information and difficulties in quantifying and assigning monetary values to these damages. These hidden external costs have raised economic, social and environmental concerns.

In order to meet new challenges, the goal of agricultural research in developing countries has substantially changed from its early emphasis on food security to a much wider agenda that includes poverty alleviation, biodiversity protection, occupational and environmental safety and social inclusions (Hall *et al.*, 2000). Innovative approaches to improve crop yields, farm incomes, farmers' health and the environment are being explored in a non-traditional way. Plant breeding using modern biotechnology, in particular genetic modification, could play a major role in achieving these objectives.

Genetically modified (GM) technology could provide solutions to problems where conventional breeding approaches have failed. This is because it is faster and sometimes more accurate to develop crop varieties with desirable traits (FAO, 2002). The process of genetic transformation allows genes to be transferred from one organism/source to another, either to provoke desirable traits and/or to suppress undesirable ones that may sometime involve genes from unrelated species as well. Products developed through this procedure are known as transgenic/biotech crops or genetically modified organisms (GMOs). Application of GM tools in agriculture started in 1983, after producing an antibiotic-resistant tobacco plant (Bevan *et al.*, 1983). Since then, several crops have been genetically modified with complex traits such as resistance/tolerance to drought, soil salinity, insect pests and diseases that are not inherently available in them. So far, crops with single traits (herbicide tolerance or insect resistance) and a few stacked traits (herbicide tolerance and insect resistance) dominate the GM market. Since the commercial introduction of this technology in 1996, the area under GM crops has increased to 395 million acres in 2011 (James, 2011). This rapid diffusion has made GM crops the fastest adopted crop production technology in the history of agriculture. The significance of GM technology is that it has been mostly adopted by poor farmers. In 2011, out of close to 17 million global beneficiary farmers from 29 countries, 15 million (or 90%) were small and resource-poor farmers from 19 developing countries (James, 2011). The reason behind this widespread adoption of GM varieties by resource-poor farmers is that it caused reduced purchases of costly inputs such as pesticides or herbicides along with increases in farm incomes and sideline benefits to the environment and human health (FAO, 2002). Brookes and Barfoot (2012) show that GM crops have generated substantial economic benefits of US$ 78.4 billion over the last 15 years by increasing crop productivity, alleviating poverty, conserving biodiversity and providing a better environment through reducing pesticide footprints and green house gas emissions.

On the other hand, there is a contentious public debate about the potentials and risks of GM technology. Opponents of the technology criticize it by pointing at its possible negative effects for the environment, including unintended effects on non-target organisms and other ecosystem disruptions (Batie and Ervin, 2001; Andow and Zwahlen, 2006; Grain, 2006; Friends of the Earth, 2008; Pemsl *et al.*, 2008; Lövei *et al.*, 2009). However, many of these claims are not backed by scientific evidence (Marra *et al.*, 2001; Shelton *et al.*, 2009). In contrast, many studies provide empirical evidence of positive impacts of GM technology on yield and pesticide reduction, in addition to health and environmental benefits (Huang *et al.*, 2002; Bennett *et al.*, 2003; Qaim, 2003; Qaim and Zilberman, 2003; Thirtle *et al.*, 2003; Traxler and Godoy-Avila, 2004; Qaim and de Janvry, 2005; Romeis *et al.*, 2008; Wolfenbarger *et al.*, 2008; Kouser and Qaim, 2011; Hansson and Joelsson, 2012; Kathage and Qaim, 2012; Krishna and Qaim, 2012).

1.1. Bt cotton: its development and deployment

Bt cotton is one example of a GM crop product that contains Cry genes from the soil bacterium *Bacillus thuringiensis.* These genes encodes for the synthesis of Cry toxins to provide resistance to certain insect species of the orders Lepidoptera and Coleoptera. Lepidoptera insects are considered to be major insect pests of cotton with medium and high levels of infestations on 88% of the global cotton area (72.5 million acres) (James, 2002). Major Lepidoptera insect pests are pink bollworm (*Pectinophora gossypiella*), American bollworm (*Helicoverpa armigera*), spotted bollworm (*Earias vittella)*, spiny bollworm (*Earias spp.*), cutworms (*Argotis spp.*), bollworm (*Helicoverpa zea*) and tobacco budworm (*Heliothis virescens*). These pests cause heavy yield losses and are responsible for intensive chemical pesticide applications in the world (Zehr, 2010). According to an estimate, yield losses due to pest infestations would be around 15% of world annual cotton production, which costs US$ 3 billion plus US$ 1.7 billion for insecticide applications (James, 2002). Out of US$ 1.7 billion, US$ 819 million are spent on hazardous pesticides categorized by World Health Organization (EJF, 2007). Three Asian countries, India, China and Pakistan, produce three-fourth of the world's cotton and spend around US$ 961 million on pesticides, which is equivalent to 57% of total cotton pesticide expenditures in the world (James, 2002). High pesticide consumption in cotton poses severe risks to farmers' health in these countries, which are exacerbated under the circumstances of their relative poverty, ineffective regulatory systems, low levels of safety awareness, lack of access to safety apparatus/equipments, illiteracy, poor labeling of pesticides, insufficient knowledge about pesticide hazards and unsafe working environments (EJF, 2007). In addition to health problems, pesticides have considerable adverse environmental effects in terms of killing of natural enemies of pests, contaminating soil and water and loss of aquatic and aerial species. Hence, there is an urgent need of shifting to alternative environmentally friendly production technology to minimize pest problems without affecting human health and the environment negatively.

Inbuilt insect resistance in Bt cotton varieties helps reducing use of harmful pesticides. Bt technology was first commercialized in 1996 in the USA by a private company, Monsanto. Since then, Bt cotton varieties have been successfully planted on more than 61.77 million acres in two developed (USA and Australia) and 11 developing countries (India, China, Pakistan, Argentina, Myanmar, Burkina Faso, Brazil, Mexico, Colombia, South Africa and Costa Rica) (James, 2011). Bt cotton has become the first and fastest diffused GM technology due to its rapid deployment. The World Development Report credits Bt cotton to be the only GM crop adopted by small and resource-poor farmers in developing countries (World Development Report, 2007). As the developing countries have been driving the global adoption of GM crops (James, 2008), most of the studies have focused on these countries to assess the farm-level effects of Bt cotton. Numerous studies show that Bt technology contributed to lower pesticide use, reduced crop damage, and higher farm incomes (Qaim, 2009; Carpenter, 2010). The most comprehensive studies on the impacts of Bt cotton are available for China and India (Huang *et al*., 2003; Pray *et al*., 2002; Kathage and Qaim, 2012; Krishna and Qaim, 2012). Furthermore, effects have been analyzed in South Africa (Bennett *et al*., 2003), Argentina (Qaim and de Janvry, 2005) and Mexico (Traxler and Godoy-Avila, 2004). While the main findings are consistent across countries, the concrete effects vary, because they depend on agro-ecological and institutional conditions. A few studies have pointed towards health (Pray *et al.*, 2002; Bennett *et al.*, 2003; Huang *et al.*, 2003) and environmental benefits (Shelton *et al*., 2002; Knox *et al.*, 2006; Morse *et al.*, 2006; Wolfenbarger *et al.*, 2008; Lu *et al.*, 2012) of growing Bt varieties, but no study has monetized these benefits. Evaluation and monetization of such benefits is important in order to make them comparable to other types of benefits and costs.

However, there are also some studies that point at negative environmental externalities of Bt cotton, including unintended effects on non-target organisms and other ecosystem disruptions, which could undermine the technology’s sustainability (Andow and Zwahlen, 2006; Gutierrez *et al.*, 2006; Pemsl *et al.*, 2008; Lövei *et al.*, 2009; Lu *et al.*, 2010). Hence, Bt cotton is a central part of the broader public controversy about the potentials and risks of GM crops and appropriate regulatory approaches. There is a need to quantify potential positive and negative externalities of GM crops from an economic perspective, which could help in formulating clearer policies about the adoption of GM crops. This dissertation evaluates and monetizes two potential positive externalities of Bt cotton, namely health and environmental benefits arising through a reduction in pesticide use. In addition it also provides unbiased yield impact of Bt cotton.

1.1.1. The relevance of Bt cotton in India: the problem statement

Cotton is called king of all crops because of its predominant position in the Indian agro-based economy. It contributes 19% to the gross domestic product (GDP) and 11% to the total exports. It provides livelihood to millions of marginal and small farmers in the country. All four species of cotton are being cultivated over an area of approximately 30 million acres (m. acres), representing more than one-third of the global cotton area of 83.03 million acres (James, 2011; CICR, 2012) (see figure 1.1). However, in spite of this large area under cotton India was only the third largest producer of cotton until 2003-04 because its production suffered from huge losses due to its susceptibility to insect pests. Among the insects, bollworms are the most serious pests of cotton crop in India causing annual losses of at least US$ 300 million (Karihaloo and Kumar, 2009). The cotton bollworm complex comprises American bollworm, pink bollworm, spiny bollworm, and spotted bollworm. Indian cotton farmers were spending US$ 340 million on insecticides each year (Manjunath, 2004; Rai *et al*., 2009). Further, the most destructive cotton pest, American bollworm, is known to have developed resistance against most of the recommended insecticides (Ramasubramanyam, 2004) forcing farmers to apply as many as 10-16 sprays. Incorporating insect resistance in cotton has become the most desired feature by farmers and challenging task for researchers.

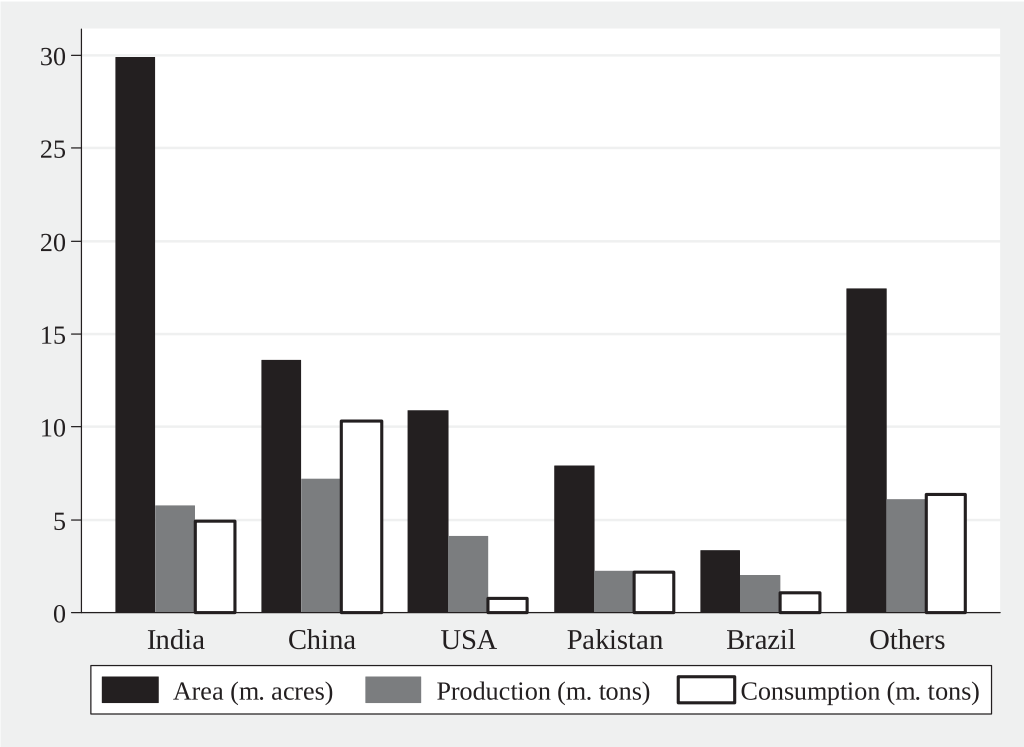

Figure 1.1: Area, production and consumption of major cotton growing countries in the world in 2011-12

Data source: ICAC, 2011

In 2002 India approved three Bt cotton hybrids, jointly developed by the Maharashtra hybrid seed company (Mahyco) and Monsanto, for cultivation in central and southern states. Later, new Bt hybrids[1] were introduced by public and private seed companies.[2] Just after five years of Bt adoption, India became the second largest cotton producer in the world in 2006-07, first time after crossing USA (ICAC, 2011). The country is accounting about 22% of the global cotton production in 2010-11, nearly doubling its share of 12% in 2001-02 (ICAC, 2011). Much of this success is attributed to the introduction of Bt cotton in 2002. With 26.19 million acres, India has the largest Bt area in the world (James, 2011).

[1] India has the largest area under hybrids in the world.
[2] Until now six Bt cotton events and 884 Bt hybrids have been approved for commercial cultivation in India (James, 2011).

However, there are some controversies about the potential benefits and risks of Bt cotton in India. Some studies are pointing at the negative social consequences of Bt cotton for smallholder farmers (Glover, 2010; Stone, 2011). Opponents of the technology argue that Bt cotton cultivation results in crop failure (Arunachalam and Ravi, 2003) and ultimately in farmers' suicides (Mukherjee, 2007). However, Gruère *et al*. (2008) have provided empirical evidence that Bt technology has no correlation with farmers' suicides.

Many studies have conducted impact evaluation of Bt hybrids in India. The results of these studies indicate that Bt technology has substantially increasing yields by about 40 % and simultaneously decreasing pesticide applications by about 50% (Qaim, 2003; Bennett *et al.*, 2006; Qaim *et al.*, 2006; Crost *et al.*, 2007; Kathage and Qaim, 2012; Krishna and Qaim, 2012). Brookes and Barfoot (2012) estimate that Bt cotton has increased farm income by US$ 9.4 billion in the period 2002 to 2010 and US$ 2.5 billion in 2010 alone.

As existing literature indicates that Bt cotton has remarkably reduced pesticide use, along with the financial gains it could also be beneficial for the environment and health of poor farmers. Acute pesticide poisoning is a common problem and responsible for high social costs among small farmers, who spray toxic pesticides without using any protective measures (Mancini *et al.*, 2005; Chitra *et al.*, 2006; EJF, 2007). A few studies in China and South Africa have shown that Bt cotton has reduced acute symptoms due to lower exposure to pesticides (Hossain *et al.*, 2004; Pray *et al.*, 2002; Bennett *et al.*, 2003; Huang *et al.*, 2003) but these studies have failed to account for unobserved heterogeneity between adopters and non-adopters of the technology which can lead to biased impact assessment. Moreover, no study has estimated Bt impact and its developments on pesticide reduction and farmers' health over time in India. This study contributes to the literature by investigating unbiased impact and impact dynamics of Bt-related pesticide reduction on the incidents of acute pesticide poisoning among Indian cotton farmers using unique panel survey data.

1.1.2. The relevance of Bt cotton in Pakistan: the problem statement

Cotton is an important cash crop in Pakistan's economy. It accounts for 7.8% of the value added in agriculture (Government of Pakistan, 2012) and together with textile industry, it contributes about 9% to the country's GDP (All Pakistan Textile Mills Association, 2010). A 10% change in its production exerts a significantly disproportionate effect of 2 to 8% on the growth of GDP (James, 2011). The growth of the domestic textile industry, which is one of the main drivers of GDP growth, heavily depends on cotton production in the country. Cotton and the textile industries dominate exports and contribute 55% to the foreign exchange earnings (Government of Pakistan, 2009b). In addition to this, cotton crop is used for edible oil production[3], livestock feed, and fuel wood.

Pakistan is the 4th largest cotton producer after China, India and USA and the 3rd largest cotton consumer (after China and India) in the world (see figure 1.1). Cotton is mainly grown in Punjab (80%) and Sindh (20%) provinces (Government of Pakistan, 2009a), with area fluctuation from 6.64 to 8.86 million acres over the last decade (see figure 1.2). During the same period cotton yield varied from 0.26 to 0.36 tons/acre, which is mainly driven by unofficial release of Bt cotton varieties in 2002. The unofficial release could not be as effective as if it would have been officially approved like in neighboring countries, India and China.[4] However,

[3] Cotton seed contributes 57.5% to total edible oil production in Pakistan (Ali *et al*., 2008).
[4] For instance, official cultivation of Bt in India has doubled cotton production from 2.44 million tons in 2001 to 5.62 million tons in 2009-10 (James, 2010).

unregulated Bt varieties help reducing yield losses slightly due to bollworm complex[5], which is a major group of pests and responsible for large fluctuation in cotton yield.[6] Cotton farmers spend around US$ 190 million annually on pesticides against bollworms, which accounts 76% of total pesticide expenditure (US$ 250 million) on cotton crop (Salam, 2008). The benefits harvested by neighboring countries from the deployment of Bt cotton and high pesticide reductions in cotton production motivated policy makers in Pakistan to give official approval of Bt cotton cultivation in 2010. Just after one year of its official approval, the Government of Pakistan is forecasting improvement in yield from 0.32 tons/acre to 0.36 tons/acre, mainly because of cultivation of official approved Bt varieties (Government of Pakistan, 2012) (see figure 1.2).

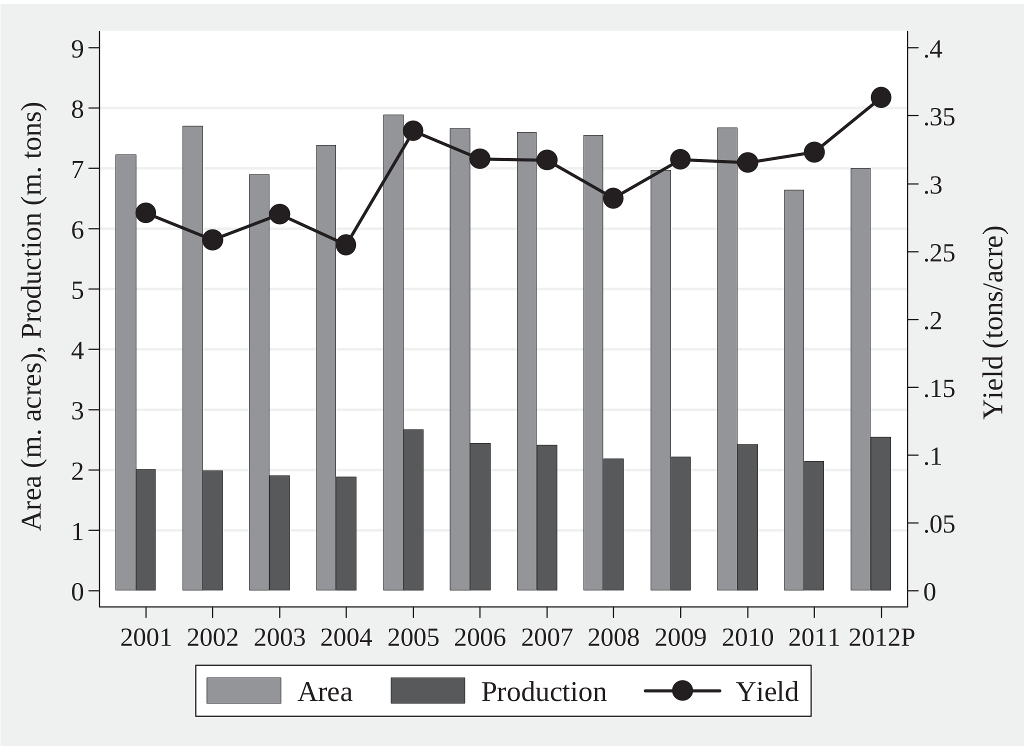

Figure 1.2: Trends in cotton area and production in Pakistan
Data source: Government of Pakistan, 2012

[5] Bollworm complex comprises American bollworm, pink bollworm, spotted bollworm and army worms.
[6] Pest infestations results in economic losses of 10 to 15% in a normal year and 30 to 40% or even more in bad crop year (Salam, 2008).

Little work has been done to evaluate the contribution of Bt technology in Pakistan. Two empirical studies have recently conducted economic impact evaluation of unofficial release of Bt varieties in the country (Ali and Abdulai, 2010; Nazli *et al.*, 2012), using farm level data of 2007 and 2009 crop season, respectively. The results of these studies indicate that Bt cotton has increased yield and reduced pesticide applications. These studies only account for observed heterogeneity but fail to control for unobserved heterogeneity in their estimates. None of the studies have analyzed impacts of officially approved Bt varieties by using farm level data and controlling for observed and unobserved heterogeneity. Many studies have estimated private optimal levels of pesticide use to investigate the contribution of Bt technology in reducing pesticide use (Huang *et al.*, 2002; Qaim, 2003; Qaim and de Janvry, 2005; Shankar and Thirtle, 2005). However, Bt reduces pesticide use and its associated health and environmental costs and in order to investigate the true contribution of Bt technology, estimation of socially optimal levels of pesticide use after internalizing these costs is required which is missing in the literature.

Available studies conclude that Bt technology has substantially reduced pesticide use in cotton production (Huang *et al.*, 2002; Qaim and Zilberman, 2003; Thirtle *et al.*, 2003; Bennett *et al.*, 2004; Qaim and de Janvry, 2005; Shankar and Thirtle, 2005; Bennett *et al.*, 2006; Qaim *et al.*, 2006). Extensive literature reveals that frequent pesticide applications cause pesticide poisonings among farmers, deteriorate soil and water quality and disrupt ecosystem functioning by killing beneficial insects (Theiling and Croft, 1988; Pimentel and Greiner, 1996; Pingali, 2001; Travisi *et al.*, 2006; Arias-Estévez *et al.*, 2008; Asfaw *et al.*, 2010). Hence, pesticide reduction through Bt adoption may entail health and environmental benefits. A few studies have investigated positive impacts of Bt-related pesticide reduction on the incidence of acute pesticide poisoning symptoms among farmers (Hossain *et al.*, 2004; Pray *et al.*, 2002; Bennett *et al.*, 2003;

Huang *et al.*, 2003), diversity of beneficial insects (Shelton *et al.*, 2002; Wolfenbarger *et al.*, 2008; Lu *et al.*, 2012), and soil and water quality (Knox *et al.*, 2006; Morse *et al.*, 2006) but monetization of these benefits are missing in the literature. Evaluation and monetization of such benefits can help making more realistic comparison of Bt cotton with alternative technologies. In addition, it can also help public and policy makers, who have serious concerns about potential health and environmental risks of Bt technology. The present study contributes to the existing literature by quantifying and monetizing health and environmental benefits of pesticide reduction associated with Bt adoption. Moreover, this study provides unbiased impact evaluation of officially approved Bt varieties in Pakistan. In order to study the contribution of Bt technology in reducing health and environmental impacts of pesticide use, private and social optimal levels of pesticides are also computed and compared across the both production technologies in Pakistan.

1.2. Objectives of the study

Against the background of the above mentioned gaps in the literature, this study attempts to analyze unbiased impact of Bt-related pesticide reduction on farmers' health by using unique panel survey data of Bt cotton in India. This study also investigates the developments of Bt-related health benefits over time. Pesticide reductions are not only beneficial for farmers' health but also for the environment. In order to value health and environmental benefits of Bt-associated pesticide reductions, this study employs a choice experimental approach and analyzes financial benefits of Bt adoption using gross margin analysis in Pakistan. In addition, this study evaluates impacts of Bt cotton on yield after accounting for self selection bias. This study also computes private and social optimal levels of pesticide use for both Bt and non-Bt technologies. The specific objectives of this study are to:

1. Estimate the impact of Bt cotton adoption on farmers' acute poisoning symptoms over time by controlling for non-random selection bias in India.
2. Quantify and monetize health and environmental benefits of Bt cotton adoption in Pakistan.
3. Analyze unbiased impact of Bt cotton on yield and estimate private and social optimal levels of pesticide use with and without Bt in Pakistan.

1.3. Data

1.3.1. Indian panel data

In order to evaluate Bt-related health benefits and its developments over time, this study builds on unique Indian panel data that was previously collected at the Institute of International Food Economics and Rural Development, in four rounds between 2002 and 2008. Personal interview method was employed for data collection, with the help of a pre-tested questionnaire, in four states of central and southern India, viz. Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu (see figure 1 in the appendix I). These four states produce more than 50% of overall cotton cultivation in India (Cotton Association of India, 2008). In 2002, Bt cotton was only commercialized in central and southern zones but not in northern region. Hence, northern India was not included in the panel survey. During the survey years, detailed information about socioeconomic characteristics, input-output quantities and their prices for each cotton plot were obtained. Farmers were particularly asked about the types, frequencies and medical expenditures of pesticide-related acute poisonings, such as skin and eye irritation, breathing problems, nausea, faintness and other symptoms. This is the only longest panel survey of Bt cotton farmers in a developing country. A balanced panel of 198 farms comprising 792 observations over all four rounds was used for the analyses. Further details about data collection procedure and sampling framework can be seen in Qaim *et al*. (2006), Subramanian and Qaim (2009) and Subramanian and Qaim (2010).

1.3.2. Sampling and farm survey in Pakistan

To estimate the second and third objectives, a cross-sectional survey of cotton farmers was carried out in the Punjab province of Pakistan. Pakistan is an interesting example where cotton producers were growing unapproved Bt varieties since 2002 (Hayee, 2004) and 75% of total cotton area was under these varieties in 2010, the year of official approval. A multi-stage sampling procedure was used for the survey in Pakistan's Punjab. Four major cotton-producing districts, namely Vehari, Bahawalnagar, Bahawalpur, and Rahim Yar Khan were purposively selected (see figure 2 in the appendix II); these four districts account for 42% of the total cotton area in the province (Government of Pakistan, 2009a). Then, two tehsils in each district and four villages in each tehsil were randomly picked. A complete list of cotton farmers was prepared in each village, from which 11 farmers were randomly selected. Finally, a sample of 352 cotton farmers, comprising 248 Bt adopters and 104 non-adopters, was achieved. The field survey was carried out between December 2010 and February 2011, immediately after the first harvest of officially approved Bt cotton cultivation.

A structured questionnaire, including sections on general socioeconomic characteristics of the farm household and details about inputs used and output obtained in the cotton enterprise, was used. In addition to this, a choice experiment was conducted to estimate farmers' willingness to pay for reducing pesticide-related health and environmental effects. The questionnaire and choice cards were pre-tested prior to data collection to ensure validity and clarity of the contents. The final questionnaire and choice cards used are shown in appendix V. Direct face-to-face interviews were conducted by a team of four local enumerators, who were agri-graduates from the University of Agriculture Faisalabad. The enumerators had ample knowledge of agronomic practices of cotton production and were familiar with the local languages. They were selected on a competitive basis, trained for two weeks prior to the actual survey and monitored by the researcher during the survey period. Interviews were conducted in local languages (*Punjabi* and *Saraiki*) known to farmers. At the end of each survey day, collected data were checked for relevancy, missing observations, outliers, mistakes and conformity.

1.4. Outline of the dissertation

The study is organized as follows. Chapter 2 undertakes the analysis with respect to the first objective of this study. This chapter analyses and discusses the unbiased impact of Bt adoption on farmers' health and its dynamics by employing Indian panel data and fixed-effects estimators. Moreover, this chapter evaluates impacts of Bt cotton on pesticide reduction over time.

Chapter 3 presents the analysis on health and environmental benefits of Bt cotton adoption in Pakistan. The choice experiment is conducted to value these non-marketable benefits. This chapter also estimates financial benefits of Bt adoption using gross margin analysis.

Chapter 4 deals with impact assessment of Bt technology on cotton yield in Pakistan. Analyses in this chapter account for potential selection bias through instrumental variables. This chapter also computes private and social optimal levels of pesticide use for Bt and non-Bt cotton.

Finally, chapter 5 concludes the study by giving an overview of the results, suggesting policy recommendations and identifying possible areas for future research.