Bt Cotton Adoption and Wellbeing of Farmers in Pakistan

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Abstract

Among the four largest cotton-producing countries, only Pakistan had not commercially adopted Bt cotton by 2010. However, the cultivation of first-generation (Cry1Ac) Bt cotton, unapproved and unregulated, increased rapidly after 2005. Using the propensity score matching method, this paper examines the economic impact of the available Bt varieties on farmers' wellbeing. The analysis is based on data collected through structured questionnaires in January-February 2009 from 206 growers in 16 villages in two cotton-growing districts, Bahawalpur and Mirpur Khas. The results indicate a positive impact of Bt cotton on the wellbeing of farmers in Pakistan. However, the extent of impact varies by agro-climatic conditions and size of farm. Bt cotton appeared most effective in the hot and humid areas where pest pressure from bollworms is high. The per-acre yield gains for medium and large farmers are higher than for small farmers. This suggests that additional public-sector interventions may be complementary to introduction of Bt cotton to make this technology widely beneficial in Pakistan.

Keyword

Bt cotton, Pakistan, propensity score matching, selection bias

1. Introduction

Pakistan is the world's fourth largest producer and the third largest consumer of cotton. Its production is important to Pakistan's agriculture and the overall economy. Nearly 26 percent of farmers grow cotton, and over 15 percent of total cultivated area is devoted to this crop, with production primarily in two provinces: Punjab (80%), which has dry conditions, and Sindh (20%), which has a more humid climate. Cotton and its products (yarn, textiles and apparel) contribute significantly to the gross domestic product (8%), total employment (17%), and, particularly, foreign exchange earnings (54%) of the country (Government of Pakistan, 2009; 2011). However, cotton production in Pakistan faces significant pest damage causing fluctuations in cotton yields and economic losses. Pest losses in Pakistan arise not only from bollworms, which are susceptible to control 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. Advanced Bt cotton varieties are available in China and India. Nonetheless, despite several administrative and research efforts during the last decade, Pakistan did not commercially approve any biotech cotton variety until 2010[1]. The delay in the approval for commercialization has resulted in the unregulated adoption of Bt cotton varieties in Pakistan. In 2007 nearly 60 percent of cotton area was under these varieties (PARC 2008). In 2011 this proportion increased to 85 percent (James 2011). The unapproved varieties were developed domestically using the Cry1Ac gene and distributed without a formal regulatory framework,

[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.

which raises several concerns about seed quality, management awareness among farmers, and biosafety.

Several studies have made preliminary comparisons of the performance of existing Bt type varieties with the recommended non-Bt varieties in Pakistan based on semi-structured questionnaires and informal interviews (Hayee, 2004; Sheikh *et al.,* 2008; Arshad *et al.,* 2009). These studies observe a relatively poor performance of existing Bt cotton compared to the recommended conventional varieties. Such preliminary results raise two major questions: If there has been lower profitability, why has the adoption of Bt varieties increased over time? And, what is the impact of Bt cotton adoption on farmers' wellbeing? Only two studies provide a systematic positive assessment of the effects of the current Bt cotton adoption in Pakistan (Ali and Abdulai, 2010; Kouser and Qaim, 2012).

This paper further examines the impact of Bt cotton varieties on farmers' well-being in Pakistan, where wellbeing is defined in terms of outcome variables such as pesticide usage, yield and gross margin[2] per acre, per capita income, and poverty headcount[3]. 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) causes by a non-bollworm pest, white fly), and a policy environment influenced by reports about Indian farmers' suicides due to Bt cotton crop failures and other adverse publicity, has raised caution and apprehension about the commercial adoption of Bt cotton in Pakistan. Given these circumstances, the evidence presented herein provides a

[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.

needed assessment of the impact of the available Bt cotton varieties[4]. The analysis is based on a survey of cotton farmers, conducted during January-February 2009 in two districts of Pakistan.

Among the many studies that have analyzed the impact of Bt cotton in developing countries, the results are mainly limited to a comparison of the average outcomes for adopters and non-adopters. However, when the samples are drawn using a non-experimental design the selection of subjects is not random and the problem of self-selection arises. In this situation, it is difficult to isolate the effect of technology from other factors that can affect the decision of adoption. In the presence of selection bias, the comparison of means can provide misleading results (Thirtle *et al.,* 2003; Crost *et al.,* 2007; Morse *et al.,* 2007a; Ali and Abdulai, 2010). To address the problem of selection bias, two-stage models are commonly applied. In the first stage, the decision model is estimated; and in the second stage, the results of the first stage are used to estimate the impact of decision on the outcome variables.

In this paper the propensity score matching method (PSM) is used to address the self-selection bias. This method takes into account the counterfactual situation: "how much did the adopters benefit from Bt cotton compared to the situation if they had not adopted". 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. Moreover, the effects differ by location (climate and pest pressure) and between large and small farms.

The paper is divided in five sections. Section 2 presents the framework for estimating adoption decisions and impact assessment. Section 3 describes the data. Results are discussed in Section 4. Conclusions and policy implications are presented in Section 5.

[4] Some of these varieties have been approved for commercial adoption for the 2010 cotton crop.

2. Analytic Framework

Let technology adopters be the "treated group", where "treatment" refers to the decision of adoption, and non-adopters are 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:

$$\tau_i = y_{1i} - y_{0i} \quad (1)$$

In non-experimental studies, where assignment of treatment is not random, the impact evaluation of a treatment can suffer from two problems. The first is the selection problem, i.e., individuals select themselves into treatment if they perceive the expected utility of profit of treatment $EU(\pi_{i1})$ minus its cost is larger than the expected utility of not being treated $EU(\pi_{i0})$, i.e., $EU(\pi_{i1} - C) - EU(\pi_{i0}) > 0$. The second is the evaluation problem, i.e., for the same individual, either y_{1i} is observed or y_{0i}, so the counterfactual outcome is always missing for the individual.

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 and 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) unconfoundedness and (ii) common support. The condition of unconfoundedness states that outcomes y_{1i}, y_{0i} are independent of the actual treatment status *I* given a set of observables, *X*.:

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

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:

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

When these two assumptions are satisfied, the experimental and non-experimental analyses identify the same parameters and then 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)*:

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

There are two key properties of propensity scores: first, propensity scores are balancing scores. This property 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 together reduce the problem of high dimensionality and matching can be performed on propensity score *p(X)* alone rather than on the full set of covariates.

Any discrete choice model, such as a logit or probit model, can be used to estimate the propensity score. The *ATT* is then estimated by matching the treated group with the control group based on the estimated propensity scores. Four 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 and Kopeinig 2008). These estimation steps add variation beyond the normal sampling variation. One solution (Lechner, 2002) 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. This paper uses the bootstrapping method to obtain the standard errors of the *ATT*.

3. Data

To examine the economic impact of the adoption of unapproved Bt varieties on costs of production and yields, a questionnaire-based survey ("Bt Cotton Survey 2009") was conducted during January-February 2009 in two cotton growing districts of Pakistan: Bahawalpur in province Punjab; and Mirpur Khas in province Sindh[5]. The selected sample is drawn from the existing sampling frame of the Pakistan Rural Household Survey (PRHS)[6]. Out of four cotton districts in the PRHS, the Bt Cotton Survey 2009 was conducted in two districts where the number of cotton growers was sufficient in the sample. This 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 is also different. Low temperature and high relative humidity cause an increase in the bollworm population susceptible to control with Bt seeds, and decline in the population of sucking pests, which are not. Bahawalpur has a hot and dry climate and Mirpur Khas has a hot and humid climate. Average rainfall is low in both districts. Approximately two-thirds of the Bahawalpur district is covered by desert. Canals are the main source of irrigation in both districts. The two districts were selected to reflect the diversity of Pakistan's cotton growing areas in terms of pest pressure.

Information on cost of inputs, cotton output, revenue from cotton sales, and total household income were collected through a structured questionnaire. Farm operator, household,

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

and farm characteristics were also collected. The sample was comprised of Bt adopters as well non-adopters. Nazli (2011) provides full details of the survey design and implementation.

4. Results

The data indicates that the majority of farms are small. Nearly 82 percent of the surveyed farmers operate less than 12.5 acres of land. Most are concentrated in the category less than 5 acres in both districts. These districts differ in the type of land tenure. A majority of farmers in Bahawalpur are owners (77.9%) while most of the farmers in Mirpur Khas are sharecroppers (73.1%). A majority of the sharecroppers indicated that the landlord provides 50 percent of the inputs except labour and the sharecropper is responsible for 50 percent of the inputs and their timely use. 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 Mirpur Khas (32%). However, in 2008, about 87 percent of the farmers in Mirpur Khas cultivated Bt cotton whereas this proportion was 74 percent Bahawalpur.

4.1 Descriptive statistics

As described above, the choice of explanatory variables (i.e., conditioning variables) in predicting propensity scores is crucial in propensity score matching analysis. The selection of covariates should fulfill the assumption of unconfoundedness. Therefore, there is a need to select variables that influence both treatment and outcomes, but are not affected by the treatment (Caliendo and Kopeinig, 2008). The variables employed in this study are based on previous research that has examined the impact of technology adoption on farmers' wellbeing in developing countries taking self-selection into account 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: human capital factors (age and education of a farmer); household characteristics (composition, wealth); accessibility factors (access to inputs and information); farm characteristics (operated land; type of tenure); and yield variation.

Table 1 provides the mean and standard deviation for the variables used in the decision model. Adopters are 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. Agriculture extension workers were likely still promoting non-Bt cotton varieties in Pakistan in 2008. Non-adopters have a significantly higher access to extension services in Mirpur Khas, whereas in Bahawalpur the estimated difference is of similar magnitude but is not significant.

The disaggregation of operated land by farm size in the full sample shows a significantly higher proportion of adopters operate large farms compared to the proportion of non-adopters who are large farmers. Conversely, a significantly higher share of non-adopters is small farmers compared to the share of adopters who are small farmers. The differences are similar but not significant in the separate results for either district. Type of tenure is not statistically different between adopters and non-adopters in the full sample or in either district.

Table 1: Characteristics of adopters and non-adopters

	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	42.82	1.05^{t}	46.00	42.34	1.32^{t}	44.65	44.20	0.06^{t}
	(11.29)	(12.94)		(11.17)	(13.15)		(11.41)	(12.89)	
Education (school years >0 = 1)	0.46	0.48	0.54	0.39	0.41	0.84	0.51	0.60	0.74
	(0.49)	(0.51)		(0.49)	(0.50)		(0.50)	(0.52)	
Household characteristics									
Household composition									
Household size (number)	7.76	8.26	-0.80^{t}	8.17	8.79	-0.79^{t}	7.44	6.70	0.73^{t}
	(3.59)	(3.48)		(3.66)	(3.52)		(3.49)	(2.98)	
Male household members 16 years and older (number)	2.51	2.74	-0.81^{t}	2.78	3.00	-0.63^{t}	2.30	2.00	0.64^{t}
	(1.42)	(1.63)		(1.36)	(1.65)		(1.44)	(1.41)	
Wealth factors									
Own vehicle (yes=1)	0.26	0.36	0.24	0.39	0.38	0.91	0.16	0.30	0.37
	(0.44)	(0.49)		(0.49)	(0.49)		(0.37)	(0.48)	
Own TV (yes=1)	0.39	0.36	0.9	0.41	0.38	0.81	0.32	0.30	0.88
	(0.48)	(0.49)		(0.49)	(0.50)		(0.47)	(0.48)	
Have non-farm income source (Yes=1)	0.35	0.33	0.85	0.50	0.35	0.19	0.24	0.30	0.70
	(0.48)	(0.46)		(0.51)	(0.48)		(0.43)	(0.48)	
Factors related to access to services									
Access to services									
Access to input dealer (distance to input shop > 10km = 1)	0.47	0.59	0.22	0.45	0.62	0.13	0.49	0.50	0.97
	(0.50)	(0.49)		(0.50)	(0.49)		(0.50)	(0.53)	
Access to agricultural extension service (Yes=1)	0.34	0.54	0.03***	0.34	0.48	0.18	0.33	0.70	0.036***
	(0.47)	(0.51)		(0.48)	(0.51)		(0.47)	(0.48)	

	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	0.56	0.11*	0.41	0.55	0.27	0.43	0.60	0.33
	(0.49)	(0.50)		(0.49)	(0.51)		(0.50)	(-0.52)	
Medium farmers (between 5 and 12.5 acres = 1)	0.37	0.38	0.85	0.40	0.38	0.84	0.34	0.40	0.74
	(0.48)	(0.49)		(0.49)	(0.49)		(0.47)	(0.52)	
Large farmers (>= 12.5 acres=1)	0.16	0.03	0.03***	0.11	0.04	0.43	0.19	0.00	0.20
	(0.36)	(0.16)		(0.31)	(0.18)		(0.39)		
Owner (Yes=1)	0.58	0.74	0.09**	0.92	0.90	0.84	0.28	0.10	0.45
	(0.49)	(0.44)		(0.28)	(0.31)		(0.45)	(0.32)	
Yield variability									
High yield variability in last 3 years (yes=1)	0.56	0.26	0.001***	0.58	0.25	0.002***	0.54	0.30	0.19
	(0..47)	(0.50)		(0..49)	(0.44)		(0.50)	(0.51)	
Low yield variability in last 3 years (yes=1)	0.14	0.18	0.62	0.22	0.20	0.92	0.09	0.10	0.88
	(0.35)	(0.39)		(0.42)	(0.41)		(0.28)	(0.32)	
Inconsequential yield variability in last 3 years (yes=1)	0.30	0.56	0.003***	0.20	0.55	0.001***	0.37	0.60	0.19
	(0.46)	(0.51)		(0.40)	(0.51)		(0.49)	(0.52)	

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

The breakdown of the yield variability variable among adopters and non-adopters shows that in Bahawalpur 58 percent of adopters versus 25 percent of non-adopters had experienced high variability over the past three years, similar percentages (20 to 22) had experienced low variability, and 20 percent of adopters but 55 percent of non-adopters had experienced only inconsequential variability. These differences between percentages of adopters versus non-adopters facing high or inconsequential variability are statistically significant, suggesting the more extreme situations motivate farmers to adopt Bt cotton or remain with conventional varieties, respectively. These results are reflected in the full sample as well, whereas in Mirpur Khas the differences related to variability of past yields are of similar direction but are not significant.

4.2. Estimation of propensity score

A Probit model is applied 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. 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, and 0 otherwise: the larger the score, the more likely the individual would be to adopt Bt cotton. Separate models are estimated for Bahawalpur and Mirpur Khas and a third model utilizes the data of the full sample.

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 2).

Table 2: 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).

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.

Testing for unconfoundedness and common support

After estimating the propensity score, the assumptions of unconfoundedness is tested by checking the balancing property. A balancing test is performed using the stratification test suggested by Dehejia and Wahba (1999; 2002). The sample is divided into five blocks based on the predicted propensity score. In each block, the predicted propensity score is tested for the similarity between adopters and non-adopters using the t-test. The propensity score does not appear 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 used to predict the propensity score is performed 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 is satisfied for both districts.

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,

[7] These results are not reported here.

.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 are discarded.

4.3 Estimation of the Impact of Bt Cotton Adoption

Table 3 presents the results for the four common matching methods for the two districts (Table 3A) and the full sample (Table 3B). 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[9]. 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 3B) show a positive impact of Bt cotton adoption on farmers' wellbeing. As compared to non-adopters, the adopters experience a significant decline in pesticide expenditure and significant increases in yield, gross margin and (for two matching methods) per capita household income. However, the district-level results show that the extent of the impact of Bt cotton adoption differ. For example, in Mirpur Khas, the adopters have a significantly higher yield and gross margin and lower pesticide expenditure than their

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

[9] The sample of Bahawalpur consists of 74 adopters and 29 non-adopters and there were 93 adopters and 10 non-adopters in the sample of Mirpur Khas.

counterparts among 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 across the districts, the analysis presented below is based on district-level results (Table 3A).

Impact on pesticide expenditure: 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.

Impact on seed expenditure: 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.

Impact on total cost of cotton production: The causal effects for total cost of cotton cultivation (including such costs as land preparation, irrigation, fertilizer and labor (including cultivation and picking) in addition to pesticides and seeds) appeared positive but insignificant in both districts. The range of these effects across the four matching methods is -362 Rs/acre (the only negative estimate) to 447 Rs/acre in Bahawalpur and 73 Rs/acre to 233 Rs/acre in Mirpur Khas.

Table 3A: Average treatment effect for the treated across different matching methods (Bahawalpur and Mirpur Khas)

	Bahawalpur				Mirpur Khas			
	Nearest neighbour	**Radius**	**Kernel**	**Stratificat ion**	**Nearest neighbour**	**Radius**	**Kernel**	**Stratificat ion**
Pesticide expenditure (Rs/acre)	-1,359**	-1,085**	-1,157**	-1,138*	-1,535**	-1,540**	-1,539**	-1,584**
	(-2.02)	(-2.11)	(-2.01)	(-1.81)	(-2.10)	(-2.43)	(-2.40)	(-2.46)
Expenditure on bollworm sprays	-1,668***	-1,647***	-1,638***	-1,671***	-1,449**	-1,177**	-1,150**	-1,263***
	(-5.92)	(-6.33)	(-6.01)	(-5.96)	(-2.53)	(-2.56)	(-2.48)	(-2.69)
Expenditure on non-bollworm sprays	308	562	480	533	-85	-363	-390	-321
	(0.64)	(1.54)	(1.18)	(1.28)	(-0.23)	(-1.03)	(-1.09)	(-0.91)
Seed expenditure (Rs/acre)	477***	563***	577***	611***	489***	412***	415***	358***
	(3.42)	(4.83)	(4.82)	(6.39)	(3.31)	(3.69)	(3.53)	(2.62)
Expenditure on seed and pesticides	-883	-522	-581	-527	-1,046	-1,128*	-1,124*	-1,227**
	(-1.15)	(-0.90)	(-0.93)	(-0.78)	(-1.53)	(-1.85)	(-1.81)	(-2.03)
Total expenditure (Rs/acre)	-362	370	314	447	213	210	233	73
	(-0.29)	(0.43)	(0.31)	(0.47)	(0.20)	(0.21)	(0.23)	(0.07)
Yield (Kg/acre)	-8	35	33	40	232***	262***	261***	255***
	(-0.08)	(0.50)	(0.41)	(0.50)	(5.54)	(7.97)	(7.94)	(7.80)
Gross margin (Rs/acre)	89	883	869	982	8,189***	9,268***	9,222***	9,172***
	(0.04)	(0.42)	(0.40)	(0.42)	(6.71)	(7.79)	(7.88)	(7.51)
Per capita income (Rs/month)	964	587	419	576	1,523***	1,140**	1,147***	1,157***
	(0.14)	(1.04)	(0.69)	(0.90)	(3.20)	(2.47)	(2.92)	(2.66)
Poverty headcount	0.19	0.10	0.13	0.08	-0.27	0.08	0.08	0.11
	(1.31)	(0.75)	(0.89)	(0.53)	(-0.85)	(0.36)	(0.34)	(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.

Table 3B: 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**	-1,587***	-1,582***	-1,541***
	(-1.98)	(-3.56)	(-3.06)	(-3.29)
Expenditure on bollworm sprays	-1,331***	-1,527***	-1,487***	-1,560***
	(-3.36)	(-6.06)	(-5.15)	(-5.92)
Expenditure on non-bollworm sprays	248	-60	-95	18
	(0.81)	(-0.20)	(-0.29)	(0.06)
Seed expenditure (Rs/acre)	610***	494***	500***	504***
	(5.84)	(6.06)	(6.06)	(6.32)
Expenditure on seed and pesticides (Rs/acre)	-473	-1,093**	-1,082**	-1,037**
	(-0.80)	(-2.23)	(-1.98)	(-2.16)
Total expenditure (Rs/acre)	948	-101	-29	-121
	(0.98)	(-0.13)	(-0.03)	(-0.16)
Yield (Kg/acre)	186***	129**	136**	128**
	(2.94)	(2.29)	(2.20)	(2.21)
Gross margin (Rs/acre)	5,733**	4,813***	4,988***	4,833***
	(2.37)	(3.22)	(3.12)	(3.07)
Per capita income (Rs/month)	1,666**	1,101*	1,115	726
	(2.43)	(1.76)	(1.61)	(1.05)
Poverty headcount	-0.13	0.12	0.12	0.10
	(-0.63)	(1.08)	(0.96)	(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.

Impact on yield: Table 3A shows that adopters have a higher yield than the non-adopters in both districts with the exception of nearest neighbour method in Bahawalpur. The difference in yield is significant only in Mirpur Khas (ranging between 232 kg/acre to 262 kg/acre).

Impact on gross margin: 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).

Impact on household income and poverty headcount: 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 3 shows 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 is not enough to reduce poverty significantly. The results show an uneven impact of Bt technology across districts. This technology appears more effective in humid Mirpur Khas as compared to dry Bahawalpur. These results indicates that the relative magnitudes of the benefits of Bt cotton depend on the weather conditions and pest pressure, both of which may differ not only across districts/regions but also among years even in the same district/region.

A comparison with difference of means method

Table 4 provides a comparison of the adoption effect estimated by the PSM method using nearest neighbour method and by the simple difference of means method. Comparing the results of these two methods for the full sample indicates that the difference between adopters and non-adopters is over-estimated by the difference of means method for the outcome variables with the exception of seed expenditure, yield and per capita income. The difference in means method suggests statistically significant decreases in expenditures for seed and pesticides and total expenditure. These effects are not statistically significant with PSM. Similar results are found for Bahawalpur. For example, the pesticide expenditure reduction is much more for adopters in the difference of means method (-1,681 Rs/acre versus -1,359 Rs/acre after controlling for selection bias). A striking difference is observed for gross margin across the two methods in Bahawalpur. The difference of means method shows much higher gross margin and per capita income for adopters than the non-adopters (3,219 Rs/acre and 1,002 Rs/acre, respectively). However, applying the PSM these estimated differences are only 89Rs/acre and 96 Rs/acre and are not significantly different from zero.

Table 4: Comparison of ATT across different estimation techniques

	Bahawalpur		Mirpur Khas		Full sample	
	PSM-Nearest neighbour	**Difference of mean**	**PSM-Nearest neighbour**	**Difference of mean**	**PSM-Nearest neighbour**	**Difference of mean**
Pesticide expenditure (Rs/acre)	-1,359**	-1,681***	-1,535**	-1,199**	-1,082**	-2,219***
	(-2.02)	(3.67)	(-2.10)	(-2.41)	(-1.98)	(-5.93)
Expenditure on bollworm sprays	-1,668***	-1,410***	-1,449**	-870***	-1,331***	-1,926***
	(-5.92)	(6.18)	(-2.53)	(-4.74)	(-3.36)	(-10.54)
Expenditure on non-bollworm sprays	308	198	-85	41	248	-294
	(0.64)	(0.59)	(-0.23)	(0.11)	(0.81)	(-1.12)
Seed expenditure (Rs/acre)	477***	553***	489***	419***	610***	480***
	(3.42)	(6.42)	(3.31)	(4.66)	(5.84)	(7.75)
Expenditure on seed and pesticides (Rs/acre)	-883	-1,114**	-1,046	-1,449***	-473	-1,739***
	(-1.15)	(2.31)	(-1.53)	(-2.91)	(-0.80)	(-4.51)
Total expenditure (Rs/acre)	-362	-152	213	-79	948	-984*
	(-0.29)	(-0.22)	(0.20)	(-0.12)	(0.98)	(-1.81)
Yield (Kg/acre)	-8	86	232***	260***	186***	139***
	(-0.08)	(1.60)	(5.54)	(8.82)	(2.94)	(3.52)
Gross margin (Rs/acre)	89	3,219*	8,189***	9,460***	5,733**	6,124***
	(0.04)	(1.89)	(6.71)	(8.61)	(2.37)	(4.97)
Per capita income (Rs/acre)	96	1,002**	1,523***	919**	1,666**	941***
	(0.14)	(2.15)	(3.20)	(2.20)	(2.43)	(2.99)
Poverty headcount	0.19	-0.038	-0.27	0.038	-0.13	-0.01
	(1.31)	(-0.34)	(-0.85)	(0.2156)	(-0.63)	(-0.09)

Note: ***, ** * denote statistical significance at the one percent and five percent levels, respectively;
In PSM-nearest neighbour, t-values (in parentheses) are calculated from bootstrapped standard errors.

In Mirpur Khas, the estimated coefficients on yield and gross margin are only somewhat higher for the difference in means method compared to the PSM and these coefficients are statistically significant under both estimation methods. Thus, the causal effect of Bt technology on yield and gross margin is overestimated in the district results when simple mean values are compared. After addressing the issue of selection bias, the size of the causal effect is reduced. Despite this reduction, the impact of Bt cotton is still substantial in Mirpur Khas, while in Bahawalpur Bt cotton does not appear to have been a beneficial option in 2008.

ATT by size of operated land

The results presented in Tables 3 indicate that the adoption of Bt cotton contributes to significantly improving the yield, the gross margin from the cotton crop, and per capita household income in Mirpur Khas. However, this increase is not enough to take farmers out of poverty. This issue can further be examined by dividing the farmers into two groups according to their operated land (medium and large farmers who operate more than 5 acres and small farmers who operate up to 5 acres). Because of small control group in Mirpur Khas across size of operated land, this analysis is conducted on the full sample of 206 households. The estimated ATT using the PSM-nearest neighbour method by farm size is reported in Table 5. In both categories of farm size, the adopters experience a significant decline in expenditure on bollworm sprays and an increase in seed costs per acre. Adopters also demonstrate a statistically significant increase in per acre yields and gross margin.

Table 5 shows that the impact of Bt cotton adoption on yield is lower (125 Kg/acre) for small farmers than for large farmers (246 Kg/acre). This result is not in line with the findings of Ali and Abdulai (2010) who reported a larger gain in yield per acre for small farmers as compared to medium and large farmers. We believe the smaller effect on small farmers is the more credible result. The results show that the small adopting farmers reduce pesticide expenditures more and increase seed expenditures less than large farmers. In the unregulated process of adoption that has occurred in Pakistan, small famers may be less well 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 could lead to non-optimal pesticide use. Likewise, because of financial constraints small farmers may be less likely than larger farmers to adopt proper pest control practices or make appropriate fertilizer applications. As a result, they may experience higher crop losses that translated into lower yields as compared to large farmers, with this effect carrying into the smaller gains they achieve from adopting Bt cotton varieties. The data of Bt cotton Survey 2009 did not provide enough information to probe deeply into these issues. Yet, suggestive results are evident in Table 5. Gross margin per acre does not increase as much for small farmers as for large farmers when Bt cotton is adopted, nor does per capita income (the latter coefficient is negative but not significant for small farmers but positive and significant for large farmers). With these per capita income effects, adoption of Bt cotton is not estimated to reduced poverty headcounts in the full sample across the two districts.

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

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

5. Conclusions and policy implications

This paper examines the impact of Bt cotton adoption on the wellbeing of cotton farmers in Pakistan taking into account self-selection bias. The propensity score matching method is used to answer the question of how much the adopters benefit from the Bt cotton adoption compared to the situation if they had not adopted. Data collected in Bahawalpur district in Punjab and Mirpur Khas district in Sindh is used for the empirical analysis.

Overall, certain significant effects were found of the unapproved first-generation varieties of Bt cotton available in Pakistan in 2008 on the wellbeing outcomes for farmers. The results are consistent with Crost *et al.* (2007) for India and Ali and Abdulai (2010) for Pakistan who also observed a significant positive impact of Bt cotton adoption after controlling for self-selection to avoid any upward bias of the estimated impacts. Despite a small sample, this study captured the influence of agro-climatic diversity. Specifically, the results show a varying effect of Bt technology in different agro-climatic conditions. The impact was found to be significant in 2008 under hot and humid conditions in Mirpur Khas where the pest pressure of bollworms was high and non significant in hot and dry Bahawalpur where the pest pressure of sucking pests was more prevalent. Demonstrating this diversity in regional effects is unique among studies for Pakistan and indicates outcomes similar to India for which past studies have shown regional differences in the performance of Bt cotton (Gandhi and Namboodiri, 2006; Qaim *et al*., 2006; Pemsl, 2006). This result suggests that regular annual monitoring and evaluation by agro-climatic regions is needed to make accurate assessments of the benefits and costs of Bt cotton adoption in Pakistan.

A final finding of this study is that gains per acre from adopting Bt cotton are estimated to be lower for small farmers than for medium and large farmers. This result is not in line with the results of Ali and Abdulai (2010) who found small adopting farmers in certain provinces of Punjab province obtained higher yields per acre than the adopting medium and large farmers. We argue that our findings are more plausible and suggest knowledge and market constraints are limiting the ability of small farmer to benefit. This needs to be further investigated if the Bt technology is to hold the promise of widespread gains among Pakistan’s farmers.

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