International Journal of Food and Agricultural Economics
ISSN 2147-8988, E-ISSN: 2149-3766
Vol. 6, No. 4, 2018, pp. 101-118

EARLY ADOPTION OF Bt COTTON AND THE WELLBEING OF COTTON FARMERS IN PAKISTAN

Hina Nazli
Pakistan Strategy Support Program, International Food Policy Research Institute, Islamabad, Pakistan, Email: hinanazli@gmail.com

Rakhal Sarker
Department of Food, Agricultural, and Resource Economics, University of Guelph, 50 Stone Road East, Guelph, Ontario, Canada, Email: rsarker@uoguelph.ca

David Orden
International Food Policy Research Institute, Washington D.C., USA

Karl Meilke
Department of Food, Agricultural, and Resource Economics, University of Guelph, Canada

Abstract

Pakistan is the world's fourth largest producer and third largest consumer of cotton. Using data from 16 villages in two cotton-growing districts of Pakistan, we attempt to determine the impacts of Bt cotton adoption on producers' wellbeing employing the propensity score matching method. While the results reveal positive impacts of Bt cotton on the wellbeing of farmers in Pakistan, the extent of impact varies by agro-climatic conditions and by farm size. The impact of Bt cotton adoption on yield for small farmers is about is about 50 percent of the same for large farmers. Similarly, the impact of Bt cotton adoption on household income was positive and significant for medium and large farmers but not for small farmers. The impacts of Bt cotton on yield and income are larger under hot and humid conditions than under hot and dry climatic conditions. Additional public-sector investments in monitoring and assessments of pest infestations across climatic zones would be helpful to make the Bt cotton technology widely beneficial in Pakistan.

Key words: *Technology adoption*, *Bt cotton, propensity score matching, farmers' wellbeing,Pakistan*
Jel Codes: *Q11, Q12, Q15, Q19*

1. Introduction

Despite significant efforts by the global community during last fifty years, poverty remains an important concern in many developing countries. Since agriculture is the main vocation in developing countries, the vast majority of the poor people in these countries reside in rural areas (de Janvry & Sadoulet, 2001). Therefore, improved agri-food production, processing and marketing can play a pivotal role in addressing rural poverty in developing countries. While the role of productivity-improving technology for food crops in reducing poverty and enhancing wellbeing of rural households in developing countries has been well documented in development economics (Binswagner & von Braun, 1991; Just & Zilberman, 1988; Mojo et al., 2007), productivity enhancing technological breakthrough for cash crops, particularly for cotton in India has been marked by controversies (Ramini & Thutupalli, 2015).

Pakistan is the world's fourth largest producer and the third largest consumer of cotton. Production of cotton is important to Pakistan's agriculture and the national economy. Nearly 26 percent of farmers grow cotton, and over 15 percent of total cultivated area is devoted to this crop. Cotton production takes place primarily in two provinces: Punjab (80%), which has dry conditions, and Sindh (20%), which has a more humid climatic condition. Cotton and cotton products such as yarn, textiles and apparel contribute significantly to the gross domestic product (8% of GDP), total employment (17%), and foreign exchange earnings (54%) of Pakistan (Government of Pakistan, 2009 and 2011). However, cotton production faces significant challenge of pest damages causing high fluctuations in cotton yields and economic losses over time. Pest losses in Pakistan arise not only from bollworms, which can be controlled with genetically modified Bt cotton seed, but also from non-bollworms or sucking pests which are not directly affected by the use of Bt varieties.

A growing body of international evidence based on farm surveys has shown that the adoption of Bt cotton in developing countries reduces pest infestations, improves yields and increases farm profits (Carpenter, 2010; Qaim, 2009; Qaim & Zilberman, 2003; Subramanian and Qaim, 2010). While advanced Bt cotton varieties have been available in China and India for more than a decade, Pakistan did not commercially approve any biotech cotton until 2010[1]. The delay in the approval for commercialization has resulted in the unregulated adoption of Bt cotton varieties in Pakistan. It is estimated that in 2007 nearly 60 percent of cotton area was under these varieties (PARC 2008). In 2011, this proportion has increased to 85 percent (James 2011). The unapproved varieties were developed domestically using the *Cry1Ac* gene and distributed without any formal regulatory framework, which raised concerns related to seed quality, management awareness among farmers, and bio-safety.

Several studies have made preliminary comparisons of the performance of existing Bt type varieties with the recommended non-Bt varieties in Pakistan based on informal interviews with semi-structured questionnaires (Hayee, 2004; Sheikh *et al.*, 2008; Arshad *et al.,* 2009). These studies report a relatively poor performance of existing Bt cotton compared to the recommended conventional varieties. While preliminary, such results raise two important questions. If there has been lower profitability, why has the adoption of Bt varieties increased over time? Secondly, what is the impact of Bt cotton adoption on farmers' wellbeing in Pakistan? Two studies provide a systematic assessment of productivity, health and environmental effects of the current Bt cotton adoption in Pakistan (Ali & Abdulai, 2010; Kouser & Qaim, 2013). Based on a survey conducted in 2007, Ali & Abdulai reveal that adoption of Bt cotton before it was officially approved had significantly improved cotton yields and income, reduced rural poverty as well as the use of pesticides in the Punjab province of Pakistan. Using a choice experiment study and survey data from Punjab, Kouser and Qaim (2013), reveal that the adoption of Bt cotton generated additional gross margin worth $204 U.S. per acre while health and environmental benefits received by cotton farmers were valued at $40 U.S. per acre. Both studies focus on the province of Punjab. Based on the data collected from various agro-climatic zones of Pakistan in 2012, Spielman et al. (2015) noted a significant social, economic and spatial heterogeneity among cotton-producing households and between Bt and non-Bt cotton-producing households across agro-climatic zones. However, they did not find any systematic pattern in the yield of Bt versus non-Bt varieties. For example, the highest

[1] In 2010, Pakistan became the twelfth country to officially plant Bt cotton along with USA, China, India, Australia, South Africa, Brazil, Argentina, Columbia, Mexico, Costa Rica, and Burkina Faso. Locally developed Bt cotton varieties expressing MON531 and one hybrid expressing the fusion gene cry1Ac and cry1Ab received approval for commercial cultivation in 2010. More Bt varieties were approved in 2012. These varieties, however, do not express the most recent technology.

yields are reported for NIAB-111 (1133 kg/acre) and FH-685 (883 kg/acre), both of which are non-Bt varieties, and MNH-886 (868 kg/acre), which is a Bt variety.

This paper further examines the impact of adopting Bt varieties on cotton farmers' well-being in Pakistan. Wellbeing is defined in this study in terms of four outcome variables such as pesticide usage, yield and gross margin[2] per acre, per capita income, and poverty headcount[3]. This is slightly different from the indices of wellbeing used by Wu et al. (2010) who used household income, the incidence of poverty (the head-count-ratio), the poverty gap and the severity of poverty to represent wellbeing. What separates this study from Ali and Abdulai (2010) and Kouser and Qaim (2013) is that we focus on both cotton producing provinces, Punjab and Sindh while both previous studies focus only on Punjab.

The lack of in-depth research about the economic performance of the available Bt varieties relative to conventional varieties, the diverse pest risks in Pakistan (particularly losses resulting from the disease of Cotton Leaf Curl Virus (CLCV) caused by a non-bollworm pest, white fly), and an acrimonious policy environment often influenced by reports about Indian Bt cotton farmers' suicides due to crop failures and other adverse publicity, have raised caution and apprehension about the commercial adoption of Bt cotton in Pakistan. While some of these apprehensions may have disappeared after the approval of Bt cotton, the evidence presented in this paper provides a much needed economic assessment of the impacts of the available Bt cotton varieties[4] in two important cotton producing provinces in Pakistan. The analysis contained in this article is based on a survey of cotton farmers, conducted during January-February 2009 in Pakistan.

While a few studies have so far analyzed the impact of Bt cotton adoption in various developing countries, the analysts mainly focused on a comparison of the average outcomes for adopters and non-adopters. Although the results are informative and interesting, they have limited significance for informed policy choices. This is primarily because the samples in these studies have not been drawn randomly. When the samples are drawn using a non-experimental design, the selection of respondents is not random and the problem of self-selection arises. In this situation, it is difficult to isolate the causal effect of technology from those of other factors (socioeconomic, location etc.) that might affect the adoption choices by farmers. In the presence of selection bias, the comparison of means can lead to misleading results (Thirtle *et al.,* 2003; Crost *et al.,* 2007; Morse *et al.,* 2007a; Ali & Abdulai, 2010). To address the issue of selection bias, two-stage models are commonly employed. In the first stage, the decision model is estimated and the results of the first stage are used in stage two to determine the impacts of the adoption decision on selected outcome variables.

We adopt a non-experimental evaluation strategy to assess the direct impacts of Bt cotton adoption on the wellbeing of cotton farmers in Pakistan. Using a cross sectional household survey of cotton producers in Punjab and Sindh, we attempt to isolate the causal effect of Bt cotton adoption on yield, gross margin, input usage and poverty by employing the propensity score matching method (PSM). This method takes into account the counterfactual situation: "how much would the adopters benefit from Bt cotton adoption compared to the situation if they had not adopted the technology". A comparison of the PSM results with the difference of means method indicates that the impact of Bt cotton adoption is overestimated if self-selection bias is not addressed. Our results also demonstrate that the effects of Bt cotton adoption on farmers wellbeing differ across locations (with varying climatic conditions and pest pressure) and between large and small farms. A direct implication of our findings is that while the adoption of Bt cotton improves some aspects of the wellbeing of cotton farmers in Punjab and

---

[2] Gross margin is the difference between total revenue and total cost of cotton production.
[3] The poverty headcount, defined as a dummy variable, takes the value '1' if a household is poor, i.e., if per capita per month income is below poverty line (Rs 1,057.81). Rs is Pakistani rupees.
[4] Some of these varieties have been approved for commercial adoption for the 2010 cotton crop.

Sindh, the extent of benefits vary across regions. Thus, the exploration of multiple pathways remains important for lasting resolution of rural poverty in Pakistan.

The analytical framework employed for estimating adoption decisions and the impact of adoption on outcome variables is presented in section 2. Section 3 focuses on data and describes the basic features of data. Results pertaining to the PSM model are presented, discussed and their policy implications are highlighted in Section 4. The final section concludes the paper.

2. The Analytical Framework

If Bt cotton technology was randomly assigned to cotton farmers, we could assess the causal effect of technology adoption on farmers' wellbeing by comparing the differences in wellbeing indicators between adopters and non-adopters. In reality, a technology is not randomly allocated and its adoption involves a process of self-selection by farmers. It is widely acknowledged that whether a farmer adopts the technology or not is influenced by a set of socioeconomic variables. Some of these variables may also affect farmers' wellbeing. Thus, if there is a positive correlation between technology adoption and farmers' wellbeing, it is difficult to sort out the causal effects of the technology. The parametric approaches such as the OLS and the instrumental variable (IV) regression analysis are not adequate to sort out these causal effects (Jalan & Ravallion, 2003). Hence, we decided to use a non-parametric procedure called the PSM to sort out the causal effect of Bt cotton adoption on cotton farmers' wellbeing in Pakistan. Assuming that Bt cotton adoption is a function of many observable factors at the household level and that the effect of technology is not constant across farmers allow us to differentiate between a "treatment" group and a "control" group at the local level. From an analytical point of view, these two groups have similar probabilities of adopting the Bt cotton technology. The key feature of the matching procedure is the creation of the conditions of a randomized experiment so that a causal effect as that in a controlled experiment can be evaluated. Such an evaluation is based on the conditional independent assumption, which in our context, states that the decision to adopt Bt cotton is random and is uncorrelated with farmers' income, once we control for other driving factors contained in X.

Following Rosenbaum and Rubin (1983), let's define technology adopters as the "treated group", where "treatment" refers to the decision of Bt cotton adoption, and non-adopters as the "control group" or "comparison group". Let y_{1i} be the level of outcome variable for an individual i who receives treatment and y_{0i} represents the potential level of outcome variable if this individual does not receive treatment. Let τ_i be a treatment indicator. The welfare effect of a treatment (commonly known as "treatment effect" or "causal effect") for an individual is the difference between the outcomes:

$$\tau_i = y_{1i} - y_{0i} \tag{1}$$

Empirical studies of technology adoption often rely on survey data which are inherently non-experimental. In such studies, the assignment of a treatment is not random. Consequently, the impact evaluation of a treatment based on survey data can suffer from two problems. The first is the selection problem, individuals select themselves into treatment if they perceive the expected utility of profit of the treatment $EU(\pi_{i1})$ minus its cost is larger than the expected utility of not being treated,$EU(\pi_{i0})$ (i.e., $EU(\pi_{i1} - C) - EU(\pi_{i0}) > 0$). Secondly, for the same individual, either y_{1i} or y_{0i} is observed and not both. Therefore, the counterfactual is always missing.

Impact evaluation examines the difference between the actual and counterfactual situation that is commonly known as Average Treatment Effect on the Treated (ATT):

$$\tau_{ATT} = E(y_{1i}|I_i = 1) - E(y_{0i}|I_i = 1) \quad (2)$$

Using the mean outcome of non-treated individuals $E(y_{0i}|I_i = 0)$ as a proxy for the treated had they not been treated $E(y_{0i}|I_i = 1)$ can give misleading results. The basic objective of the impact analysis is to find ways such that $E(y_{0i}|I_i = 0)$ can be used as a proxy for $E(y_{0i}|I_i = 1)$. The PSM method provides a well-known solution to this problem (Rosenbaum and Rubin, 1983, 1985; Rubin, 1997; Dehejia & Wahba, 1999, 2002). The underlying principle is to match the individuals in the treated group with the individuals in the control group that are similar in terms of their observable characteristics on the basis of similar propensity scores.

The validity of matching methods depends on two conditions: (i) un-confoundedness and (ii) common support. The condition of un-confoundedness states that outcomes y_{1i}, y_{0i} are independent of the actual treatment status *I* given a set of observables, *X*.:

$$(y_{0i}, y_{1i}) \perp I_i|X \quad (3)$$

The condition of common support rules out the phenomenon of perfect predictability of *I* given *X*, and ensures that for each value of *X* there should be both treated and untreated cases:

$$0 < \Pr(I_i = 1|X) < 1 \quad (4)$$

When these two assumptions are satisfied, the experimental and non-experimental analyses identify the same parameters. Consequently, the treated group can be matched with the non-treated group for each value of *X* using an appropriate matching algorithm.

To avoid the problem of dimensionality causes by large number of covariates in the model, Rosenbaum and Rubin (1983) introduced propensity score as the conditional probability of receiving a treatment given pre-treatment characteristics. Propensity scores summarize all of the covariates into one scalar: the probability of being treated, *p(X)*:

$$p(X) = p(I_i = 1|X) \quad (5)$$

There are two key properties of propensity scores. First, propensity scores are balancing scores which states that if *p(X)* is the propensity score, then conditioning covariates should be independent of the decision of treatment, i.e., $X \perp I_i|p(X)$ (Rosenbaum and Rubin, 1985; Sianesi, 2004). Thus, grouping individuals with similar propensity scores creates the situation of a randomized experiment with respect to the observed covariates. Second, if treatment assignment is ignorable given the covariates, i.e., $(y_{0i}, y_{1i}) \perp I_i|X$, then treatment assignment is also ignorable given the propensity score, i.e., $(y_{0i,} y_{1i}) \perp I_i|p(X)$. These two properties reduce the problem of high dimensionality. Therefore, matching can be performed on propensity scores *p(X)* only rather than on the full set of covariates.

After calculating the propensity scores, one needs an algorithm to match farmers in the adopter group with farmers in the non-adopter group based on the closeness of their propensity scores. Any discrete choice model, such as a logit or a probit can be used to estimate the propensity scores. The *ATT* is then estimated by matching the treated group with the control group based on the estimated propensity scores. Four matching methods are widely used: nearest neighbour matching, radius matching, kernel matching, and stratification matching (Becker and Ichino, 2002). In all matching algorithms, each treated individual *i* is paired with some group of ‘comparable’ non-treated individuals *j* and then the outcome of the treated individual *i*, y_i, is linked with the weighted outcomes of his ‘neighbours’ *j* in the comparison (control) group. After matching, the average treatment effect on treated is calculated to compare the outcome variables. The difference is the estimate of the effect of the treatment.

Testing the statistical significance of treatment effects and computing their standard errors is not straightforward. The estimated variance of the treatment effect in PSM should include the variance attributable to the derivation of the propensity score, the determination of the common support and (if matching is done without replacement) the order in which treated individuals are matched (Caliendo & Kopeinig 2008). These estimation steps add variation beyond the normal sampling variation. One solution is to use bootstrapping, where repeated samples are drawn from the original sample, and properties of the estimates (such as standard error and bias) are re-estimated with each sample (Lechner, 2002). We used the bootstrapping method to obtain the standard errors of the *ATT* in this paper as it has been the most widely used approach (Imbens, 2004).

3. Data Description

To examine the economic impacts of the adoption of Bt varieties on costs of production and yields, a survey was conducted in two cotton growing districts of Pakistan; Bahawalpur in the province Punjab and Mirpur Khas in Sindh[5]. The selected sample is drawn from the existing sampling framework of the Pakistan Rural Household Survey (PRHS)[6]. While there are four cotton districts in the PRHS, this survey was conducted in only two districts where the number of cotton growers was sufficient in the sample. Our survey covered 13 cotton growers in 8 villages in each district. Two observations were dropped as incomplete, leaving a total sample of 206 cotton growers in 16 villages.

The selected districts have different agro-climatic conditions in terms of rainfall, minimum and maximum temperature and humidity. Because of these differences, the pest pressure on the cotton crop was also different. Low temperature and high relative humidity cause an increase in the bollworm population (controllable with Bt seeds) and decline in the population of sucking pests. Bahawalpur has a hot and dry climate and Mirpur Khas has a hot and humid climate. These two districts were selected to reflect the diversity of Pakistan's cotton growing areas in terms of pest pressure. Average rainfall is low in both districts. Approximately two-thirds of the Bahawalpur district is covered by desert. Canals are the main sources of irrigation in both districts.

Information on the costs of inputs, cotton output, revenue from cotton sales, and total household income were collected through a structured questionnaire. Farm operator, household, and farm characteristics were also collected. The sample farmers included Bt cotton adopters as well non-adopters. Additional details on the survey design and its implementation can be found in Nazli (2011).

The majority of farms in our sample are small. Nearly 82 percent of the farmers operate less than 12.5 acres of land. Most are concentrated in the category of less than 5 acres in both districts. However, these districts differ in terms of the type of land tenure. A majority of farmers in Bahawalpur are owner-operators (77.9%) while most of the farmers in Mirpur Khas are sharecroppers (73.1%). Most of the sharecroppers surveyed indicated that the landlord

---

[5] The Bt Cotton Survey 2009 received financial supported from Innovative Development Strategies Ltd, Islamabad, and the Institute for Society, Culture and Environment, Virginia Tech, Arlington, Virginia. The Pakistan Agricultural Research Council (PARC) provided essential in-kind support for the field research.

[6] This survey was conducted jointly by the World Bank and Pakistan Institute of Development Economics (PIDE).

provides 50 percent of the inputs other than labour and that the sharecroppers are responsible for 50 percent of the inputs and their timely application. Output is divided on a 50-50 basis.

The adoption of Bt cotton in these two districts increased rapidly during 2006-2008, reflecting the national trend. In 2006, the adoption rate in Bahawalpur was higher (36%) than that in Mirpur Khas (32%). This was reversed in 2008, when about 87 percent of the farmers in Mirpur Khas cultivated Bt cotton and only 74 percent in Bahawalpur.

The choice of explanatory variables (also known as conditioning variables) in predicting propensity scores is very important in propensity score matching analysis. The covariates must satisfy the assumption of unconfoundedness. Therefore, analysts need to select conditioning variables that influence both treatment and outcome, but are not affected by the treatment (Caliendo and Kopeinig, 2008). The choice of these variables should also be guided by economic theory and the knowledge of previous research (Smith and Todd, 2005). The conditioning variables employed in this study are based previous studies that have examined the impacts of technology adoption on farmers' wellbeing in developing countries taking self-selection into account such as Diagne and Demont, 2007; Mendola, 2007; Adekambi *et al.*, 2009; González, 2009; Wu *et al.*, 2010; Ali and Abdulai, 2010; Kassie, *et al.*, 2010; Otsuki, 2010; Becerril and Abdulai, 2010. These factors can be divided into five groups: (i) human capital factors (age and education of a farmer); (ii) household characteristics (composition, wealth); (iii) accessibility factors (access to inputs and information); (iv) farm characteristics (operated land; type of tenure); and (v) yield variation.

Table 1 provides the means and standard deviations of the variables used in the decision model. Adopters are defined as those farmers who cultivated Bt cotton in 2008, including households that grew both Bt and non-Bt varieties. The mean, standard deviations, value of t-test for the two-group mean comparison test and p-values for the Fisher's Exact test are reported in Table 1. The results show no significant difference between adopters and non-adopters for the variables related to human capital, household characteristics or access to input dealers in either district. Non-adopters have a significantly higher access to extension services in Mirpur Khas but not in Bahawalpur.

In terms of operated land per farm, higher proportion of Bt cotton adopters are large or medium farms compared to the non-adopters. On the other hand, non-adopters are mostly small farmers compared to the other adopters of Bt cotton in our sample. There is no significant difference in terms of tenure between adopters and non-adopters in the full sample or in either districts. Finally, the adopters experience more yield variability than non-adopters. While this result is statistically significant in the full sample and in Bahawalpur, it is not in Mirpur Khas. In Bahawalpur, 20 percent of the adopters but 55 percent of non-adopters had experienced only inconsequential variability during past three years. These differences suggest that the more extreme these variations, the stronger would be the motivation of farmers to adopt Bt cotton.

Table 2 compares yield per acre, gross-margin, household income per capita and the incidence of poverty of adopters and non-adopters in Bahawalpur and Mirpur Khas. On average, yield per acre, gross margin and household income per capita of adopters are all higher than those of the non-adopters in these two districts. While the incidence of poverty appears to be very similar, it is slightly lower among the adopters than the non-adopters.

Table 1. Characteristics of the Adopters and Non-Adopters of Bt Cotton

	Full sample			**Bahawalpur**			**Mirpur Khas**		
	Adopter	**Non-adopter**	**t-values/ p-values**	**Adopter**	**Non-adopter**	**t-values/ p-values**	**Adopter**	**Non-adopter**	**t-values/ p-values**
Human capital factors									
Age (years)	45.17 (11.29)	42.82 (12.94)	1.05[t]	46.00 (11.17)	42.34 (13.15)	1.32[t]	44.65 (11.41)	44.20 (12.89)	0.06[t]
Education (school years >0 = 1)	0.46 (0.49)	0.48(0.51)	0.54	0.39 (0.49)	0.41 (0.50)	0.84	0.51 (0.50)	0.60 (0.52)	0.74
Household Characteristics									
Household composition									
Household size (number)	7.76 (3.59)	8.26 (3.48)	-0.80[t]	8.17 (3.66)	8.79 (3.52)	-0.79[t]	7.44 (3.49)	6.70 (2.98)	0.73[t]
Male household members 16 years and older (number)	2.51 (1.42)	2.74 (1.63)	-0.81[t]	2.78 (1.36)	3.00 (1.65)	-0.63[t]	2.30 (1.44)	2.00 (1.41)	0.64[t]
Wealth factors									
Own vehicle (yes=1)	0.26 (0.44)	0.36 (0.49)	0.24	0.39 (0.49)	0.38 (0.49)	0.91	0.16 (0.37)	0.30 (0.48)	0.37
Own TV (yes=1)	0.39 (0.48)	0.36 (0.49)	0.9	0.41 (0.49)	0.38 (0.50)	0.81	0.32 (0.47)	0.30 (0.48)	0.88
Have non-farm income source (Yes=1)	0.35 (0.48)	0.33 (0.46)	0.85	0.50 (0.51)	0.35 (0.48)	0.19	0.24 (0.43)	0.30 (0.48)	0.70
Factors related to access to services									

Access to services									
Access to input dealer (distance to input shop > 10km = 1)	0.47 (0.50)	0.59 (0.49)	0.22	0.45 (0.50)	0.62 (0.49)	0.13	0.49 (050)	0.50 (0.53)	0.97
Access to agricultural extension service (Yes=1)	0.34 (0.47)	0.54 (0.51)	0.03***	0.34 (0.48)	0.48 (0.51)	0.18	0.33 (0.47)	0.70 (0.48)	0.036***
	Full sample			**Bahawalpur**			**Mirpur Khas**		
	Adopter	**Non-adopter**	**t-values / p-values**	**Adopter**	**Non-adopter**	**t-values / p-values**	**Adopter**	**Non-adopter**	**t-values / p-values**
Farm characteristics									
Small farmer (< 5 acres=1)	0.42 (0.49)	0.56 (0.50)	0.11*	0.41 (0.49)	0.55 (0.51)	0.27	0.43 (0.50)	0.60 (-0.52)	0.33
Medium farmers (between 5 and 12.5 acres = 1)	0.37 (0.48)	0.38 (0.49)	0.85	0.40 (0.49)	0.38 (0.49)	0.84	0.34 (0.47)	0.40 (0.52)	0.74
Large farmers (>= 12.5 acres=1)	0.16 (0.36)	0.03 (0.16)	0.03***	0.11 (0.31)	0.04 (0.18)	0.43	0.19 (0.39)	0.00	0.20
Owner (Yes=1)	0.58 (0.49)	0.74 (0.44)	0.09**	0.92 (0.28)	0.90 (0.31)	0.84	0.28 (0.45)	0.10 (0.32)	0.45
Yield variability									
High yield variability in last 3 years (yes=1)	0.56 (0.47)	0.26 (0.50)	0.001***	0.58 (0.49)	0.25 (0.44)	0.002***	0.54 (0.50)	0.30 (0.51)	0.19
Low yield variability in last 3 years (yes=1)	0.14 (0.35)	0.18 (0.39)	0.62	0.22 (0.42)	0.20 (0.41)	0.92	0.09 (0.28)	0.10 (0.32)	0.88
Inconsequential yield variability in last 3 years (yes=1)	0.30 (0.46)	0.56 (0.51)	0.003***	0.20 (0.40)	0.55 (0.51)	0.001***	0.37 (0.49)	0.60 (0.52)	0.19

Note: Results are means. Figures in parentheses are standard deviations. t-values are computed for the two-group mean comparison test and p-values are for the Fisher's Exact test. ***, **, * denote statistical significance at the one percent, five percent and ten percent levels, respectively. *t* indicates t-value, otherwise p-values

Table 2. Cotton Farmers' Wellbeing Indicators: Adopters and Non-Adopters

Indicators	Bahawalpur		Mirpur Khas	
	Adopter	Non-Adopter	Adopter	Non-Adopter
Yield (kg/acre)	845	759	873	613
Gross-Margin (Rs./acre)	16,432	13,213	20,776	11,316
Household Income (Rs./cap/month)	2,216	1,215	2,087	1,167
Poverty (Head count)	0.50	0.55	0.54	0.50
Number of Households	74	29	91	12

4. Estimation of Propensity Score and Empirical Results

The propensity score represents the estimated propensity of being an adopter. The dependent variable takes the value of 1 if the household is an adopter of Bt cotton, and 0 otherwise. The larger the score, the more likely the household will adopt Bt cotton. We used a Probit model in this study to estimate the propensity scores. Rubin and Thomas (1996) suggest using all the covariates included in the model to predict the propensity score, even if they are not statistically significant. Separate models are estimated for Bahawalpur and Mirpur Khas and a third model utilizes the data of the full sample. The empirical analysis was performed using the 'STATA' statistical package.

The mean propensity scores for Bahawalpur, Mirpur Khas, and the full sample are 76 percent, 91 percent, and 81 percent, respectively. The diagnostic statistics suggest that the estimated models provide an adequate fit for the data (Table 3). A comparison of results shows that the probability of Bt cotton adoption is determined by different factors in Bahawalpur and Mirpur Khas. For example, longer distance to an input shop and access to agricultural extension have negative effects on the probability of adoption, while high yield variability increases the probability in Bahawalpur. In Mirpur Khas, education, ownership of assets, access to agricultural extension services and small farm size appears to reduce the probability of adoption, while high yield variability again significantly increase Bt cotton adoption. In the full sample, education, access to agricultural extension, yield variability and location appear to be important. A negative and significant district dummy indicates that the probability of adoption is lower if the district is Bahawalpur.

To ensure proper matching of the propensity scores between adopters and non-adopters, the assumptions of unconfoundedness need to be tested by checking the balancing property, after estimating the propensity score. A balancing test was performed using the stratification test suggested by Dehejia and Wahba (1999; 2002). The sample was divided into five blocks based on the predicted propensity score. In each block, the predicted propensity score was tested for the similarity between adopters and non-adopters using the t-test. The propensity score was not statistically different for adopters and non-adopters in these blocks. Once all the blocks are balanced, the individual mean t-test between adopters and non-adopters for each variable was used to predict the propensity score in each block. The low values of t-test show that the distribution of conditioning covariates does not differ across adopters and non-adopters in the matched sample[7]. The balancing property was satisfied for both districts.

[7] These results are not reported here for brevity. However, those can be obtained through the corresponding author.

To make the samples of treated and control groups comparable, matching was undertaken within a region of common support (region of overlap between the propensity scores of treated and non-treated units). The region of common support for Bahawalpur is [.18504992, .96829685] and for Mirpur Khas is [.32751401, .99729959] and for the full sample is [.18504992, .99729959]. The values that do not fall in these ranges were removed from further analysis and the propensity scores were estimated using adopters and matched non-adopters (Sienesi, 2004).

Table 3. Propensity scores for Bt cotton adoption (probit estimates)

	Bahawalpur		**Mirpur Khas**		**Full sample**	
	Coeffi-cient	**z-value**	**Coeffi-cient**	**z-value**	**Coefficient**	**z-value**
Age	0.078	(0.87)	0.171	(1.31)	0.080	(1.14)
Age square	-0.001	(-0.55)	-0.002	(-1.5)	-0.001	(-0.97)
Education (=1 if school years>0)	-0.544	(-1.54)	-0.714*	(-1.78)	-0.485*	(-1.83)
Adult household members(=1 if >15 years)	-0.167	(-1.38)	0.009	(0.05)	-0.064	(-0.67)
Owns a vehicle (yes=1)	0.110	(0.29)	-1.102***	(-2.12)	-0.214	(-0.71)
Owns TV (yes=1)	0.295	(0.86)	0.314	(0.64)	0.323	(1.22)
Non-farm work (yes=1)	0.246	(0.79)	0.054	(0.13)	0.094	(0.38)
Distance to input shop (=1 if distance >10 km)	-0.604**	(-2.08)	0.213	(0.43)	-0.383	(-1.59)
Agriculture extension contact (yes=1)	-0.604*	(-1.64)	-1.200***	(-3.27)	-0.593***	(-2.35)
Small farmer (< 5 acres=1)	-0.145	(-0.38)	-0.757*	(-1.76)	-0.340	(-1.26)
Owner (owner farmer=1)	-0.757	(-0.77)	0.924	(1.35)	0.362	(0.96)
High yield variability in last 3 years (yes=1)	1.06***	(3.12)	0.814**	(2.04)	0.842***	(3.4)
Low yield variability in last 3 years (yes=1)	0.608	(1.56)	0.178	(0.20)	0.401	(1.18)
District (Bahawalpur =1)					-1.151***	(-3.08)
Constant	-0.483	(-0.21)	-0.881	(-0.31)	-0.105	(-0.07)
Model Statistics						
Number of observations	103		103		206	
Log likelihood	-48.47		-24.22		-78.91	
Wald chi-square (df=13)	28.4***		22.05**		42.44***	
Pseudo R^2	0.21		0.26		0.21	
Predicted probability	0.76		0.91		0.81	

Note: The dependent variable is the decision to adopt Bt cotton equals one, zero otherwise. ***, **, * denote statistical significance at the one percent, five percent and ten percent levels, respectively; z-values (in parentheses) are calculated from robust standard errors; df is degrees of freedom (df=13 for the district models and 14 for the full sample).

4. The Impact of Bt Cotton Adoption

Table 4 presents the results for the four common matching methods for the two districts (Table 4A) and the full sample (Table 4B). The statistical significance of the ATT was tested using t-values calculated from bootstrapped standard errors[8]. In Bahawalpur, none of the adopters is dropped when the region of common support is imposed and in Mirpur Khas and in the full sample all households fall in the region of common support. However, the number of matched differ across different matching methods. For example, in Bahawalpur, 74 adopters were matched with 19 non-adopters when nearest neighbour matching method is used. These numbers are 74 and 28 in radius matching and kernel matching and 73 and 29 in stratification matching methods. In Mirpur Khas, 93 adopters are matched with 9 non-adopters in nearest neighbour matching and in other matching methods these numbers are 93 and 10 for adopters and non-adopters, respectively.

The results of full sample (Table 4B) show a positive impact of Bt cotton adoption on farmers' wellbeing. Compared to non-adopters, the adopters experience a significant decline in pesticide expenditure and significant increases in yield, gross margin and per capita household income (for NNM and Radius). However, the impacts of Bt cotton adoption differ at the district-level. For example, in Mirpur Khas, the adopters have a significantly higher yield and gross margin and lower pesticide expenditure than those of the non-adopters. The Bt adopters in Bahawalpur do not experienced a statistically significant increase in yield or gross margin compared to non-adopters. In view of the differential impacts of Bt cotton adoption between these two districts, results pertaining to these districts are mostly presented and discussed below.

The decline in pesticide expenditure by adopters in both districts is driven by a significant decline in number of bollworm sprays (not shown). The adopters have a significantly lower per acre expenditure on bollworm sprays than the non-adopters. The causal effect of Bt cotton adoption on expenditure on bollworm sprays ranges across the four matching methods from -1,638 Rs/acre to -1,671 Rs/acre in Bahawalpur; and from -1,150 Rs/acre to -1,449 Rs/acre in Mirpur Khas.

Per acre seed expenditure is significantly higher for adopters in both districts. Across the matching methods, the adopters pay Rs 477 to Rs 611 per acre more than the non-adopters for seed in Bahawalpur; this range is Rs 358 to Rs 489 per acre in Mirpur Khas. The sum of pest and seed expenditure indicates that the decline in pesticide expenditure is higher than the increase in seed expenditure, with the difference statistically significant in Mirpur Khas using three of the four matching methods.

The higher yield of Bt cotton with little change in total cost results in a higher gross margin. The adopters in Mirpur Khas experience a significantly higher gross margin as compared to non-adopters, ranging from 8,189 Rs/acre to 9,268 Rs/acre. The adopters of Bahawalpur also obtain a higher gross margin (ranging from 89 Rs/acre to 982 Rs/acre). However, no significant advantage to Bt variety is observed for this district. An average difference between the gross margin of similar pairs of adopters and non-adopters in the nearest neighbour matching method is 89 Rs/acre in Bahawalpur i.e., only 0.5 percent higher than the gross margin of the non-adopters and 8,189 Rs/acre in Mirpur Khas (65% percent higher than the non-adopters).

[8] Following Becker and Ichino (2002), the bootstrapped standard errors are calculated using 1000 replications. The estimated standard errors are then used to calculate t-values.

Table 4. Average Treatment Effect for the Treated Across Different Matching Methods (Bahawalpur and Mirpur Khas)

	Bahawalpur				Mirpur Khas			
	Nearest neighbour	Radius	Kernel	Stratification	Nearest neighbour	Radius	Kernel	Stratification
Pesticide expenditure (Rs/acre)	-1,359** (-2.02)	-1,085** (-2.11)	-1,157** (-2.01)	-1,138* (-1.81)	-1,535** (-2.10)	-1,540** (-2.43)	-1,539** (-2.40)	-1,584** (-2.46)
Expenditure on bollworm sprays	-1,668*** (-5.92)	-1,647*** (-6.33)	-1,638*** (-6.01)	-1,671*** (-5.96)	-1,449** (-2.53)	-1,177** (-2.56)	-1,150** (-2.48)	-1,263*** (-2.69)
Expenditure on non-bollworm sprays	308 (0.64)	562 (1.54)	480 (1.18)	533 (1.28)	-85 (-0.23)	-363 (-1.03)	-390 (-1.09)	-321 (-0.91)
Seed expenditure (Rs/acre)	477*** (3.42)	563*** (4.83)	577*** (4.82)	611*** (6.39)	489*** (3.31)	412*** (3.69)	415*** (3.53)	358*** (2.62)
Expenditure on seed and pesticides	-883 (-1.15)	-522 (-0.90)	-581 (-0.93)	-527 (-0.78)	-1,046 (-1.53)	-1,128* (-1.85)	-1,124* (-1.81)	-1,227** (-2.03)
Total expenditure (Rs/acre)	-362 (-0.29)	370 (0.43)	314 (0.31)	447 (0.47)	213 (0.20)	210 (0.21)	233 (0.23)	73 (0.07)
Yield (Kg/acre)	-8 (-0.08)	35 (0.50)	33 (0.41)	40 (0.50)	232*** (5.54)	262*** (7.97)	261*** (7.94)	255*** (7.80)
Gross margin (Rs/acre)	89 (0.04)	883 (0.42)	869 (0.40)	982 (0.42)	8,189*** (6.71)	9,268*** (7.79)	9,222*** (7.88)	9,172*** (7.51)
Per capita income (Rs/month)	964 (0.14)	587 (1.04)	419 (0.69)	576 (0.90)	1,523*** (3.20)	1,140** (2.47)	1,147*** (2.92)	1,157*** (2.66)
Poverty headcount	0.19 (1.31)	0.10 (0.75)	0.13 (0.89)	0.08 (0.53)	-0.27 (-0.85)	0.08 (-.36)	0.08 (0.34)	0.11 (0.50)
Common support region imposed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Balancing property satisfied	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of treated units	74	74	74	73	93	92	93	92
Number of comparison units	19	28	28	29	9	10	10	10

Note: The analysis is conducted using *pscore* module in STATA. ***, **, *denote statistical significance at the one percent, five percent, and ten percent levels, respectively; t-values (in parentheses) are calculated from bootstrapped standard errors.

The matching results for per capita monthly income indicate an insignificant causal effect in Bahawalpur whereas this effect appeared positive and significant in Mirpur Khas. No significant difference in the poverty levels (headcount) of adopters and non-adopters is observed in either district despite the increased per capita income in Mirpur Khas.

Table 5. Average treatment effect for the treated across different matching methods (Full sample)

	Full sample			
	Nearest neighbour	**Radius**	**Kernel**	**Stratification**
Pesticide expenditure (Rs/acre)	-1,082** (-1.98)	-1,587*** (-3.56)	-1,582*** (-3.06)	-1,541*** (-3.29)
Expenditure on bollworm sprays	-1,331*** (-3.36)	-1,527*** (-6.06)	-1,487*** (-5.15)	-1,560*** (-5.92)
Expenditure on non-bollworm sprays	248 (0.81)	-60 (-0.20)	-95 (-0.29)	18 (0.06)
Seed expenditure (Rs/acre)	610*** (5.84)	494*** (6.06)	500*** (6.06)	504*** (6.32)
Expenditure on seed and pesticides (Rs/acre)	-473 (-0.80)	-1,093** (-2.23)	-1,082** (-1.98)	-1,037** (-2.16)
Total expenditure (Rs/acre)	948 (0.98)	-101 (-0.13)	-29 (-0.03)	-121 (-0.16)
Yield (Kg/acre)	186*** (2.94)	129** (2.29)	136** (2.20)	128** (2.21)
Gross margin (Rs/acre)	5,733** (2.37)	4,813*** (3.22)	4,988*** (3.12)	4,833*** (3.07)
Per capita income (Rs/month)	1,666** (2.43)	1,101* (1.76)	1,115 (1.61)	726 (1.05)
Poverty headcount	-0.13 (-0.63)	0.12 (1.08)	0.12 (0.96)	0.10 (0.83)
Common support region imposed	Yes	Yes	Yes	Yes
Balancing property satisfied	Yes	Yes	Yes	Yes
Number of treated units	167	167	167	166
Number of comparison units	29	38	38	39

Note: The analysis is conducted using *pscore* module in STATA.
***, **, *denote statistical significance at the one percent, five percent, and ten percent levels, respectively; t-values (in parentheses) are calculated from bootstrapped standard errors.

Do the choice of matching methods matter? Results presented in Table 5 reveal that different matching methods produced somewhat different quantitative results (point estimates). However, there are no changes in the statistical significance of the coefficients at standard confidence levels. Overall, the matching estimates indicate that the adoption of Bt cotton increases the wellbeing of cotton farmers by reducing pesticide expenditure on bollworm sprays and by increasing yields, gross margins and per capita incomes. The increase in income, however, is not enough to reduce poverty significantly. The results demonstrate that the impacts of Bt technology are rather uneven and vary across districts. This technology appears to be more effective in humid region of Pakistan, such as Mirpur Khas compared to the relatively dry region such as Bahawalpur. These results indicate that the relative magnitudes of the benefits of Bt cotton depend on the weather conditions and pest pressure, both of which may vary across districts/regions and even for the same district/region over time.

Table 6. Impact of Bt Cotton Adoption on Household Wellbeing Across Operating Land Categories Using PSM-Nearest Neighbour Method

	Small farmers (≤ 5 acres)	**Large farmers (> 5 acres)**
Pesticide expenditure (Rs/acre)	-1,849*** (-3.62)	-1,015 (-0.94)
Expenditure on bollworm sprays	-1,529*** (-4.25)	-1,551*** (-3.75)
Expenditure on non-bollworm sprays	-320 (-1.11)	536 (0.68)
Seed expenditure (Rs/acre)	374*** (3.30)	562*** (3.39)
Expenditure on seed and pesticides (Rs/acre)	-1,475*** (-2.94)	-454 (-0.38)
Total expenditure (Rs/acre)	-732 (-0.91)	731 (0.39)
Yield (Kg/acre)	125* (1.88)	246** (2.02)
Gross margin (Rs/acre)	5,230*** (2.68)	8,094* (1.77)
Per capita income (Rs/acre)	-182 (-0.68)	2,698* (1.76)
Poverty headcount	0.27 (1.41)	-0.32 (-1.12)
Number of treated units	70	97
Number of comparison units	16	14
Total matched units	86	111

Note: ***, ** * denote statistical significance at one percent, five percent and ten percent levels, respectively. The t-values (in parentheses) are calculated from bootstrapped standard errors.

The results presented in Table 3 indicate that the adoption of Bt cotton contributes to improving the yield and the gross margin from the cotton crop significantly. But the impacts of adoption on per capita household income or on poverty are not very strong. Why have significant increases in yield and gross margin not led to increase in income and reduce poverty in Pakistan? We attempted to examine this issue further by dividing farmers into groups based on the size of their operation. Due to data paucity, we put farmers into two groups only, small farmers who operate up to 5 acres and medium and large farmers who operate more than 5 acres. Because of small control group in Mirpur Khas across the size of operated land, this analysis is conducted on the full sample of 206 households. The estimated ATT based on the PSM-nearest neighbour method by farm size is reported in Table 6. The adopters irrespective of the groups experienced a significant decline in expenditure on bollworm sprays and an increase in seed costs per acre. They also enjoyed a statistically significant increase in per acre yields and gross margin. However, the impact of Bt cotton adoption on yield is lower (125 Kg/acre) for small farmers than for large farmers (246 Kg/acre). While Bt cotton adoption has a significant positive impact on household income for medium and large farmers, it is essentially zero for the small farmers. The result pertaining to the impact of Bt cotton adoption on yield obtained in this study is not in line with the findings of Ali and Abdulai (2010) who reported a larger gain in yield per acre for small farmers compared to medium and large farmers. As indicated earlier, our data set is newer and more inclusive in the sense that it represents both cotton growing regions in Pakistan. We believe the smaller effect on small farmers is a credible result for a cash crop like cotton in Pakistan. The results show that the small adopting farmers reduce pesticide expenditures more and increase seed expenditures less than large farmers. Considering the differences in capacity to access relevant information and input uses, small famers may be less informed than large farmers. For example, both the Pakistan Agricultural Research Council (2008) and the Bt cotton Survey 2009 found that most small farmers believe Bt cotton has resistance against all kind of pests. This is not true and could potentially lead to sub-optimal use of pesticides. Moreover, because of binding financial constraints small farmers are less likely to purchase and apply appropriate fertilizer and pest control at the right time compared to the large farmers in Pakistan. All these factors can contribute to lower yields for small farmers relative to large farmers; this effect is carried into the smaller gains for other wellbeing indicators they achieve from adopting Bt cotton. While the survey data we used did not provide enough information to probe deeper into these issues, some suggestive results can be found in Tables 4 and 5.

6. Concluding Remarks

It is widely held in the development literature that the diffusion of a productivity enhancing technology can reduce poverty. However, the relationship between technology adoption and the realization of a set of desirable outcomes in reality can be complicated due to the involvement of some region-specific and crop-specific factors. Using data from a household survey of cotton farmers in Punjab and Sindh, two notable cotton producing regions in Pakistan, we examine the causal effects of Bt cotton adoption on pesticide expenditures, yield, gross-margin and poverty in Pakistan. Given the non-experimental nature of the data, a propensity score matching model was used to address selectivity bias and estimate reliable causal effects of Bt cotton adoption on the wellbeing of cotton farmers in Pakistan.

The results show that the adoption of Bt cotton has statistically significant effects on three of the four wellbeing outcomes for cotton farmers in Pakistan. The results are broadly consistent with those of Crost *et al.* (2007) for India and Ali and Abdulai (2010) for Pakistan. Our results are in line with Spielman et al. (2015) who also demonstrate that the agro-climatic factors significantly influence the wellbeing outcomes for Bt cotton adopters in Pakistan. In particular, the impacts of adoption were found to be was found to be larger and more significant under hot and humid conditions in Mirpur Khas than under hot and dry climatic conditions of Bahawalpur. Demonstrating this diversity in regional effects is unique among studies for Pakistan and are consistent with similar findings related to the performance of Bt cotton in India (Gandhi & Namboodiri, 2006; Qaim *et al*., 2006; Pemsl, 2006). A direct implication of this result is that regular monitoring and evaluation of pest infestations across agro-climatic regions are needed to harness the full potential of the Bt cotton technology in Pakistan. Our results also revealed that yield gains are lower for small farmers than for medium and large farmers. This result is contrary to the findings of Ali and Abdulai (2010). While we believe that our finding is more plausible than that of Ali and Abdulai (2010), this issue needs to be further investigated so that the promise of widespread gains from the adoption of Bt technology is fully realized by cotton farmers' in Pakistan.

Acknowledgement

An earlier version of this paper was presented at the 28th Triennial International Conference of Agricultural Economists in Foz do Iguaçu, Brazil, August 18-24 2012. A revised version of that article has been published as a Working Paper No. 004 in September 2012 by the International Food Policy Research Institute (IFPRI), Washington, D.C. Helpful comments from several conference participants and some colleagues at IFPRI are gratefully acknowledged. Partial financial and in-kind supports from Innovative Development Strategies Ltd., Islamabad, the Institute for Society, Culture and Environment, Virginia Tech, Arlington, Virginia,Ontario Ministry of Agriculture, Food and Rural Affairs, Canada and the Pakistan Agricultural Research Council received for this project are also gratefully acknowledged. The usual disclaimer applies.

References

Adekambi, S., Adéyèmi, Diagne, A., F. P., & Biaou, G. (2009). The Impact of Agricultural Technology Adoption on Poverty: The case of NERICA rice varieties in Benin. *Paper presented at the International Association of Agricultural Economists' 2009 Conference, Beijing, China, August 16-22, 2009.*

Ali, A. & Awudu A. (2010). The Adoption of Genetically Modified Cotton and Poverty Reduction in Pakistan. *Journal of Agricultural Economics* Vol. 61, No. 1, 175–192

Arshad, M., Suhail, A., Gogi, M. D., Yaseen, M., Asghar, M., Tayyib, M., Karar, Haider, K. Hafeez, F. & Ullah, U. N. (2009). Farmers' perceptions of insect pests and pest management practices in Bt cotton in the Punjab, Pakistan. *International Journal of Pest Management*, 55:1, 1 – 10.

Becerril, J. & Awudu A. (2010).The Impact of Improved Maize Varieties on Poverty in Mexico: A Propensity Score-Matching Approach. *World Development* Volume 38, Issue 7, July 2010, Pages 1024-1035

Becker, S.O. & Ichino. A. (2002). Estimation of average treatment effects based on propensity scores. *The Stata Journal*, 2 (4): 358–377.

Caliendo, M. & Kopeinig, S. (2008). Some practical guidance for the implementation of propensity score matching, *Journal of Economic Surveys*, Vol. 22, (2008) pp. 31–72.

Crost, B., Shankar, B., Bennett, R., & Morse, S (2007). Bias from Farmer Self-Selection in Genetically Modified Crop Productivity Estimates: Evidence from Indian Data. *Journal of Agricultural Economics*, Vol. 58, No. 1, 2007, 24–36.

Dehejia, R., & Wahba, S. (1999). Causal Effects in Nonexperimental Studies: Reevaluating the Evaluation of Training Programs, *Journal of the American Statistical Association*, 94, 1053-1062.

Dehejia, R., & Wahba, S. (2002). Propensity score-matching methods for nonexperimental causal studies. *The Review of Economics and Statistics*, 84 (1): 151–161.

Gandhi, V., & Namboodiri, N. (2006). *The Adoption and Economics of Bt Cotton in India: Preliminary Results from a Study*, Working Paper No. 20006-09-04. Indian Institute of Management, Ahmedabad.

González, V., Pablo, I., Maffioli, A, & Rozo, S. (2009). *The Impact of Technology Adoption on Agricultural Productivity: The Case of the Dominican Republic*, OVE Working Papers 0509, Inter-American Development Bank, Office of Evaluation and Oversight (OVE), Washington, D.C..

Government of Pakistan (GoP). 2011. *Pakistan Economic Survey 2010-11*. Federal Bureau of Statistics, Government of Pakistan.

Government of Pakistan (GoP). 2009. *Census of Manufacturing Industries 2005-2006*. Federal Bureau of Statistics, Government of Pakistan.

Hayee, A. (2004). *Cultivation of Bt Cotton - Pakistan's Experience*. Action Aid, Pakistan.

James, Clive. 2011. Global Status of Commercialized Biotech/GM Crops: 2010. *ISAAA Brief* No. 43. ISAAA: Ithaca, NY.

Kassie, M., Bekele S., & Muricho. G. (2010). *Adoption and Impact of Improved Groundnut Varieties on Rural Poverty: Evidence from Rural Uganda.* Discussion Paper Series, EfD-DP 10-11. Environment for Development

Kouser, S. & Qaim, M. (2012). Valuing financial, health, and environmental benefits of Bt cotton in Pakistan. Discussion paper No. 105. Courant Research Centre, Georg-August-University of Goettingen

Lechner, M., (2002). Program Heterogeneity and Propensity Score Matching: An Application to the Evaluation of Active Labor Market Policies, *Review Economics and Statistics*, 84(2): 205-220, May.

Mendola, M. (2007). Agricultural technology adoption and poverty reduction: A propensity-score matching analysis for rural Bangladesh. *Food Policy*. Volume 32, Issue 3, 372-393.

Morse, S., Bennett, R. & Ismael, Y. (2007). Isolating the 'farmer' effect as a component of the advantage of growing genetically modified varieties in developing countries: a Bt cotton case study from Jalgaon, India. *Journal of Agricultural Science* (2007), 145, 491–500.

Nazli, H. (2011). *Impact of Bt Cotton Adoption on Farmers' Wellbeing in Pakistan*. Unpublished PhD Dissertation, Food Agricultural and Resource Economics, University of Guelph, Canada.

Otsuki, T. (2010). *Estimating Agroforestry's Effect on Productivity in Kenya: An Application of a Treatment Effects Model*. OSIPP Discussion Paper : DP-2010-E-001

PARC (2008). *Status of Cotton Harboring Bt Gene in Pakistan*. Institute of Agr-Biotechnology & Genetic Resources, National Agricultural Research Centre, Pakistan Agricultural Research Council, Islamabad.

Pemsl, D. (2006) *Economics of Agricultural biotechnology in Crop Protection in Developing Countries - The Case of Bt Cotton in Shandong Province, China*, Publication Series, Special Issue No. 11, Hannover, Pesticide Policy Project.

Qaim, M. Subramanian, A. Naik, G., , & Zilberman, D. (2006). Adoption of Bt cotton and impact variability: insights from India. *Review of Agricultural Economics.* 28, 48-58.

Rosenbaum, P.R. & Rubin, D.B. (1983). The central role of the propensity score in observational studies for casual effects. *Biometrika*, 70 (1): 41-55.

Rosenbaum, P.R. & Rubin, D.B. (1985). Constructing a control group using multivariate matched sampling methods that incorporate the propensity score. *The American Statistician*, 39(1): 33-38.

Rubin, D.B. & Thomas, N. (1996). Matching using estimated propensity scores: relating theory to practice. *Biometrics* 52(1): 249–264.

Sheikh, A. D., Mahmood, M. A., Hussain, A., Bashir, A. & Saeed, R. 2008. *Bt-Cotton Situation in Punjab*. Technology Transfer Institute. Faisalabad.

Sianesi, B. (2004). An Evaluation of the Active Labour Market Programmes in Sweden. *The Review of Economics and Statistics*, 86(1), 133-155.

Spielman, D.J., Nazli, H., Ma, X., Zambrano, P., & Zaidi, F. (2015). Technological opportunity, regulatory uncertainty, and Bt cotton in Pakistan. *AgBioForum*, *18*(1), 98-112.

Thirtle, C., Beyers, L., Ismael, Y., & Piesse.J. (2003). Can GM-technologies help the poor? The impact of Bt cotton in Makhathini Flats, KwaZulu-Natal. *World Development* 31 (4): 717–732.

Wu, H., Ding, S., Pandey, S., & Tao, D. (2010). Assessing the Impact of Agricultural Technology Adoption on Farmers' Well-being Using Propensity-Score Matching Analysis in Rural China. *Asian Economic Journal 2010, Vol. 24 No. 2, 141–160*