SANDEE

Working Paper, No 79–13

Economic and Environmental Impacts of Bt Cotton: Evidence from Pakistan

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Abstract

This study estimates the benefits from adopting Bt cotton seeds in Punjab, Pakistan over two cropping seasons in 2008 and 2009. This study uses reduced-form panel models to determine the average effects of Bt cotton technology on short-run profits, yields and farm inputs. This reduced form approach controls for biases resulting from self-selection and endogenous farm inputs. The study shows that farmers grow Bt cotton because it provides resistance against cotton bollworms infestations and gives higher yields. On average, econometric estimation suggests that Bt adopting farmers receive 10 percent higher yields per hectare, reduce per hectare pesticide use by some 22 percent, and increase per hectare use of irrigation water by 8 percent as a result of a conversion of 78% of cropped area into Bt cotton. Our estimates of the increase in cotton yield are below estimates from previous studies conducted in Pakistan and India, which do not use panel methods. Allowing more Bt cotton varieties and ensuring the availability of quality Bt cotton seeds in the market is likely to lead to further increase in the private benefits from Bt cotton, but raises legitimate concerns related to irrigation water availability and biodiversity losses.

Keywords: *Bt cotton, Endogeneity, Self-selection bias, Fixed effect, Random effects, Reduced-form panel models, Pakistan*

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1. Introduction

Cotton production in Pakistan faces a rising incidence of disease and insect attacks. Small farms, which dominate[1] Pakistan's agriculture, are particularly vulnerable to pest infestation, because of their inability to bear any form of financial risks. Pesticides are a very important input in cotton production and account for 33 percent of input costs (Farooqi (2010)). Adoption of *Bacillus thuringiensis* (Bt) cotton, which provides resistance to the common cotton pest called bollworm, is seen as a solution to the current pest related challenges to cotton.

The Bt cotton seed includes a genetically engineered modified soil bacterium gene, *Bacillus thuringiensis*. This gene has a natural toxin against several insects and pests, especially bollworms.[2] Thus, its proponents argue that using this type of cotton seed could lead to reduced pesticide use and a consequent positive impact on the environment. There is evidence to suggest that countries such as USA, Australia, China, Mexico, Argentina, South Africa, and India, which have allowed the cultivation of Bt cotton at a commercial level, have gained in terms of lowered pesticide use and costs and higher yields (Qaim, et al. (2006), Thirtle, et al. (2003), Qaim and de Janvry (2005), Qaim and Matuschke (2005), Bennett, et al. (2006)).

Bt cotton was officially introduced in Pakistan in the year 2010. However, even prior to this, Bt cotton was being grown in large tracts (over 50% of the area under cotton) with unapproved Bt cotton seed varieties (Nazli (2009)). Hayee (2005) reports that some large farmers in the provinces of Sindh and Punjab first planted Bt cotton seed smuggled from Australia and neighboring countries in the early 2000s, and then started marketing seeds produced at their farms to other farmers. We designed this study taking into consideration the prevalence of un-authorized Bt cotton seeds in the study area.

Because of the importance of Bt cotton in Pakistan's cotton farming system, our study tries to further investigate the benefits and costs associated with Bt cotton. It answers three questions: a) Does the use of Bt cotton seeds lead to a decline in pesticide use in cotton production? b) Are input costs, such as fertilizer, labor and irrigation water costs, higher for Bt cotton versus non-Bt cotton? and c) Are yield and revenue from Bt cotton production higher relative to non-Bt cotton crops? The objective of this study is to determine the average effect of adoption on yield, input use and profit.

While there have been studies in Pakistan that have looked at the efficacy of Bt cotton, these studies have been limited by their use of single year data on a cross-section of farmers (Hayee (2005), Sheikh, et al. (2008), Arshad, et al. (2007), Nazli (2009), Nazli, et al. (2010), Nazli (2010), Ali and Abdulai (2010)). Focusing on cross sectional single year data is problematic because this does not account for variations in weather conditions and insect pest infestation in different years that may affect yields. In our study, we take into account these possible variations and use data from two cropping seasons. Our study also improves on the available literature in Pakistan by using a reduced-form panel estimation method that controls for endogeneity in estimation. Endogeneity emerges from two sources, namely farmer self-selection and endogenous farm inputs. Our findings related to yield, farm inputs and profitability are largely different from previous Pakistani studies, suggesting that controlling for endogeneity avoids over or underestimation of the true benefits of Bt cotton.

The remaining paper is organized as follows. Section 2 describes adoption of Bt cotton in various countries and its impacts on pesticide use. Section 3 provides details of study area and data collection strategy. Empirical methods

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[1] Government statistics show that above 85 percent farmers possess landholdings with a size of less than 5 hectares
[2] There are two types of pest attack in cotton production. They include sucking and chewing pests. Chewing pests are major pests in Pakistan and farmers have to make use of huge amounts of pesticides to control chewing pests (bollworms).

used to compute impacts of Bt cotton are discussed in section 4. Section 5 elaborates empirical results of the study and the last section concludes.

2. Adoption of Bt Cotton and its Impacts on Pesticide Use: A Review

The increased use of pesticides in Pakistan raises environmental concerns and also makes Pakistani cotton less competitive in the world market. Farmers can reduce pesticide use on cotton crops in multiple ways. These include biological control methods, mechanical controls, integrated pest management and selection of cotton varieties with resistance against pests. Most of these options require continued research and development and a good deal of effort toward introducing, motivating and training targeted farmers in order to convince them of the benefits of any new method. However, with genetically modified (GM) cotton seeds, little investment is required in disseminating this technology as long as the Bt seed is available in the market.

GM seeds, first adopted in developed countries, are expensive. Nonetheless, the use of the Bt cotton seed, in particular, has spread widely in developing countries in recent years. The main reason for this is the many identified private benefits of Bt cotton (see Table A1). Studies by Huang, et al. (2002, 2005), Qaim and Zilberman (2003), Bennett, et al. (2003), Pray et al. (2002), Bennett, et al. (2006), and Qaim, et al. (2006) suggest that Bt cotton use reduces pesticide sprays and increases seed cost and yields. Wu et al. (2008) provide evidence that the planting Bt cotton not only significantly decreases spraying against the pest cotton bollworm, but it also reduces the pest cotton bollworm on other crops.

An important benefit of Bt cotton to farms, as identified by its proponents, is reduction in health costs from pesticide exposure. The human health impacts of pesticide use are generally difficult to measure (Antle and Pingali (1995), Antle, Cole and Crissman (1998), Ajayi (2000)). However, a few studies, such as Pray et al. (2002), report that a larger percent of non-Bt growing farmers (around 22 percent) identified various health problems related to pesticide use compared to farmers planting only Bt cotton (5-8 percent). Kousar and Qaim (2011) also argue that Bt cotton has led to a notable decline in acute pesticide poisoning cases among cotton growers in India. Similarly, Huang et al. (2002, 2002a, 2005) estimate that there are health benefits more broadly from genetically modified seed use.

The view on Bt cotton, however, is not always sanguine. There are some studies that find that Bt cotton does not significantly increase yield and income and bollworms continue to grow (Hayee (2005), Huang, et al. (2002), Ismael et al. (2002)). These studies identify a variety of factors for the failure of Bt cotton such as limited knowledge on how to use the technology, prevalence of a black market for un-improved Bt cotton varieties, and climatic variations and other disasters. There is also much concern about the impact of Bt cotton on the earnings of small farmers, who may be forced to buy seeds for every crop from foreign monopolies (Qaim and de Janvary (2003)). For instance, Hayee (2005), comparing Bt cotton variety with local cotton variety in Pakistan, shows that small farmers adopt Bt cotton hoping to lower costs but they may actually incur higher costs because of high costs of seeds and the need for more fertilizers and irrigation. Negating these findings are studies by Sheikh et al. (2008), Nazli (2009, 2010) and Ali and Abdulai (2010), who indicate that the overall outcome of adopting Bt cotton is positive for all farm categories, but in varying degrees.

While the literature on the impacts of Bt cotton on small farmers is mixed, other worries remain about the long term impacts of Bt cotton. Two public bads that can occur are the loss of biodiversity and genetic pollution (Park et al. (2011)). Biodiversity loss may occur as farmers start planting only Bt cotton on their farms. This will increasingly result in fewer varieties of cotton available in the field. Genetic pollution i.e. genes from Bt cotton escaping into natural ecosystem, is another major concern because this may result in a decline in the naturally prevalent gene pool. High seed price also remains an important long-term public cost of using Bt cotton (Nazli (2009)).

Overall, the literature on Bt cotton seems to suggest that it offers private benefits to farmers. However, there are still some questions about whether small farmers are overly exposed to risks because of the high costs of seeds. The longer term public implications, in terms of biodiversity loss and gene reduction, are largely under-explored. In our study, we focus primarily on the yield and pesticide use implications for farmers and are unable to address these other public good issues.

3. Study Area and Data

Our study is undertaken in the cotton growing area of Southern Punjab, Pakistan (see Figure 1). Punjab is divided into irrigated and non-irrigated areas and we focus on irrigated Southern Punjab, where 90 percent of cotton farms are concentrated.[3] For our study, we further divided the cotton growing districts into three regions with similar conditions in terms of sowing time, soil type, rainfall, etc. The first cotton growing region includes six districts (Multan, Khanewal, Pakpattan, Sahiwal, Vehari and Muzaffar Garh) and the second comprises five districts (Bahawalpur, RY Khan, Bahawalnagar, Rajanpur and Lodhran). The third region consists of Dera Ghazi Khan, Layyah, Bhakkar and Mianwali. At the time of this study, farmers commonly used both Bt and non-Bt cotton seeds in these districts.[4]

A three-stage stratified sampling technique was used for collecting data. In the first stage, we randomly selected three districts, one from each cotton growing area. The selected districts include Multan, R Y Khan and Mianwali. The second stage involved preparation of a list of cotton growing farmers who purchased cotton seed (either Bt and non-Bt or both) from registered private seed companies/input dealers during cotton growing season of 2008. The list was organized alphabetically by the name of the village in each district. This list represented our target population in each selected district. In the third sampling stage, respondents were identified from the list of cotton growers using systematic simple random sampling. If a selected respondent refused to respond, did not farm or was not available in the area after three visits to farm, the following respondent in the list was considered. In this manner we identified 96 respondents from each selected district. In addition, we obtained plot level data from the selected farmers who were growing Bt cotton and non-Bt cotton at their farms. We selected the largest two plots, one each for Bt and non-Bt (if a farmer was planting both types of cotton).

Based on the above strategy, the total sample size of farmers from the three selected districts was 288. These respondents were interviewed during both the first and the second crop seasons in 2009. This data was related to the first crop of 2008 and the second crop of 2009. Three respondents could not be interviewed due to death, migration, etc. Thus, the final sample for this study is 573 observations of farmers from two cotton growing seasons in the Punjab province. We also had observations on 801 plots.

We conducted an interview-based survey in August–October, 2009 and January–March, 2010 to gather information about input–output and others characteristics in cotton cultivation for two cropping seasons (2008 and 2009). Data were obtained on farming practices, Bt cotton adoption, socio-economic characteristics and related information. Plot level information was collected on inputs, outputs and prices in Bt and non-Bt plots per farmer. We found some Bt adopters cultivating conventional (non-Bt cotton) crop at the same time, so we asked them the same questions for both their Bt and non-Bt crops. This allows us to make comparison of Bt technology in a with and without situation across and within farms as well.

3.1 Summary Statistics

Table 1 provides summary information on the farmers in our sample and compares farmers who used both Bt and non-Bt seeds for growing cotton with farmers who used only Bt seeds. In our sample, the average farmer had 17 hectares in cotton production. Sample farmers, on average, had 20 and 15 years of farming and cotton growing experience respectively. Farming experience and cotton growing experience are higher for farmers growing both types of cotton relative to those growing only Bt cotton. On average, both Bt and non-Bt farmers have 4 years of schooling. Farmers growing Bt and non-Bt cotton were slightly more likely to avail of credit and had slightly more numerous plots. We also found that farm size decreased from the first crop season to the second crop season, mainly due to reduced rented-in land. Regarding area allocated to the cotton crop, farmers using both Bt and non-Bt cotton seeds and those growing only Bt cotton seed increased the area allocated to cotton from the 2008 to

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[3] A few years ago, adoption of Bt cotton seed was not commonly practiced, however, partial adoption was there. The major reason is that Bt cotton was not allowed to be practiced during these years since no genetically modified seed was released or introduced officially in the market for commercial purpose. Some Bt cotton seed was smuggled by private company and growers. That smuggled seed was multiplied and distributed among cotton growers (Hayee (2005)). However, the Government of Pakistan has now allowed planting Bt cotton in the country from the year 2010.

[4] On the other hands, in some districts in western Punjab (Mianwali, Bhakkar, Sargodha etc.), only Bt cotton was planted. These districts are not known for cotton and mainly grow grams. However, rising raw cotton prices and availability of Bt cotton seed seem to have induced farmers of these districts to grow Bt cotton

the 2009 cropping season. Overall, there were few major differences in socio-economic characteristics between farmers who chose to grow Bt and non-Bt cotton in their farms, relative to farmers who were focused exclusively on Bt cotton.

Summary statistics on cotton (see Table 2) show that 78 percent of the total area in cotton is in Bt cotton. The mean cotton yield in the sample plots is 2,395 kg per hectare. The mean net revenue, i.e. gross margin, is PKR 49,784 (USD 586)[5] per hectare of cotton produced. Fertilizers used include three major nutrients available in different types of fertilizer bags, which were converted into kg of NPK.[6] The mean NPK applied by the farmers is 249 kg per hectare. Labor cost includes both family labor[7] and hired labor and on average costs PKR 7,754 (USD 91) per hectare. On average, 4 liters of pesticides are used per hectare.

4. Empirical Analyses

In order to examine the farmers' decision to adopt Bt cotton and to understand its impacts, we undertake two kinds of analyses. First, we examine plots using Bt cotton seeds and alternatives and estimate average net revenue or gross margin across different types of plots. We also undertake econometric analyses to examine the adoption decision and its impact on yield.

4.1 Comparative Analysis

There are three types of plots in our sample: non-Bt plots (these are non-Bt cotton plots that belong to farmers who don't grow any Bt cotton in any of their farm plots), Bt1 plots (these are Bt cotton plots that belong to farmers who exclusively grow Bt cotton in all their farm plots) and Bt2 plots (these are Bt cotton plots that belong to farmers who grow both Bt and non-Bt cotton). We estimate the economic value of each type of plot. We compare the average values of various inputs and outputs related to both types of Bt cotton plots (Bt1 and Bt2) with non-Bt plots using t-tests. This type of comparison helps to identify the average effect of adoption of Bt cotton technology on farmers' yield and returns.

The revenue of households growing Bt and/or non-Bt cotton is estimated by multiplying the quantity produced by the price received by farmers at the farm gate.[8] Similarly, total cost of various inputs is computed by multiplying quantity of inputs with their respective prices paid by the farmers. After computing average revenue and total variable costs, the net revenue is determined by deducting total variable cost from total revenue. Fixed cost is not considered in the analysis, since adoption of Bt cotton does not involve purchase of any special equipment.

4.2 Econometric Analyses

In order to examine the impact of Bt cotton seed on yield, we can estimate a cotton production function. The production function represents a technical relationship between dependent variable (yield per hectare) and inputs. The production function is as under:

$$Y_{it} = \alpha + \gamma_t + \beta \sum_{i=1}^{k} \chi_{itk} + \delta \, BT_{it} + aFS_i + (\eta_i + \varepsilon_{it}) \tag{1}$$

where Y_{it} is the quantity of cotton yield per hectare of farm i in season t, and x_{it} includes a vector of farm inputs, such as seed, fertilizer, pesticide, irrigation and labor of farm i in season t and k is the number of inputs. BT_{it} shows adoption of Bt cotton seed of farm i in season t. FS_i is farm size in hectares, which helps us determine if there is any variation in farm output as farm size changes. α, β, a and δ are parameters to be estimated. All unobserved variables of farm household systematically affecting the level of output are shown by η_t, whereas γ_t indicates

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[5] US$1=PKR 85

[6] Very few farmers apply phosphorus and potash nutrients on cotton crop. So due to presence of zero observations, total fertilizer nutrients are considered in the analyses.

[7] In every village, it is a common practice that producers hire workers to perform various agricultural practices. It results in competition for hiring services of farm workers and, therefore, wage rate is the same among all farmers in the particular village. Therefore, family labor is valued at prevailing village wage rate.

[8] Real prices of output and variable inputs have been employed in the analysis. GDP deflator was used to estimate real prices of variable inputs and output.

disturbance due to season related production shocks, such as weather variation, that may influence cotton production. A residual ε_{it} is assumed to be independently and identically distributed.

This functional form used to estimate productivity of Bt cotton (1), however, does not give consistent estimates because of endogeneity emerging from two sources – farmers' self-selection and endogenous farm inputs. The availability of Bt cotton seed in the market indicates that the decision to adopt Bt cotton is voluntarily made. Given that farmers choose to adopt this technology, there is a possible correlation between unobservable characteristics that affect the outcome of the decision (e.g. yield) and those that influence the adoption decision itself. Thus, farmers who choose to adopt Bt cotton may have some 'un-observed' entrepreneurial skills that may lead them to adopt Bt cotton, but these same skills may also contribute to increased yields. Thus, attributing all the increase in yields to Bt cotton seed would be in-appropriate. Further, the use of farm inputs is commonly endogenous and based on choices that farmers make. Ignoring this endogeneity results in biased estimates of the determinants of yield. Thus, we treat input variables as endogenous and estimate separate regressions for several inputs.

While there are several statistical options for dealing with problems of endogeneity, many previous studies related to Bt cotton (see Table A1) do not control for endogeneity (Pray et al. (2001), Qaim and Zilberman (2003), Sadashivappa and Qaim (2009). Those that do address this problem, generally use the Instrumental Variable (IV) approach (Huang et al. (2002, 2002a), Qaim et al. (2003), Qaim and de Janvry (2003), Shankar and Thirtle (2005), Mutuc et al. (2011)), panel methods (Bennett et al. (2004), Crost et al. (2007)) or propensity score matching (Ali and Abdulai (2010), Nazli (2010)).[9]

Our approach to addressing endogeneity is to use panel data estimation methods, which help deal with issues related to both observable and un-observable characteristics (Krishna and Qaim (2012)). Further, panel methods are robust and require fewer assumptions than the IV method (Stock et al. (2002)). Using panel methods, Crost et al. (2007), for example, show that more than half of the yield advantage of Bt cotton in the studies with cross-sectional data is the result of self-selection bias. We too address the problems related to selectivity in adoption of Bt cotton and endogeneity of pesticide and other inputs, by using a reduced-form panel data based random effects (RE) and fixed effects (FE) methods. We are able to use panel methods because we have data from two cropping seasons.

Employing RE or FE model does not fully solve the endogeneity bias. Ideally, we would estimate a profit function since this would not involve any choice variables as explanatory variables (Vincent (2008)). However, information about input and output prices may also be endogenous because some farmers may be able to bargain during the process of purchasing inputs in large amounts or using long-term personal contacts with input dealers. Access to information also plays an important role in creating problems of endogeneity as farmers reside far away from market and do not have access to print and electronic media. The reduced-form panel modeling approach avoids this problem by excluding the unit values of input and output prices and considering exogenous variables only (Krishna and Qaim (2012)).

Our empirical reduced-form panel model is given by

$$X_{it} = \beta_0 + \beta_{it} \sum D_i \times yr_t + \delta BT_{it} + aFS_i + \varepsilon_{it} \tag{2}$$

Where X_{it} is the dependent variable and includes the net revenue,[10] yield, seed, pesticide, fertilizer, irrigation and labor inputs of ith farmer in time period t. Separate regressions are run for each dependent variable.

$D_i \times yr_t$ are interaction terms for district and year dummies. Since we have three districts in our data set and two years – the district Multanx2008 is used as the base. The performance of new technology such as Bt cotton depends on weather during a cropping season. While weather remains the same for all farmers in a given location, it varies over time (even in a particular location) and across locations. Prices of farm inputs and output exhibit the same pattern. Thus the purpose of including an interaction term in the model is to control for weather, prices and any other factors that vary overtime but do not change within a given location, i.e. district.

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[9] Crost et al. (2007) argue that some studies using IV and indicating that there is no severe endogeneity problem may be actually using weak instruments.

[10] Net revenue per hectare=Total returns per hectare minus total variable cost per hectare

The variable BT_{it} reflects the decision to adopt Bt cotton. It is measured as the share of Bt cotton in the total cotton area grown by the farmer. A significant, positive value of the coefficient of BT_{it} indicates that X_{it} increases with the percentage share of the Bt cotton area. In this specification, the *BT* variable is un-likely to be endogenous.[11] One reason is that the time span of the data is short, just two years. So it is likely that the reduced panel method controls for time-invariant farmer characteristics. Further, district-year dummies help reduce endogeneity since some of the time-varying unobserved factors are probably common across farmers in a given district. These will be controlled through the district dummies. As previously noted, FS_i refers to farm size and controls for the effect of scale.

5. Results and Discussion

5.1 Performance of Bt Cotton

We undertake two types of mean comparisons of different inputs and output used among farmers growing non-Bt cotton with Bt cotton (Bt1 and Bt2). The first compares non-Bt plots with all Bt plots for each cotton season (2008 and 2009). Thus, the variable Bt plot includes information on Bt1 and Bt2 plots. This comparison allows us to examine differences on average across Bt and non-Bt plots.

The second strategy compares non-Bt plots with Bt2 plots, i.e. Bt plots of farmers with mixed farms or farmers who were growing Bt cotton and non-Bt cotton on their farms in different plots. This comparison allows us to understand better the decisions of farmers who use both Bt and non-Bt seeds as it controls for farm and farmer characteristics.

The results are given in Table 3. The first column for each cropping season contains information about mean values for non-Bt cotton plots, the second column shows means values for all Bt plots.[12] Mean values for Bt2 plots of those farmers growing Bt cotton and non-Bt cotton are given in column three. For understanding the difference between Bt and non-Bt seeds, we mainly examine and discuss below differences between columns 1 and 2, i.e. non-Bt and all Bt plots. This is also because the results from comparing non-Bt plots with Bt2 plots are very similar to those related to non-Bt and all Bt plots.

Following our a *priori* expectations, the cost of seeds on Bt plots is higher (76 percent higher during cropping season 2008 and 69 percent during cropping season 2009) compared to non-Bt plots. However, the quantity of seed used is less on Bt plots compared to non-Bt plots during both cropping seasons as farmers apply costly inputs with more care and efficiency.

As expected, Bt cotton appears to reduce the need for pesticide sprays. Farmers sprayed 2 sprays less during 2008 and 1 spray less during 2009 on Bt cotton plots relative to non-Bt plots. However, this reduction in pesticide sprays came from the reduced use of pesticides against bollworms. Simultaneously, farmers sprayed more pesticide against sucking pests on Bt plots. None the less, overall, expenses on pesticides on Bt plots relative to non-Bt plots was lower by 35 percent in 2008 and 37 percent in the cropping season 2009. Figure 2 compares the average amount of inputs or irrigation and pesticide used across 2008 and 2009. As the figure shows, Bt plots receive more irrigation and less pesticide.

Table 3 shows that Bt cotton growers may see an increase in input costs. On average, across the two seasons, costs on non-Bt plots were 5 percent lower than costs on Bt cotton plots. Table 3 also indicates that Bt plots give higher gross revenue and net revenues, large enough to compensate for the high variable cost incurred.

This information becomes even clearer in Figure 3, which shows the average gross revenue, input costs and net revenue (combining 2008 and 2009) related to Bt versus non-Bt cotton plots. On average, across the two seasons, the net revenues to Bt cotton use were PKR 53,249 (US$626)per hectare versus a return of PKR 41,832 (US$492) per hectare for non-Bt cotton. Yields for Bt cotton plots were, on average, higher by 17 percent; and average net revenue per hectare on Bt cotton plots was 27 percent higher relative to non-Bt plots across the two seasons.

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[11] Using reduced-form panel methods does not control for endogeneity fully but it helps to reduce endogeneity.
[12] All Bt plots include Bt plots of those growing only Bt cotton and those growing both types of cotton on their farms.

We note that yield on both Bt plots and non-Bt plots declined in the second crop season, mainly due to unfavorable climatic conditions (Government of Pakistan (2010)). Table 3 shows that Bt plots perform comparatively well even under adverse conditions.

5.2 Results of Reduced-form Panel Models for Farm Input Use

To run our reduced form panel models, we first aggregated farm-level data related to inputs and then obtained the value of these variables per hectare, i.e., we divided each input by farm size (following Crost et al. (2007)). In this way, a balanced panel data were obtained. Table 4 shows the coefficients of the reduced-form estimations with seed, pesticide, fertilizer, irrigation and labor being dependent variables.

The Breusch-Pagan Lagrangian Multiplier (LM) test helps in deciding between a random effects regression and a simple OLS regression (Breusch and Pagan (1979). Results of this test statistics show that OLS models are not appropriate for the data set, so we use panel models. The Hausman test is used for selecting between RE or FE models. Results of the test indicate that FE model is the preferred model for all farm inputs except labor. We present results from the RE and FE models in Table 4, but discuss results related to FE models for all inputs below.

Table 4 shows that the estimated coefficient of Bt cotton share variable is statistically significant for the pesticide equation. Elasticity estimated at sample mean values shows that a 10 percent increase in the share of Bt cotton in total cotton area can lead to a reduction in pesticide use by 3 percent. Aggregating and noting the 78 percent share of Bt cotton in total cotton cropped area, the total reduction in the pesticide use in our study area as a result of Bt cotton production is around 22 percent per hectare.

The estimated coefficient of interaction of district and year dummy for Mianwali district shows that pesticide use is higher in Mianwali district for the year 2008 compared to Multan district during the same year. This may be due to the fact that the farmers in Mianwali district may have less experience in cotton production than those in Multan district, as cotton constitutes only 6.5 percent of total area sown in Mianwali district (Government of Punjab (2011)). All other estimated coefficients of interactions of district dummies and year are insignificant.

Regarding the effect of Bt cotton on fertilizer and seed use, the coefficient of Bt cotton share in cotton areas is negative for both variables. However, both coefficients are statistically in-significant. Thus, we cannot be sure that fertilizer use and seeds decline with an increase in Bt cotton area. This result is different from other Pakistani studies (Nazli et al. (2010), Nazli (2009)), which show that adoption of Bt cotton results in higher seed and fertilizer costs. We note that the geographical and time effects on fertilizer use are significant in our study. Higher fertilizer use is estimated in Multan district during the year 2009 compared to 2008, and lower fertilizer use is estimated in Mianwali and R Y Khan districts during the year 2008 relative to the base of Multan in the year 2008. All variables are statistically insignificant in the case of seed use. Thus, there is some inter-district and time related variation on the effect of Bt cotton production on fertilizer and seed use.

Irrigation water is an important resource in crop production. The coefficient of Bt cotton share is statistically significant in the irrigation regression, suggesting that Bt seed use increases irrigation. As expected, farmers who grow Bt cotton need to irrigate more than other farmers, with implications for over-all water use in the region. A 10 percent increase in Bt cotton acreage contributes to 1.1 percent increase in the number of irrigations provided. This reinforces the results in Table 3, which shows that average Bt plot is irrigated 1.3 and 0.1 times more than the average non-Bt plot in 2008 and 2009, respectively. Coefficients of the interaction terms of district and year dummies show that farmers from Multan district use larger amounts of irrigation compared to those in Mianwali and R Y Khan Districts.

The estimated coefficient for Bt cotton share is positive and significant for the labor regression along with significant and negative square term (for both the RE and FE models). We include the square of Bt cotton area-share in the labor regression to allow for non-linear linkages between Bt cotton and labor. Our results suggest that labor cost in cotton production increases at decreasing rate with more allocation of area to Bt cotton type. Although the labor cost increases, it may create more employment opportunities for the rural poor, particularly for rural female workers at the harvesting stage because of higher yields.

5.3 Results of Reduced-form Panel Models for Net Revenue and Yield

Most farmers' objective is to maximize profit. In the present study, net revenue per hectare is treated as short-run profit for cotton growers over a periodof one year. It shows the contribution of each cotton seed choice, given the farm's fixed costs. Table 5 shows results of net revenue and yield effects of Bt cotton technology. The Bruesch-Pagan LM test for random effects model suggest that OLS models are not appropriate for the data set for net revenue and yield. The Hausman test favors fixed effects reduced-form panel models

The estimate of Bt cotton on yield is according to a *priori* expectation (see Table 5). As indicated by the positive and significant coefficient of the Bt cotton share variable, yield increases as farmers allocate more cotton area to Bt cotton. Per hectare yield increases by around 377 kg as a result of a one percent increase in the share of Bt in the total cotton area. In elasticity terms, a 10 percent increase in Bt cotton acreage, for instance, results in a 1 percent increase in yield. Taking Bt cotton area as 78 percent of total cotton area, yield increases by about 10 percent per in our study area as a result of the conversion from non-Bt to Bt cotton by 78 percent.

District and year dummies for Mianwali and RY Khan for the year 2008 are positive and statistically significant. Results imply that farmers from Mianwali and RY Khan during the year 2008 received higher cotton yield by 331 and 465 kg per hectare respectively compared to those of Multan during the year 2008. But farm size is not related to cotton yield, as its coefficient is statistically insignificant.

Table 5 shows that short-term profit or net revenue increases with more area allocated to Bt cotton. This coefficient indicates that the cotton growers can increase their net revenue by PKR 13,070 per hectare (US$154) or 2 percent by increasing the area allocated to Bt cotton by 10 percent. Given that on average 78 percent of cropped area in cotton is in Bt cotton, the move from non-Bt to Bt cotton by 78 percent is estimated to result in a 12 percent increase in net revenue per hectare. Farm size has a significant impact on short-term profits as well.

District and year dummy for Multan during the year 2009 is positive and statistically significant, implying that net revenues are comparatively higher in 2009 compared to 2008. It suggests that cotton growers learn through experience over a time span about new technology. However, the coefficient of district and year dummy for Mianwali during the year 2008 is statistically negative, implying that farmers from this district received less profit relative to counterparts from Multan district during the base year, 2008. The reason lies in the fact that farmers from Multan district are more specialized in cotton production compared to those of Mianwali.

5.4 Discussion

78% of cropped area in our study region has been converted to Bt cotton. This increase in Bt cotton seed use is associated with higher yield and net revenue (gross margin) by 10 and 12 percent respectively.[13] However, our estimates of the positive effect of Bt cotton on yield are generally lower than similar results from other studies. For example, using the ratio of Bt cotton seed to non-Bt cotton seed, Crost et al. (2007) find that Bt cotton had a yield advantage of 31 percent over non-Bt cotton for India. Our yield increase is also lower relative to estimates identified for Pakistan by Nazli (2010) and Ali and Abdulai (2010).

One reason for our lower yield estimates relative to other studies may be because Bt cotton seed in Pakistan was un-approved at the time of our study and seed quality may have been adulterated. Further, since the use of the plot level fixed effect accounts for time-invariant un-observable heterogeneity, this may also have contributed to our lower estimates of yield.

Our estimates suggest that pesticide use declines by 22 percent per hectare with the use of Bt cotton seed in 78% of the cropped area. Other studies such as Pray et al. (2001), Huang, et al. (2002), Qaim and Zilberman (2003) and Subramanian and Qaim (2009) also find that Bt cotton reduces pesticide use. However, these studies, which are based in China and India, show a larger pesticide reduction compared to our study. However, our estimated

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[13] Using econometric results, first we estimate respective elasticities at sample mean values. Thus, we obtain the percentage change in the outcome variable as a result of a 1% increase in share of Bt cotton area. We then multiply this elasticity with the proportion of Bt cotton area in our study area.

impact of Bt cotton seed on pesticide use falls in between estimates by Ali and Abdulai (2010) and those of Nazli, et al. (2010) and Nazli (2010) for Pakistan. We think our results are robust relative to the other studies in Pakistan because of our use of reduced-form panel methods.

The other inputs of interest, which are significantly affected by Bt cotton production are labor costs and water use. Our econometric analysis suggests that labor costs increase at a decreasing rate as Bt cotton acreage increases. Further, irrigation water use increases by 8 percent per hectare when we account for the fact that 78 percent cotton area is under Bt cotton. If farmers allocate all of their cotton area to Bt cotton, the increase in water use would be 11 percent. The increased irrigation water use associated with Bt cotton reinforces results obtained in other Pakistan studies (Nazli et al. (2010), Nazli (2010)). Our study, however, did not reinforce results associated with other inputs such as fertlizers and seeds. We found no significant change associated with seed and fertilizer user as a result of Bt cotton.

6. Conclusions

Cotton is an important cash crop that makes a significant contribution to the economy of Pakistan. Raw cotton and cotton related products accounts for around 60 percent in foreign exchange earnings. However, with the passage of time, Pakistani cotton growers have experienced significant increases in the costs of production and stagnating yields. Pesticides are a major contributor to the cost of production. For example, in our sample, pesticides account for 19 and 24 percent of variable costs per hectare of cotton produced (Bt and non-Bt, respectively). Huge amounts of pesticide are imported and also domestically produced in the country. Thus, Bt cotton offers a solution in that this technology has a natural resistance against bollworms, the main cotton pest. After many years of discussion, the Pakistan Government approved commercial use of Bt cotton from the cotton cropping season of 2010.[14]

Our study seeks to examine the economic performance of Bt cotton in the Punjab province of Pakistan and to assess whether use of this new technology offers benefits both in terms of increased profits and reduced pesticide use. Our analysis builds on data from two cropping seasons, 2008 and 2009, from three districts in Punjab.

Bt cotton has three important advantages over non-Bt cotton in the form of a decline in pesticide use, an increase in the yield and higher net revenues. Our findings suggest that the average farmer growing Bt cotton is likely to have a higher income relative to a farmer using non-Bt seeds. On average, the net revenue or return to Bt cotton use was PKR 53,249 (US$ 626) per hectare versus a return of PKR 41,833 (US$ 492) for non-Bt cotton. After controlling for other factors and taking into account that 78% if the area has been converted to Bt cotton, this represents an average increase of per hectare yields by 10 percent and per hectare profits by 12 percent for farmers growing Bt cotton.

The higher returns from Bt cotton are mainly attributable to the reduction in pesticide costs. Our study controls for other factors that may be contributing to pesticide reduction and estimates that the 78% conversion of cotton growing area to Bt cotton is resulting in farmers using 22 percent less pesticides.

While pesticide costs will likely decline with the conversion from non-Bt to Bt cotton, costs associated with other inputs such as water and labor are likely to increase. The increase in irrigation water use is a reason for concern given the huge demands in Pakistan for agricultural water. Our study suggests that if farmers were to fully convert to Bt cotton in our study area, this would contribute to a 11% increase in irrigation water use.

Farmers are clearly recognizing the benefits of Bt cotton because it reduces the costs of pesticide use and risks of pest attacks. Since collecting data for this study, the use of Bt cotton in Punjab has further increased and now dominates cotton production. However, market supply currently cannot meet this huge demand and growers face problems of non-availability of quality Bt cotton seeds. Unapproved Bt varieties with different names are now available in the market and this may well lead to a reduction in yields. Thus, there is a need to ensure that availability of high quality supply of seeds—this is particularly important for small farmers who are vulnerable to any form of financial risks.

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[14] Government of Pakistan allowed planting of Bt cotton from the cropping season 2010 after approving nine Bt cotton varieties.

There are legitimate concerns about what the implications of GM technologies may mean for maintaining the gene pool of different crop varieties. The potential long-term adverse impacts of Bt cotton use include increased use of irrigation water, biodiversity loss, genetic pollution, possible effects on land fertility. Crop diversity is a major concern with the introduction of Bt cotton in Pakistan as more research may be concentrated on Bt cotton varieties, ignoring other non-Bt cotton varieties. This may result in availability of few cotton varieties. Addressing these issues is beyond the scope of our paper. However, our paper is able to clarify why such public worries can get over-shadowed, give the private returns to farmers from using Bt cotton.

Acknowledgements

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Tables

Table 1: Socio-economic characteristics of sampled farmers

Variables	All Farmers	Farmers growing Bt and Non Bt cotton	Farmers growing only Bt cotton
Age of respondent (Years)	44 (12)	44 (12)	44 (12)
Total area under cotton production (hectares)	17 (24)	14 (23)	20 (24)
Farming experience (year)	20 (11)	21 (11)	19 (11)
Cotton growing experience (Years)	15 (12)	19 (11)	12 (12)
Education (schooling years)	4 (2)	4 (2)	4 (2)
No. of parcels or plots	2 (1)	3 (11)	2 (1)
Farmers getting credit (%)	21	24	20
Credit availed (PKR)	211,426 (316,291)	220,839 (348,717)	201,597 (286,633)
Number of observations	573	233	340

Figures in parentheses are standard deviations

Table 2: Summary Statistics of variables in the reduced-form panel models

Variables	Mean	SD	Min	Max
Net revenue (Rs/hec)	49,784	26,632	–19,389	151,880
Yield (kg/hec)	2,394.54	751.84	296.52	5,930.32
Seed (kg/hec)	18.17	4.81	9.88	32.12
Fertilizer (kg/hec)	249.30	79.91	1.32	600.44
Pesticide (Liter/hec)	4.32	2.20	0.41	16.89
Irrigation (No.)	9.75	3.17	4	16
Labor (Rs/hec)	7,754.28	2205	1086.40	18,585.20
Share of Bt	78.38	29.68	0	100
Multanx2008	0.17	0.37	0	1
Multanx2009	0.17	0.37	0	1
Mianwalix2008	0.16	0.37	0	1
Mianwalix2009	0.16	0.37	0	1
RYKhanx2008	0.17	0.37	0	1
RYKhanx2009	0.17	0.37	0	1
Number of observations	570			

Table 3: Input use, output and returns on per hectare basis in cotton production

Items	Cropping season 2008 (mean)			Cropping season 2009 (mean)		
	Non-Bt plots	All Bt plots (average of Bt1 and Bt2)	Bt2 plots (of farmers growing Bt and non-Bt)	Non-Bt plots	All Bt plots (average of Bt1 and Bt2)	Bt2 plots (of farmers growing Bt and non-Bt)
Seed (kg)	20	18***	20	19	18***	20
Cost of seed (Rs)	1,133	1998***	1998***	1176	1991***	19675***
Fertilizer (NPK kg)	254	232***	264	281	254***	286
Irrigation (No.)	9	10***	12***	10	10	11***
Pesticide (No.)	7	5***	6***	7	6***	6***
Sucking sprays (No.)	3	3*	3*	3	3**	4***
Chewing sprays (No.)	4	2***	2***	4	2***	3***
Pesticide (Liter)	6	4***	4***	6	4***	4***
Pesticide (Rs)	6,504	5,331***	5,376***	7,792	6,594***	6,820**
Labor (Rs)	7,769	7,407	6,315	8,106	7,980	6,883
Variable cost (Rs)	30,096	31,804***	31,688**	32,869	34,306*	33,896
Yield (kg)	2,272	2,611***	2,575***	1,994	2,373***	2,384***
Gross revenue (Rs)	69,807	79,883***	78,871***	76,824	92,726***	92,149***
Net revenue (Rs)	39,710	48,078***	47,183**	43,955	58,420***	58,252***
Observations	134	288	134	99	280	95

***, ** and * are level of significance at 1%, 5% and 10% respectively

Table 4: Estimates of the reduced-form panel models for input use

VARIABLES	Seed (kg/hec)		Pesticide (liter/hec)		Fertilizer (kg/hec)		Irrigation (No.)		Labor (PakRs 000)[15]	
	RE	FE	RE	FE	RE	FE	RE	FE	RE	FE
BT	-0.89	-1.08	-1.46***	-1.57***	-11.16	-26.35	0.67	1.35*	4.46**	5.50**
	(0.79)	(1.24)	(0.34)	(0.46)	(12.29)	(20.10)	(0.44)	(0.79)	(1.74)	(2.17)
BT square									-3.64***	-4.44***
									(1.33)	(1.71)
FS	0.00	-0.01	-0.00	-0.01	0.02	-0.45	-0.00	0.00	-0.00	-0.01
	(0.01)	(0.02)	(0.00)	(0.01)	(0.16)	(0.28)	(0.01)	(0.01)	(0.00)	(0.01)
mianwali_2008	-3.59***	0.15	-0.22	1.24***	-52.45***	-29.03***	-1.39***	-2.62***	-0.29	-0.09
	(0.70)	(0.54)	(0.28)	(0.22)	(11.14)	(7.63)	(0.39)	(0.41)	(0.28)	(0.23)
mianwali_2009	-3.76***		-1.46***		-23.95**		1.24**		-0.20	
	(0.66)		(0.24)		(10.71)		(0.49)		(0.27)	
multan_2009	-0.49	-0.48	0.06	0.06	29.55***	30.68***	3.25***	3.18***	0.49**	0.50**
	(0.56)	(0.57)	(0.21)	(0.21)	(10.70)	(10.71)	(0.39)	(0.39)	(0.25)	(0.25)
rykhan_2008	1.00	0.30	0.58**	0.22	40.72***	-22.20**	1.61***	-1.16**	-0.20	-0.65***
	(0.66)	(0.62)	(0.27)	(0.26)	(10.09)	(9.79)	(0.45)	(0.49)	(0.24)	(0.23)
rykhan_2009	0.69		0.34		61.02***		2.90***		0.47**	
	(0.64)		(0.23)		(10.49)		(0.40)		(0.23)	
Constant	19.83***	19.24***	5.40***	5.20***	240.04***	273.48***	7.94***	8.77***	5.31***	5.25***
	(0.71)	(1.03)	(0.28)	(0.38)	(11.14)	(15.76)	(0.41)	(0.66)	(0.51)	(0.58)
R-squared		0.01		0.14		0.09		0.30		0.06
Breusch-Pagan test	16.15***		7.60***		3.36**		0.00		8.856***	
Hausman test	138.43***		100.49***		226.07***		10.18*		3.863	
Observations	570	570	570	570	570	570	570	570	570	570

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

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[15] For labor variable, taking square term of Bt cotton share in total cotton area gives significant results as Bt cotton share and its square are statistically significant whereas considering only Bt cotton share variable, this variable becomes statistically insignificant.

Table 5: Estimates of the reduced-form panel models for yield and net revenue

VARIABLES	Net revenue (PakRs 000/hec)		Cotton yield (kg/hec)	
	RE	FE	RE	FE
Bt	13.07***	9.84*	461.05***	377.27**
	(4.27)	(5.76)	(124.46)	(158.37)
FS	0.14***	0.13*	2.94**	2.59
	(0.04)	(0.07)	(1.22)	(1.83)
mianwali_2008	7.82**	-8.78***	138.70	331.23***
	(3.56)	(2.75)	(116.54)	(66.29)
mianwali_2009	16.59***		-192.85	
	(3.87)		(117.74)	
multan_2009	16.77***	17.11***	39.35	47.86
	(2.67)	(2.65)	(87.47)	(86.27)
rykhan_2008	17.62***	-3.00	408.55***	464.56***
	(3.33)	(3.38)	(109.05)	(84.84)
rykhan_2009	20.02***		-71.11	
	(3.75)		(112.34)	
Constant	25.80***	40.63***	1,964.13***	1,950.56***
	(3.42)	(4.94)	(103.99)	(138.07)
R-squared		0.18		0.17
Breusch-Pagan test		31.28***		44.47***
Hausman test		9.53*		67.64***
Observations	570	570	570	570

Robust standard errors in parentheses
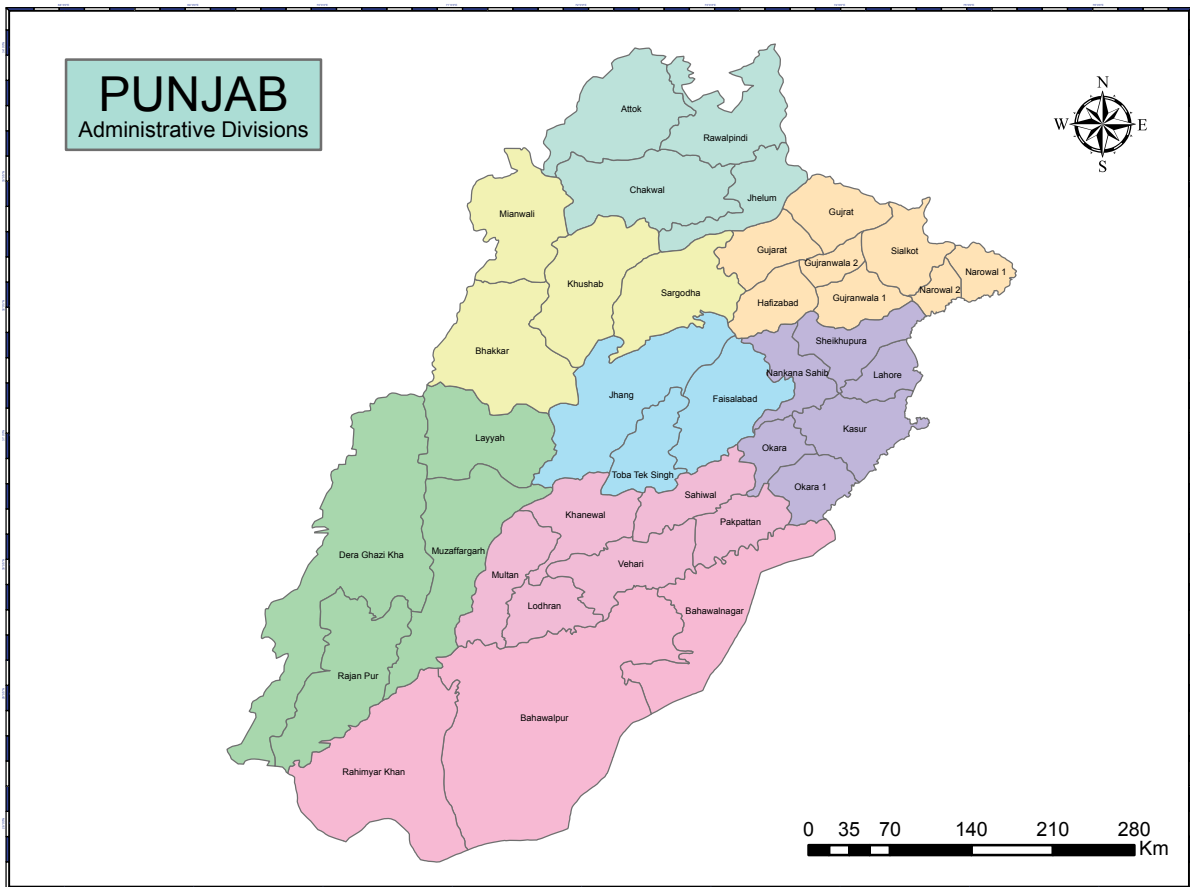*** p<0.01, ** p<0.05, * p<0.1

Figures

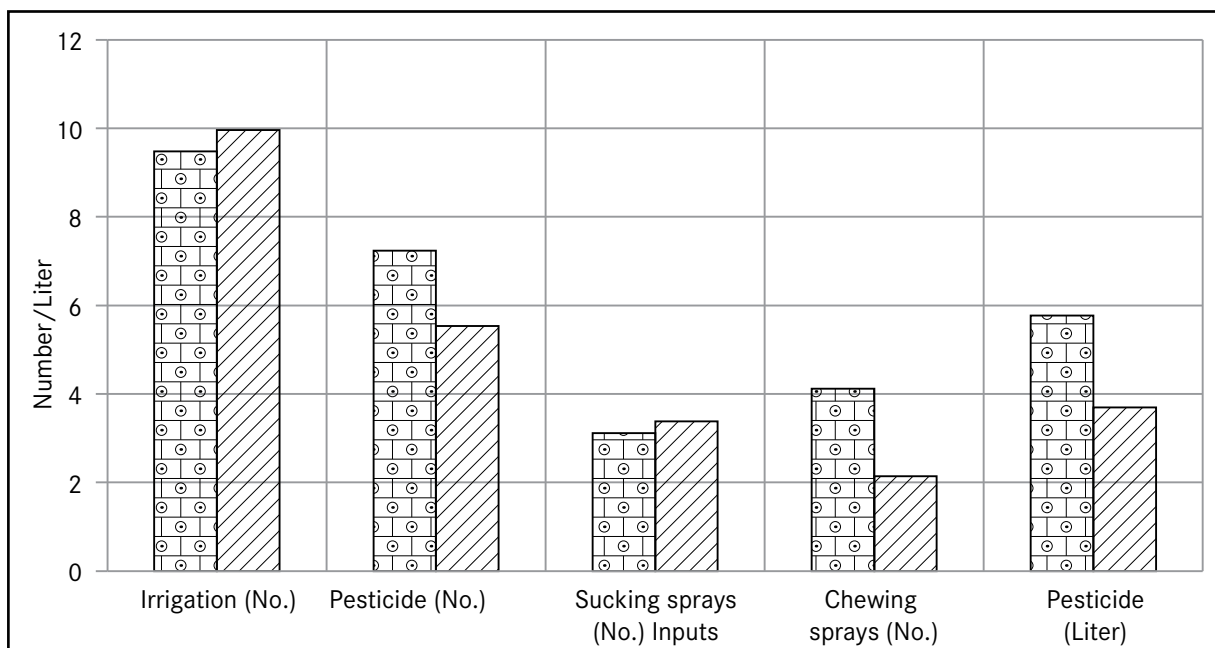**Figure 1:. Map of Punjab province and study location**

Figure 2: Comparison of average inputs (2008 and 2009) in non-BT and Bt plots
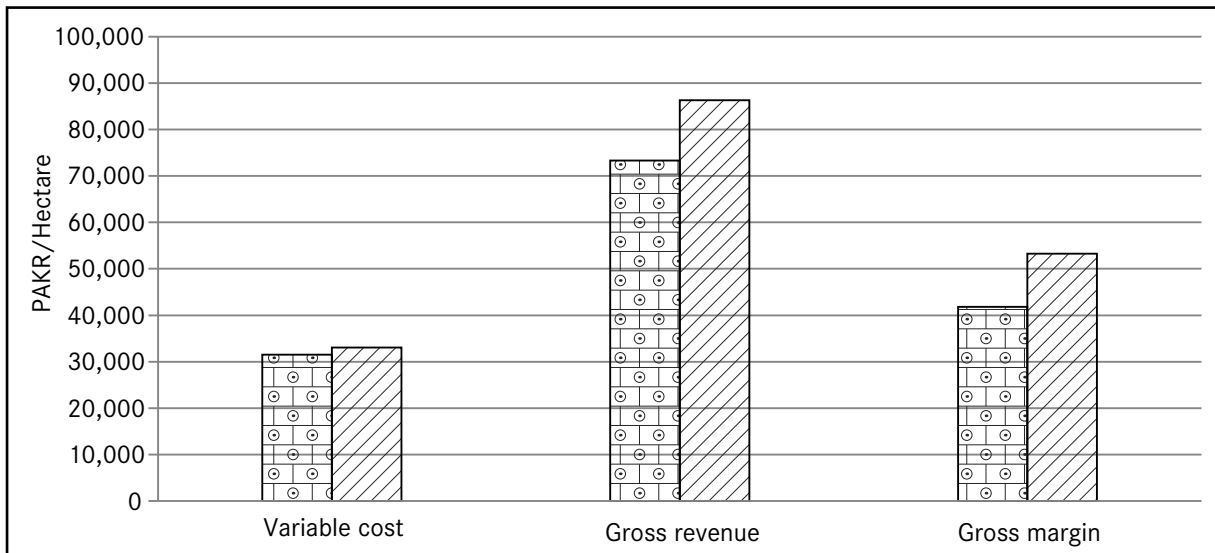
Figure 3: Comparison of average input costs and returns (2008 and 2009) in non-BT and Bt cotton plots

Annex

Table A1: Summary of the past studies on the estimation of impacts of Bt cotton
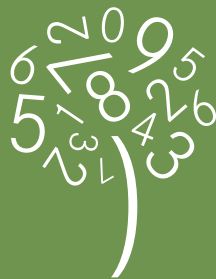
Reference	Type of data	Estimation method	Impact on yield (%)	Impacts of Bt cotton on input use (% difference)				
				Number of Sprays	Pesticide quantity	Pesticide cost	Seed cost	Fertilizer cost
Studies using econometric methods but not controlling for endogeneity								
Pray, et al. (2001), China	Cross-sectional	Consumer surplus and producer surplus model	-7		-82	-88	79	+
Qaim & Zilberman (2003), India	Cross-sectional	DC	80	-42	-69			
Thirtle et al. (2003), South Africa	Panel data	CD stochastic frontier	33-54			-36	69	
Bennett et al. (2006), India	Cross-sectional	CD	48	-40		-66	232	
Qaim et al. (2006), India	Cross-sectional	Translog	27	-38	-50	-41	221	14
Sadashivappa and Qaim, (2009), India	Cross-sectional	CD and DC	CD 37 and DC 32	-32	-41	-29	166	19
Abid, et al. (2011), Pakistan	Cross-sectional	CD	26.8		-27			
Studies using econometric methods and controlling for endogeneity								
Huang, et al. (2002), China	Cross-sectional	Cobb Douglas and DC	CD 8 and DC 9		-57 to -81	-55 to –82	-2 to 333	3 to -23
Huang, et al. (2002a), China	Cross-sectional	Cobb Douglas and DC	CD 15 and DC 7-8	-67	-81	-82		
Qaim, et al., (2003), Argentina	Cross-sectional	Quadratic and DC	30	-48	-49	-50		
Qaim, 2003, India	Field trials	DC	80	-42	-69			
Qaim& de Janvry (2003), Argentina	Panel data	Quadratic and DC	Quadratic 32 & DC 30			-46 to -47	449 to 617	
Bennett et al. (2004), South Africa	Panel and cross-sectional	Quadratic	65			-53 to -96	48 to 101	
Shankar &Thirtle (2005), South Africa	Cross-sectional	CD and DC	DC 40		-50		-19[16]	
Crost et al. (2007), India	Panel data	CD and net revenue fixed effects	CD 92 & Fixed effects 31			-13 to-14	-4.86	3 to 7
Ali &Abdulai (2010), Pakistan	Cross-sectional	Propensity score matching	24		-15			
Nazli, (2010), Pakistan	Cross-sectional	Propensity score matching	26		-27			
Mutuc, et al. (2011), Philippines	Panel data	CD and DC	33-45	+	-			
Mal, et al. (2011),India	Cross sectional	Stochastic frontier	+					
Studies using other methods								
Morse, et al. (2007), India	Panel data	Gini coefficient	43 to 27	NA	NA	10.18 to -60	207 to 165	-18 to -45
Subramanian &Qaim (2009), India	Cross-sectional	Social accounting matrix	32 to 39	NA	-46 to 59	NA	NA	NA
Rao&Dev (2009), India	Cross-sectional	Partial budgeting	32	NA	NA	-18	134	-1
Hayee (2005), Pakistan	Cross-sectional	Partial budgeting	-50	NA	NA	-65	450	-20
Sheikh, et al. (2008), Pakistan	Cross-sectional	Partial budgeting	20	-35	NA	-51	286	-4.5
Nazli (2009), Pakistan	Cross-sectional	Partial budgeting	6 to 39	-1.38	NA	-23.94	70.6	NA
Nazli, et al. (2010), Pakistan	Cross-sectional	Partial budgeting	15	-2	-9.6	-24	66.5	12

CD stands for Cobb Douglas production function and DC for damage control function
Adopted from Crost et al. (2007) and further extended by the author

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[16] Seed rate used in cotton production

Table A2: Salient characteristics of the selected farms

Characteristics	Farmers growing Bt and non-Bt cotton		Farmers growing Bt cotton	
	2008	**2009**	**2008**	**2009**
Farm size (hectares)	18.73	17.63	20.77	19.19
Irrigated land as percent of farm size	92.74	97.20	85.02	94.31
Cotton area as percent of farm size	59.26	62.84	39.00	45.00
Bt cotton area as percent of cotton area	44.07	59.68	100.00	99.01
Non-Bt cotton area as percent of cotton area	57.09	41.64	–	–

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