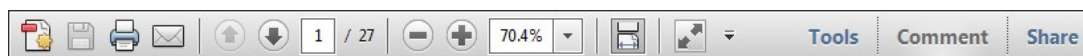
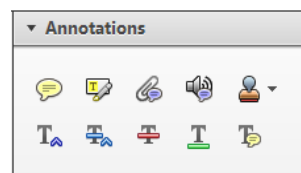


Once you have Acrobat Reader open on your computer, click on the [Comment](#) tab at the right of the toolbar:



This will open up a panel down the right side of the document. The majority of tools you will use for annotating your proof will be in the [Annotations](#) section, pictured opposite. We've picked out some of these tools below:



### 1. [Replace \(Ins\)](#) Tool – for replacing text.

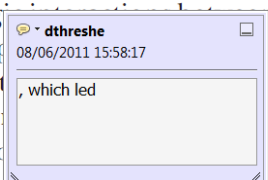


Strikes a line through text and opens up a text box where replacement text can be entered.

#### How to use it

- Highlight a word or sentence.
- Click on the [Replace \(Ins\)](#) icon in the Annotations section.
- Type the replacement text into the blue box that appears.

standard framework for the analysis of microeconomic behavior. Nevertheless, it also led to the development of a new class of strategic form games. The number of competitors in the industry is that the structure of the game is a main component. At the micro level, are exogenous variables and important works on entry by firms (M. Henceforth) we open the 'black b



### 2. [Strikethrough \(Del\)](#) Tool – for deleting text.



Strikes a red line through text that is to be deleted.

#### How to use it

- Highlight a word or sentence.
- Click on the [Strikethrough \(Del\)](#) icon in the Annotations section.

there is no room for extra profits as mark-ups are zero and the number of firms (set) values are not determined by Blanchard and ~~Kiyotaki~~ (1987), perfect competition in general equilibrium of aggregate demand and supply in the classical framework assuming monopoly between an exogenous number of firms

### 3. [Add note to text](#) Tool – for highlighting a section to be changed to bold or italic.



Highlights text in yellow and opens up a text box where comments can be entered.

#### How to use it

- Highlight the relevant section of text.
- Click on the [Add note to text](#) icon in the Annotations section.
- Type instruction on what should be changed regarding the text into the yellow box that appears.

dynamic responses of mark-ups consistent with the **VAR** evidence

sation by Markov. The standard framework for the analysis of microeconomic behavior. The number of competitors in the industry is that the structure of the sector is a main component. At the micro level, are exogenous variables and important works on entry by firms (M. Henceforth) we open the 'black b



### 4. [Add sticky note](#) Tool – for making notes at specific points in the text.

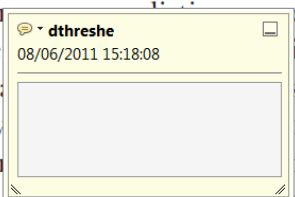


Marks a point in the proof where a comment needs to be highlighted.

#### How to use it

- Click on the [Add sticky note](#) icon in the Annotations section.
- Click at the point in the proof where the comment should be inserted.
- Type the comment into the yellow box that appears.

standard and supply shocks. Most of the standard framework for the analysis of microeconomic behavior. The number of competitors in the industry is that the structure of the sector is a main component. At the micro level, are exogenous variables and important works on entry by firms (M. Henceforth) we open the 'black b



### 5. **Attach File** Tool – for inserting large amounts of text or replacement figures.

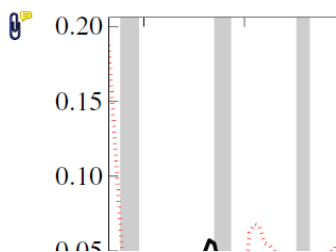


Inserts an icon linking to the attached file in the appropriate place in the text.

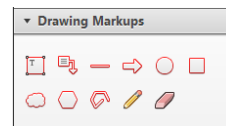
#### How to use it

- Click on the **Attach File** icon in the Annotations section.
- Click on the proof to where you'd like the attached file to be linked.
- Select the file to be attached from your computer or network.
- Select the colour and type of icon that will appear in the proof. Click OK.

END

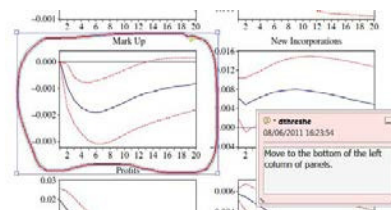


### 6. **Drawing Markups** Tools – for drawing shapes, lines and freeform annotations on proofs and commenting on these marks. Allows shapes, lines and freeform annotations to be drawn on proofs and for comment to be made on these marks.



#### How to use it

- Click on one of the shapes in the Drawing Markups section.
- Click on the proof at the relevant point and draw the selected shape with the cursor.
- To add a comment to the drawn shape, move the cursor over the shape until an arrowhead appears.
- Double click on the shape and type any text in the red box that appears.



# A Question of Integrity: Variants of Bt Cotton, Pesticides and Productivity in Pakistan

Xingliang Ma, Melinda Smale, David J. Spielman, Patricia Zambrano, Hina Nazli and Fatima Zaidi<sup>1</sup>

2

(Original submitted September 2015, revision received February 2016, accepted April 2016.)

## Abstract

*Bt cotton remains one of the most widely grown biotech crops among smallholder farmers in lower income countries, and numerous studies attest to its advantages. However, the effectiveness of Bt toxin, which depends on many technical constraints, is heterogeneous. In Pakistan, the diffusion of Bt cotton occurred despite a weak regulatory system and without seed quality control; whether or not many varieties sold as Bt are in fact Bt is also questionable. We utilise nationally representative sample data to test the effects of Bt cotton use on productivity. Unlike previous studies, we invoke several indicators of Bt identity: variety name, official approval status, farmer belief, laboratory tests of Bt presence in plant tissue, and biophysical assays measuring Bt effectiveness. Only farmer belief affects cotton productivity in the standard production model, which does not treat Bt appropriately as damage-abating. In the damage control framework, all Bt indicators reduce damage from pests. Biophysical indicators have the largest effect and official approval has the weakest. Findings have implications for impact measurement. For policy-makers, they suggest the need, on ethical and productivity grounds, to improve variety information and monitor variety integrity closer to point of sale.*

<sup>1</sup>Melinda Smale is at Michigan State University, East Lansing, MI, USA. E-mail: ms-male@msu.edu, melinda.smale@gmail.com for correspondence. Xingliang Ma is an independent researcher based in Washington, DC, USA. David J. Spielman, Patricia Zambrano and Fatima Zaidi are all with the International Food Policy Research Institute, Washington, DC, USA. Hina Nazli is with the Pakistan Strategy Support Programme, Islamabad, Pakistan. This work was supported by IFPRI's Pakistan Strategy Support Program with funding from the US Agency for International Development; and by the CGIAR Research Program on Policies, Institutions, and Markets. The authors gratefully acknowledge data, information and insights provided by Guillaume Gruère, Ahsan Rana, Mubarik Ali, Khuda Bakhsh, Asif Ali, Shaukat Ali, Masooma Naseer Cheema, Aamer Irshad, Arif Nadeem, Muhammad Anjum Ali, Kauser Abdulla Malik, Shahzad Kouser, Sohail J. Malik, Steve Davies and Andrew Roberts; and Saira Malik, Tahir Ahmad, and Lorena Danessi for their administrative support. Researchers Asjad Tariq, Saqib Shahzad, Shehryar Rashid, Amina Mehmood and Asma Shahzad provided valuable assistance. Any and all errors are the sole responsibility of the authors.

CE: Kuttidurai	Dispatch: 9.6.16	WILEY	12174	J A G E
PE: Balakumar C	No. of pages: 20		Manuscript No.	Journal Code

**Keywords:** *Bt cotton; damage abatement; Pakistan; pesticides; productivity.*

**JEL classifications:** *O33, Q12, Q16.*

## 1. Introduction

Bt cotton varieties confer genetic resistance to a major order of insect pests (*lepidoptera*). Following their initial release in the United States in 1996, experts predicted that Bt cotton varieties would boost yields especially in lower income countries, where conventional methods of controlling these pests – which involve the repeated application of insecticides – are especially costly or poorly managed (e.g. Qaim and Zilberman, 2003). Subsequent reviews of economic analyses based on farm surveys (Qaim, 2009; Smale et al., 2010), as well as meta-analyses (Areal et al., 2013; Finger et al., 2011; Klümper and Qaim, 2014), have generally borne out this prediction. Perhaps the strongest evidence is that on a global scale, Bt cotton remains one of the most widely grown genetically modified (GM) crops among smallholder farmers in lower income countries.

However, the *effectiveness* of Bt cotton as a strategy for abating pest damage on farms depends on several factors, some of which may jeopardise the economic potential of the crop and raise ethical concerns. First, the expression of Bt toxin is heterogeneous, and depends on technical constraints related to the conditions in the laboratory where the transformation is conducted, and the backcrossing procedure (e.g. Xia et al., 2005; Showalter et al., 2009). In Pakistan, breeders often develop Bt cotton varieties by backcrossing local genotypes with alien Bt varieties that contain the Bt gene through a Cry1Ac event that was not patented in Pakistan (Ali et al., 2012). Second, Bt toxin is expressed across a range of values, not all of which may be lethal for the targeted pest. In 2012, Cheema et al. (2015) collected Bt cotton seed samples from farmers and seed dealers in selected districts in Punjab and found sub-lethal concentrations of the Bt toxin in 98% of the genotypes tested.

Third, farmers who grow Bt cotton varieties may manage them differently than they would non-Bt varieties because they believe them to be intrinsically different. Not all management practices are observable and some affect yields, costs and profitability. The host variety may in fact convey greater (or less) yield potential than the genetic background of the non-Bt variety, either complementing (or counteracting) Bt expression (see studies by Huang et al., 2002 for China; Crost et al., 2007 and Gruère and Sun, 2012 for India; Areal et al., 2013).

Further, in Pakistan, the diffusion of Bt cotton varieties occurred despite a weak regulatory system and without seed quality control (Rana, 2014). Evidence of Bt cotton cultivation was found as early as 2002 but it was not until 2010 that Pakistan's National Biosafety Committee gave its first variety-specific approvals for the release of Bt cotton (Nazli et al., 2012). Between 2010–2014, there were 32 approved varieties of Bt cotton in Pakistan although numerous other unapproved Bt varieties of possibly variable quality are thought to be available in the market (Spielman et al., 2015). Evidence from controlled tests conducted on field samples has shown that whether varieties sold as Bt actually carry the transgenes is questionable. Ali et al. (2010) found that 19% of seed samples drawn from farmers' fields in Sindh and 10% of those collected in Punjab tested non-positive for Bt toxin expression; Ali et al. (2012) found that 30% of the seed samples obtained directly from the market tested non-positive for the Bt gene expression.

In this paper, we use a damage control framework to test how the integrity of Bt cotton varieties affects cotton productivity among smallholder growers in Pakistan. By variety integrity, we refer to the physical, physiological and genetic characteristics of the seed which are consistent, measurable or recognisable to farmers (e.g. true to type; true to label, as in Sperling *et al.*, 2004). We invoke five different definitions of Bt integrity based on data from face-to-face interviews, with different and increasingly reliable meanings for effectiveness, as detailed below (Section 3.2).

We estimate the damage control model with non-linear least squares, which imposes some restrictions on choice of more flexible functional forms because of its complexity. We assume that the potential yield function follows a conventional Cobb-Douglas production function and that the cumulative distribution function of the damage abatement component follows an exponential form. We estimate and compare five models, each including one of the Bt indicators.

Our analysis contributes to the literature in two ways. First, as compared to previous applied microeconomics studies conducted in Pakistan (Ali and Abdulai, 2010; Nazli *et al.*, 2012; Kouser and Qaim, 2014; Abedullah and Qaim, 2015), we utilise data collected from a detailed survey of a nationally representative sample of cotton growers. Ali and Abdulai (2010), Kouser and Qaim (2014) and Nazli *et al.* (2012) demonstrated that Bt cotton varieties are more productive and farmers who grow them use less pesticide. Abedullah and Qaim (2015) found that Bt farms were both more technically and more environmentally efficient. Secondly, as compared to previous analyses of the productivity impacts of Bt cotton (e.g. Huang *et al.*, 2002; Qaim and de Janvry, 2005; Kouser and Qaim, 2014), which differentiated Bt and non-Bt varieties based solely on name, we utilise farmer perceptions as well as results of laboratory tests in our analysis. Clearly, a variable based on name is appropriate if cotton varieties sold and/or planted as Bt consistently carry the Bt genes and consistently express themselves at lethal levels. As we argue above, this is not likely to be the case. If, as the evidence suggests for Pakistan, variety integrity is questionable and the effectiveness of Bt expression is heterogeneous, use of a variable based on name could bias results.

The lack of, or ineffectiveness of, the Bt toxin in a so-called Bt cotton variety raises non-trivial issues both for Pakistan's economy and the international cotton market. Cotton is an important source of rural income in Pakistan, with approximately 2.2 million farms being directly engaged in cotton cultivation, accounting for 26% of all farms in the country (GOP, 2012). Cotton also accounts for over 50% of foreign exchange earnings via the textiles industry (GOP, 2013). Globally, Pakistan has been consistently ranked as the world's fourth largest cotton producer and third largest consumer (GOP (Government of Pakistan), 2013).

Ineffectiveness of Bt cotton could potentially contribute to the natural evolution of pest resistance, encumbering farmers with greater losses and insecticide costs in the future. Kouser and Qaim (2014) observe that while cotton growers in Pakistan apply less pesticide to plots where they plant Bt varieties, these reductions are small in comparison to those observed in studies from other lower income countries. This is consistent with findings from China, where Huang *et al.* (2002) reported that despite reductions in pesticide application, overuse continued among cotton growers even after adoption of Bt cotton varieties. Pemsil *et al.* (2005) identified market and institutional failures as possible reasons for such practices, although more recent work by Liu and Huang (2013) attributes this problem to the risk preferences of cotton farmers. A competing hypothesis is that, because the effectiveness of Bt cotton varieties

may not be high enough to resist pests effectively, farmers continue to apply high levels of pesticides to ensure their crop is adequately protected from cotton bollworms. In Pakistan, one possible reason they can afford to do this is the relatively low cost of Bt cotton seed (of various qualities).

This paper presents our modeling framework, with reference to key literature and previous findings (Section 2). In section 3, we present the elements of our empirical strategy, including the data source and variable definitions. Findings, including regression results and robustness checks, are discussed in the section 4. In section 5 we present the conclusions and implications for public policy in Pakistan and further research.

## 2. Empirical Strategy

### 2.1. Relevant models

In their landmark 1986 article, Lichtenberg and Zilberman (1986) distinguished the crop production roles of damage-abating and productivity-enhancing inputs. Farmers apply inputs such as fertiliser to augment the yields they expect to attain, while they deploy pesticides to counteract yield losses relative to planned or expected output. A major insight in this article was to show that standard production models (the Cobb-Douglas, specifically) can lead to biased findings concerning the marginal productivity and efficiency of pesticide use. Since this study, numerous adaptations and advances from the basic model have been proposed, many of which have focused on model specification (e.g. Fox and Weersink, 1995; Saha *et al.*, 1997; Guan *et al.*, 2005; Chambers *et al.*, 2010). Huang *et al.* (2002) demonstrated that the specification bias in estimates of marginal productivity of pesticides generated by applying a Cobb-Douglas model instead of a damage control framework could be negative rather than positive as originally argued by Lichtenberg and Zilberman (1986).

In the original notation of Lichtenberg and Zilberman (1986), the damage control function is defined as  $Y = F[\mathbf{Z}, G(\mathbf{X})]$ , where the vector  $\mathbf{Z}$  includes productive, or 'conventional' inputs as usually modeled in a production analysis and the vector  $\mathbf{X}$  consists of control inputs.  $G(\mathbf{X})$  is increasing in  $\mathbf{X}$  and approaches an upper limit of 1, where  $Y = F(\mathbf{Z})$ . As  $\mathbf{X}$  decreases,  $G(\mathbf{X})$  and  $Y = F(\mathbf{Z}, 0)$  approach the lower limit of 0, or a level that represents maximum destructive capacity. In empirical work, the function is generally simplified as a proportional one:  $Y = F(\mathbf{Z})G(\mathbf{X})$ . A damage abatement effect is then understood as the proportion of the destructive capacity (represented as a cumulative density function valued between 0 and 1) that can be offset by utilising a given amount of a control input. Weibull, exponential and logistic functions are commonly selected to represent the cumulative distribution function  $G(\mathbf{X})$ , which lies in a  $[0,1]$  interval. Meanwhile,  $F(\mathbf{Z})$  is interpreted as potential or maximum yield that can be obtained with zero pest damage or maximum pest control.

A damage control input can be understood not only as an input such as pesticide but also as a crop variety carrying genetic resistance to pests or disease, tolerance to abiotic stresses, or as any other input that a farmer uses with the goal of mitigating yield losses (Horna *et al.*, 2008). Thus, economists have applied the damage control framework to measure the impact of growing Bt cotton varieties. Within this body of work, the most pertinent studies are those conducted by Shankar and Thirtle (2005) in South Africa, Pemsil *et al.* (2005) in China, Qaim and de Janvry (2005) in Argentina, and Kouser and Qaim (2014) in Pakistan.



Shankar and Thirtle (2005) employed a Cobb-Douglas functional form for  $F(Z)$  'due to the relatively small size of the available sample', which included a cross-section of only 91 observations out of a sample of 100 smallholder cotton farmers in Makhathini Flats, KwaZulu-Natal, South Africa. Data collected on input use were also cursory in these initial years of Bt cotton use, including conventional inputs land (ha), labour (days), total seed quantities (kg) and pesticides (kg). The authors recognised that while a damage abatement input such as a pesticide should only be included in the damage function, in the case of varieties with genetic traits that confer insect resistance, the genetic background of the variety into which the genes are inserted could also generate an effect in the production function. Comparing several models, they found that in the most parsimonious models, conventional inputs had strong and expected signs, but in none of the production models was the Bt indicator statistically significant. At the same time, the Bt indicator and pesticide use were both highly significant in damage control, regardless of model.

A second landmark study was conducted by Qaim and de Janvry (2005) on Bt cotton and pesticide use in Argentina. Given that Bt cotton had not been widely adopted in Argentina, the study utilised various methods to address a potential bias in estimated parameters resulting from self-selection by early adopters, including plot-based estimation for partial adopters, which controls for intrinsic, unobserved farmer characteristics. Qaim and de Janvry (2005) found that growing Bt cotton varieties had a positive effect in their production model (a quadratic functional form). Since Bt genes had been incorporated in varieties that had never been grown in Argentina, this result could have reflected a germplasm effect (although the authors argued to the contrary). The damage function showed a significant effect of growing Bt cotton on the reduction of pest damage, along with pesticides.

In both of these papers, Bt use was measured as a binary dummy variable. Neither study described whether categorisation was based on farmer belief that the variety was Bt, comparing names reported by farmers to a supplier or official list, or another form of verification. Pemsal *et al.* (2005) addressed this shortcoming in an analysis based on data collected in Shandong Province, China. Recognising that 'the variety dummy may include also non-pest control effects if other factors cannot be adequately controlled' (p. 47), they measured the Bt trait by selecting cotton leaf samples from the plots of the farmers they surveyed and examining the tissue for toxin expression. They estimated the insecticide use function and production function with damage abatement simultaneously, adding farmer experience, village fixed effects, herbicide and crop rotation to labour and pesticide factors. A variety dummy was included in the model in addition to their variable measuring the concentration of Bt toxin. The authors estimated a Cobb-Douglas production model with an exponential form for the damage function.

The findings of Pemsal *et al.* (2005) differ substantively from others reported in the literature at that time. The authors highlighted the lack of standards and market imperfections in China's cotton seed market that accompanied the introduction of Bt cotton. A striking finding reported by Pemsal *et al.* (2005) was that neither the coefficient on pesticide use nor that on Bt toxin concentration was statistically significant in the damage control model, contradicting previous work for China (Huang *et al.*, 2002) and other work we cite here. They suggest that the variability in input quality, combined with the low variability in pesticide use and its generally high level of use could explain this result. Further, the variety dummy was significant and positive in

the insecticide use equation, but of no statistical significance in the damage control model.

In focusing on how Bt is measured, we are influenced by Pemsal *et al.* (2005). Otherwise, the analysis by Kouser and Qaim (2014), applied to data collected in Pakistan, is the most pertinent to our study. Like Qaim and de Janvry (2005), Kouser and Qaim (2014) specified a quadratic form for the production function, reporting that similar results were obtained when other functional forms were employed. Their Bt variable was a dummy variable and the data they use were collected from a sample of 352 farmers located in four districts in Punjab, where 42% of the country's cotton crop is produced. Kouser and Qaim (2014) found that the Bt variety dummy both increased cotton yield in both the standard production model and reduced losses in the damage control model. This finding suggests both a germplasm effect and a Bt effect, though as noted by Pemsal *et al.* (2005), these could be confounded in the binary variable measuring Bt.

Shankar and Thirtle (2005), like Qaim and de Janvry (2005), chose the logistic distribution as the more suitable characterisation for  $G(\mathbf{X})$  than either the exponential or the Weibull distributions. They noted that the exponential form implies concavity when  $G(\mathbf{X}) > 0$ , or that damage abatement increases at a decreasing rate, contending that a positive second derivative of the function is plausible; they also found 'counter-intuitive' results when testing the models with a Weibull specification (Qaim and de Janvry, 2005; p. 104). In contrast, Pemsal *et al.* (2005) and Kouser and Qaim (2014) estimate their model assuming an exponential distributional form. Kouser and Qaim (2014) concluded that their findings were robust to form of the damage function.

## 2.2. Specification

We estimate the damage control model with non-linear least squares, which imposes some restrictions on choice of more flexible functional forms because of its complexity. Concerning the production model, we chose the Cobb-Douglas functional form for comparability and because it is parsimonious. We also tested the quadratic functional form, but most of the estimated coefficients were statistically insignificant although they have predominantly the same sign as those generated using the Cobb-Douglas functional form. With respect to the damage function, the Weibull functional form is restrictive on its domain and cannot be applied when many inputs are close to zero in value. Estimation with a logistic functional form returned similar results to those obtained with the exponential form, except that many coefficients lost their statistical significance. Thus, in the empirical analysis that follows, we assume that  $F(\mathbf{Z})$  follows a conventional Cobb-Douglas production function and the damage abatement function follows an exponential cumulative distribution function form:

$$F(\mathbf{Z}) = \beta_0 \prod_i Z_i^{\beta_i},$$

$$G(\mathbf{X}) = 1 - e^{-\gamma_1 X_1 - \gamma_2 X_2},$$

where the vector  $\mathbf{Z}$  consists of conventional inputs (labour, fertiliser, seed, irrigation), specified as logarithms. For comparative purposes, we estimate both a standard production model and a damage control model.

In our production function formulation, we test the effects of our different Bt indicators as dummy variables on the intercept term. In addition, we include the years of



education of the household head to account for the effect of human capital and management capacity, land cultivated in the preceding year for scale effect and the agro-climatic zones within the cotton-growing regions to control for differences in rainfall and temperature that could potentially affect cotton production. The scale of the farm operation, which is captured by land cultivated in the previous season to ensure that it is predetermined in the current season, may relate positively to productivity through improving access to a range of inputs and information (Feder and Slade, 1984). On the other hand, larger scale may reduce the intensity of input use and management, detracting from per acre yields. Insecticide use is also included in the initial production function estimation for completeness and purposes of comparison with the damage abatement model.

In the damage abatement model, the vector  $\mathbf{X}$  is composed of insecticide use and the same Bt variables. The vector  $\mathbf{Z}'$  in this model is identical to  $\mathbf{Z}$  without Bt variables. We test multiple Bt indicators in separate models. The dependent variable in both models is observed cotton production in kgs per acre.

Since Bt cotton in Pakistan has diffused broadly through unofficial channels beginning in 2002, variety identity and the effectiveness of Bt expression are uncertain, the potential bias in parameter estimates from self-selection is unlikely to be important and also difficult to discern. Bt cotton was grown on over 2.9 million ha in Pakistan according to James (2014) and cultivated by 85% of cotton farmers in our data.

### 3. Data and Variables

#### 3.1. Data sources

Data for this study are drawn from two sources: (1) a household survey, and (2) a biophysical survey, both conducted during the 2013 *kharif* (monsoon) season when cotton is grown throughout Pakistan. The household survey was designed by the International Food Policy Research Institute (IFPRI) and implemented by Innovative Development Studies (IDS). Data were collected in face-to-face interviews with 728 farmers who were selected in a statistically representative sample of all cotton-growing agro-climatic zones in both Punjab and Sindh Provinces, accounting for more than 99% of the cotton cultivated in Pakistan. Households were selected in a two-stage sampling procedure stratified by cotton-growing agro-climatic zones (Figure 1). In the first stage, 52 villages are chosen with probabilities that were proportional to farming population sizes. In the second stage, 14 cotton households are chosen from each village with equal probability of selection.

The detailed survey was conducted in three rounds during the course of the 2013 cotton-growing season. The first round was implemented at planting (April 2013), and obtained data on household, farm and plot characteristics of cotton growers. The second round was implemented during or immediately following the first picking, and obtained data relating to input use up to the first picking (October 2013). The third round was conducted in February 2014 after the harvest and obtained data on the harvest from each picking and the total sales of cotton. Of the original sample of 728 households, 46 chose not to grow cotton in *kharif* 2013, 70 lost their crops to flood or other natural disasters, four migrated, eight dropped out in the second or third round surveys, and 29 did not participate in the corresponding biophysical survey.

Summary statistics for those who remained in the sample and those who did not, provided in an Online Appendix (Table S1), demonstrate that the observable

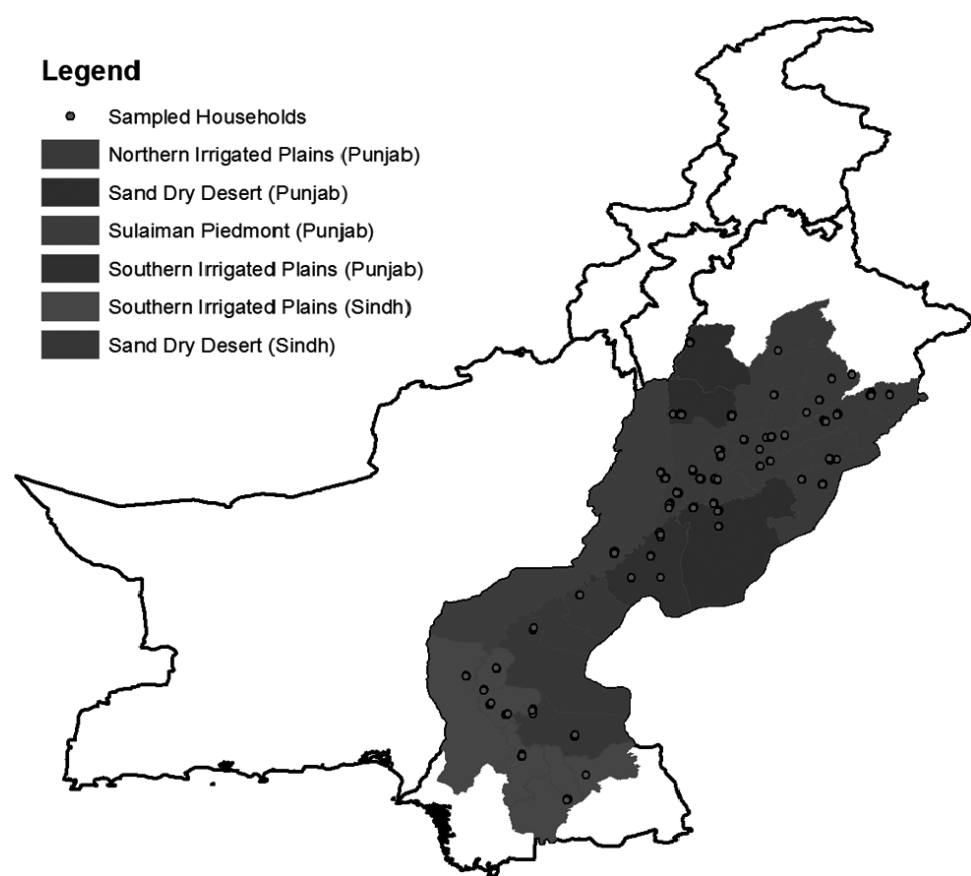


Figure 1. Survey sites. *Note:* Shown at this scale, dots approximate villages because multiple households were interviewed per village 8  
*Source:* Authors.

household characteristics of the two groups of farmers are not significantly different. For example, years of education of household head and daily expenditure on food per person in the household as a measure of poverty status, are both insignificant in the mean comparison test across these two groups. They also have similar average household size and total land owned and operated in 2012. Although there is slight difference in household age it is unlikely that it will make a difference in cotton cultivation practices. We believe that the sample retained sufficient coverage of the heterogeneity of cotton-growing households and cotton agro-climatic zones found in Pakistan. However, we recognise that the combination of household survey dropouts and households that could not be surveyed for either the first or second rounds of the bio-physical survey does limit the size of the analytical sample.

Fertiliser application rates and irrigation hours were elicited by plot. If more than one variety was sown per plot, it is not possible to ascertain how much of the input was applied to each. We restricted the analysis to plots with only one cotton variety in order to accurately measure the contribution of each input. An alternative might have been to weigh input use by variety area shares on each plot, although this procedure would have introduced measurement errors of a different nature. Complete

information is available for a total of 535 households, with each household's unique cotton variety in the main plot meeting these criteria.

The second component of data collection – the biophysical survey – was led by the University of Agriculture, Faisalabad (UAF) and the National Institute for Genomics and Advanced Biotechnology (NIGAB), Islamabad, in collaboration with IFPRI and IDS. In the biophysical survey, leaf and boll tissue samples were collected from the main cotton plots of sample farmers and were analysed in the lab to detect the presence of Bt toxin by Strip tests and to measure its concentration levels by ELISA tests. A total of two rounds of tests were conducted, the first at approximately 70 days after sowing (DAS) and the second at approximately 120 days after sowing (DAS). The first round of data collection conducted through the biophysical survey, which was constructed in a way that is consistent with the procedure reported by Pemsal *et al.* (2005), is utilised here. Data collected and tested in the same way as the 120 DAS generated similar results.

In the first round, the bio-physical study team randomly selected five plants in the main plot of each sample farmer. They then collected leaf samples from among leaves of similar size, position, colour and age from each identified plant separately. These leaf samples were shipped to the lab and two samples that were collected from different plants were randomly selected to conduct both the strip and ELISA tests. Both UAF and NIGAB used the industry-standard equipment (Envirologix™ QuickStix™ Combo Kits) for Bt toxin detection and followed the same statistical procedure to measure Bt toxin expression. To establish a threshold for Bt effectiveness based on the ELISA test results, the UAF team conducted a bioassay study in which cotton leaf samples from 25 cotton varieties with known levels of Bt toxin concentration were fed to 936 targeted insects (*H. armigera* or American bollworm) to determine mortality rates after 3 days of cotton leaf consumption. A Logit regression of the mortality status over the ELISA scores suggests that any ELISA score  $>0.60 \mu\text{g/g}$  will kill the target insect with likelihood  $>50\%$ . Similarly an ELISA score of  $0.74 \mu\text{g/g}$  is associated with a likelihood of 60% mortality of the target insect,  $0.88 \mu\text{g/g}$  corresponds to a likelihood of 70%,  $1.06 \mu\text{g/g}$  80% and  $1.34 \mu\text{g/g}$  90%.

### 3.2. Measuring Bt

Most of the applied economics literature on the impact of GM crops assumes that farmers know with certainty whether the variety they grow is GM or not. While this assumption may be valid in countries where GM varieties have been commercialised with well-articulated input supply chains, biosafety and seed marketing regulations and labeling and packaging practices, it is less likely to be so in countries where farmers buy their seed from local informal and unregulated markets, or acquire it from neighbours, friends or acquaintances.

Several approaches were observed in survey instruments used in previous studies. One method is to ask farmers directly if they planted Bt cotton. A more sophisticated method involves asking the farmer if he/she has ever heard of Bt cotton. If the answer is negative, the enumerator provides a definition and then asks farmers whether they planted Bt cotton. A third approach is to ask the farmer to name the varieties he/she has planted and, with the help of local experts, classify the varieties as Bt or non-Bt based on reported names.

In our analysis, following Pemsal *et al.* (2005), we test five Bt indicators (Table 1). The first, 'Bt name', was developed by linking the farmer's survey response when

Table 1  
Summary statistics for variables measuring Bt gene expression, by main plot

Variable	Percent	Definition
Bt name	85.4	Variety is sold as Bt cotton seed
Bt official	54.8	Variety is officially approved as Bt cotton
Bt belief	71.0	Farmer believes the variety is Bt cotton
Bt presence	79.6	Strip test detects the presence of Bt toxin in a variety
Bt effective	53.1	ELISA test score surpassed the Bt expression threshold

**Note:** Percentages are based on household survey responses and laboratory tests of cotton tissue samples taken from the main cotton plot of surveyed households ( $N = 535$ ).

**Source:** Authors.

asked the name of the variety planted to publicly available information about whether a named variety is Bt or not. This information is generally provided by the seed supplier, but since we rely on farmers' accuracy in reporting variety names and expert judgement to classify names, we consider this indicator to be the least reliable. We retain it in our analysis primarily because it is the most frequently employed definition in the literature. The second, 'Bt official', refers to whether the variety named by the farmer is on the officially approved list of Bt varieties. As noted above, this is not expected to be conclusive given that regulations were established late, without seed quality controls. Third, we include 'Bt belief', which measures whether the farmer reported (believed) that the variety he planted was Bt or not. The fourth indicator, 'Bt presence', indicates the presence of Bt toxin in a variety if its leaf sample tested positive with strip tests and its ELISA reading was greater than or equal to a minimal level. 'Bt effective' measures the effectiveness of a Bt variety in controlling targeted insects. We define a variety as Bt effective if its ELISA reading is  $>0.88 \mu\text{g/g}$ , a threshold established by a scientific bioassay experiment conducted in Pakistan in 2014. Pemsil *et al.* (2005) established a standard level of approximately  $0.62 \mu\text{g/g}$  in the context of China in early 2000s. We experimented with this reference level as well and our statistical findings did not change.

Table 1 shows the percentage of varieties grown on main cotton plots in our sample, by each Bt indicator. We can see that there are many more Bt varieties (by name) grown by farmers (85.4%) than officially approved Bt varieties (54.8%). The percentage of plots planted to varieties that farmers believed to be Bt (71%) was also lower than the percentage named as varieties that are classified as Bt, based on publicly available information, as Bt (85.4%). Although 80% of plots were planted to varieties for which the leaf strip test results showed presence of Bt, only 53% surpassed the threshold for effectiveness.

Pairwise cross-tabulations provide some useful insights (Table 2). While 84% of varieties that tested positive for the presence of Bt were believed to be Bt by the farmer, 69% of those that failed the leaf strip test were also believed to be Bt. Bt belief is positively and significantly ( $<1\%$ ) associated with the likelihood of Bt presence. However, Bt presence is a much less stringent criterion than 'Bt effective'. 52% of varieties that surpassed the threshold for Bt effectiveness were believed to be Bt, but 54% that did not were also believed to be Bt. Furthermore, only 56% of varieties sampled from farmers that were classified as officially approved varieties were effective, compared with 50% that were effective but not officially approved. Neither Bt belief nor Bt official status is statistically related to Bt effectiveness.

Table 2

Farmers' Bt beliefs about cotton varieties grown and Bt approval status, by presence and effectiveness of Bt

			Bt presence Yes	Bt effective Yes
Bt Belief	No	<i>n</i>	107	84
		%	69.03	54.19
	Yes	<i>n</i>	319	200
		%	83.95	52.63
Pearson Chi-squared ( <i>P</i> -value)			0.000	0.743
Bt Official	No	<i>n</i>	183	120
		%	75.62	49.5
	Yes	<i>n</i>	243	164
		%	82.95	55.97
Pearson Chi-squared ( <i>P</i> -value)			0.037	0.141

**Note:** Figures are based on household survey responses and laboratory tests of cotton tissue samples taken from the main cotton plot of surveyed households (*N* = 535).

**Source:** Authors.

Thus, when farmers plant approved Bt varieties of cotton, their chances of achieving Bt effectiveness are not far from a coin toss (50/50). In practice, Pakistani cotton farmers are obliged to rely on the names of cotton varieties, which could be false, or their own beliefs, to determine if a variety is Bt or not and to plan accordingly for its cultivation. Lacking sufficient information, farmers' belief may not be accurate and therefore they may not make the optimal production decisions. These statistics are relevant to our analysis because we propose that farmers' perceptions of what they grow affect how they manage their crops, such as the timing and quantity of insecticide applications, how well the crop performs in terms of harvested yield and their capacity to control damage from pests.

### 3.3. Other explanatory variables

Summary statistics for other explanatory variables are shown in Table 3. We asked farmers about the use of pesticides in various forms and in different cultivation time periods and then aggregated them into a single measure. For fertiliser, we computed the quantity of nitrogen contained in each type of fertiliser applied to the plot during the entire growing season and divided by the plot area to obtain a rate of N nutrient kgs applied per acre. For labour – a particularly important input given that cotton is a labour-intensive crop – we asked detailed questions about the use of family labour, contracted labour and hired labour, differentiating male and female labour in the whole cotton cultivation season. Here, to simplify our conventional input variables, we aggregated over categories to generate the total number of labour hours. For water and irrigation inputs, and given that many farmers rely on monsoon rains during the *kharif* season, groundwater and canal water from Pakistan's expansive Indus River basin irrigation system, we asked detailed questions about water management. We



Table 3  
Summary of variables

Variable (unit)	Definition	Mean	Std. Dev.	Min	Max
Yield (kg/acre)	Total harvest per acre	930.46	443.14	53	3,040
Labour (hours)	Total number of hours by family labour, hired labour and contract labour per acre during the cotton cultivation season	155.43	89.12	21	968
Seed (kg/acre)	Quantity of planted seed per acre	6.79	2.60	2	16
Insecticide (gram/acre)	Insecticides per acre	2,276.40	1,592.91	0	10,000
N nutrients (kg/acre)	Quantity of nitrogen from fertilisers per acre	83.29	37.05	0	246.79
Irrigation hours (hours)	Total time of irrigation per acre during the cotton cultivation season	12.95	13.31	0	83
Land cultivated (acres)	Total land cultivated in 2012 (year preceding survey)	9.13	17.76	0.5	253
Education (years)	Total number of years of education	4.67	4.54	0	17

*Source:* Authors.

calculated the total time (hours) irrigating the plot from the total number of irrigations and hours per irrigation.

Finally, we consider agro-climatic zones among our explanatory variables to account for the potentially heterogeneous conditions under which cotton is cultivated in Pakistan. The vast majority of farms are located in the Northern Irrigated Plains of Punjab, followed by the Southern Irrigated Plains of Sindh. The Sand Dry Deserts of either province and the Sulaiman Piedmont, represent a minority given much lower population densities in these areas.

## 4. Results

### 4.1. Production function estimation

Estimation results for the standard production model (Table 4) show that none of the Bt indicators is significantly associated with variation in cotton yields except for Bt belief. If farmers believe they are growing a Bt variety of cotton, observed yields may increase – although the coefficient is statistically significant only at 10%. This suggests that when farmers believe they are growing a Bt variety, they may manage it differently – in a way that is unobserved or that we have not captured among the conventional inputs included in the standard production model.

As was found by Shankar and Thirtle (2005), we find no effect of any other Bt indicator, including Bt presence or effectiveness. Nor do we find a positive effect of insecticide use in the standard production model. These findings are consistent with the notion that the Cobb-Douglas model is mis-specified for damage-abating inputs (Lichtenberg and Zilberman, 1986; Huang *et al.*, 2002). Bt name or Bt official could affect productivity in a standard production model if genetic backgrounds were systematically differentiated, which would be the case if Bt genes were inserted into

Table 4  
Cobb-Douglas production function estimation results

Explanatory variables	(1) Bt name	(2) Bt official	(3) Bt belief	(4) Bt presence	(5) Bt effective
Bt: name	0.035 (0.066)				
Bt: official		-0.041 (0.046)			
Bt: belief			0.088* (0.052)		
Bt: presence				-0.067 (0.057)	-0.038 (0.061)
Bt: effective					-0.062 (0.049)
Labour	0.315*** (0.048)	0.322*** (0.047)	0.309*** (0.047)	0.322*** (0.047)	0.318*** (0.047)
Seed	-0.012 (0.059)	-0.004 (0.059)	-0.015 (0.059)	-0.017 (0.059)	-0.018 (0.059)
Insecticide	0.010 (0.011)	0.009 (0.011)	0.010 (0.011)	0.009 (0.011)	0.009 (0.011)
Nitrogen	0.105*** (0.039)	0.104*** (0.039)	0.103*** (0.039)	0.103*** (0.039)	0.105*** (0.039)
Irrigation	-0.041* (0.024)	-0.040 (0.024)	-0.044* (0.024)	-0.039 (0.024)	-0.041* (0.024)
Cultivated land	-0.032 (0.029)	-0.029 (0.029)	-0.041 (0.029)	-0.028 (0.029)	-0.030 (0.029)
Education	0.010 (0.007)	0.010 (0.007)	0.010 (0.007)	0.011 (0.007)	0.011 (0.007)
Constant	4.766*** (0.238)	4.791*** (0.237)	4.795*** (0.238)	4.816*** (0.240)	4.865*** -0.275
Observations	535	535	535	535	535
R-squared	0.128	0.133	0.129	0.130	0.132

**Note:** All variables except Bt measures are logarithmic. Standard errors in parentheses; \*\*\* $P < 0.01$ , \*\* $P < 0.05$ , \* $P < 0.10$ .

**Source:** Authors.

superior varieties (Shi *et al.*, 2013). This possibility is discussed by Qaim and de Janvry (2005) and Pemsil *et al.* (2005).

Additional results indicate that labour and nitrogen application significantly explain variation in yields, as expected. The effects of other inputs, such as irrigation and seeding rate, are either not statistically significant or not positively associated with the yield. Mitchell *et al.* (2009) find that farmers in the US adopt a higher seeding density for GM maize to boost yield, while our results suggest that a higher density does not improve Bt cotton yield in Pakistan therefore should not be recommended. The negative estimated coefficient for irrigation hours, although significant, could reflect heavier pest pressures in the irrigated areas, diminishing returns to water use in the presence of waterlogging or salinity, or measurement error. Given the various sources of water and various time periods irrigated, it is hard for farmers to track the exact duration that they irrigated their plot each time. We find no evidence of a land

size effect on cotton productivity, and nor does farmer education affect yields. The F-test on the vector of dummy variables representing agro-climatic zone fails to reject the hypothesis that they are jointly equal to zero. Thus, these are not included in Table 4. According to the Cobb-Douglas functional form, the sum of estimated input elasticities (well below 1) suggests decreasing returns to scale. This finding may reflect the particularly labour-intensive nature of cotton production on these smallholder farms. The mean values of the constant term suggest that without inputs, expected yields are close to 1 T/ha. The data show that mean yields across main plots are 2.2 T/ha.

#### 4.2. Damage abatement model estimation

In the second stage of the analysis we include a damage abatement component in the econometric estimation, following the specification described above (Table 5). The

Table 5  
Damage abatement model estimation results

Explanatory variables	(1) Bt name	(2) Bt official	(3) Bt belief	(4) Bt presence	(5) Bt effective
Labour	0.213** (0.099)	-0.06 (0.189)	-0.059 (0.155)	0.361*** (0.099)	0.344*** (0.097)
Seed	-0.221* (0.123)	-0.292 (0.24)	-0.026 (0.189)	-0.024 (0.126)	-0.038 (0.123)
Nitrogen	0.117 (0.083)	0.102 (0.172)	-0.028 (0.136)	0.160* (0.083)	0.162** (0.082)
Irrigation	-0.149*** (0.045)	-0.027 (0.086)	-0.016 (0.07)	-0.133*** (0.046)	-0.130*** (0.045)
Land	-0.11 (0.083)	0.055 (0.171)	0.002 (0.14)	-0.051 (0.084)	-0.047 (0.082)
Education	0.02 (0.015)	0.049* (0.029)	0.009 (0.024)	-0.018 (0.015)	-0.015 (0.015)
Bt: name	3.160*** (0.439)				
Bt: official		1.580*** (0.197)			
Bt: belief			2.025*** (0.255)		
Bt: presence				3.467*** (0.531)	3.566*** (0.874)
Bt: effective					1.419** (0.691)
Insecticide	0.196*** (0.009)	0.159*** (0.009)	0.163*** (0.009)	0.217*** (0.009)	0.212*** (0.009)
Constant	6.562*** (0.683)	8.063*** (1.372)	7.861*** (1.112)	4.994*** (0.679)	5.027*** (0.659)
Observations	535	535	535	535	535
Adjusted R-squared	0.975	0.932	0.948	0.975	0.976

**Note:** All variables except Bt measures are logarithmic. Standard errors in parentheses; \*\*\* $P < 0.01$ , \*\* $P < 0.05$ , \* $P < 0.10$ .

**Source:** Authors.

fact that the constant terms are higher in this set of regressions than among those reported in Table 4 is consistent with the notion that  $F(Z)$  represents yield in the absence of pest damage (Qaim and de Janvry, 2005). We find that all Bt variables, in addition to insecticide use, positively and significantly reduce damage. The marginal effects are greater for Bt use than for insecticide use, and vary by different Bt measures. The strongest effect of all is the coefficient of the variable that measures Bt presence with Bt effectiveness. This model shows the strength of the experimentally-defined Bt measures relative to Bt belief or Bt name. The weakest magnitude of effect among all Bt measures is for official approval of the variety. This suggests that government approval fails to capture the true status of Bt cotton varieties in Pakistan.

Since we believe Bt presence combined with Bt effective best measures the effect of Bt, we use the last two specifications in Table 5 to interpret the contributions of other inputs. In these two specifications, the estimated yield elasticity of labour is again on the order of 0.3 and highly significant, similar to the Cobb-Douglas production model. The elasticity of N nutrient kgs per ha is 0.17, which is higher than in the basic Cobb-Douglas model, and statistically significant. Both labour and nitrogen inputs are only significant in models where Bt is measured based on the bio-physical studies, but not in the models where Bt is measured either by public information (Bt official) or farmers' private information (Bt name and Bt belief).

To better visualise the damage abatement effect from different Bt measures, we use the estimation results reported in Table 5 to compute the average predicted damage abatement effects for each Bt measure. As the damage abatement function  $G(X)$  lies between 0 and 1, the function is essentially a multiplier that indicates how effective each damage abatement choice is for yield protection. The closer the value is to 1, the more affecting is the damage abatement. Figure 2 illustrates the differences among the indicators we have tested. Bt name was omitted because it is the most unreliable of our indicators.

Our results suggest that without Bt, half of the yield will be lost if only an average amount of insecticide is applied. Officially approved Bt varieties, together with insecticides, can protect 88% of cotton yield from pest damages. If a farmer grows a variety

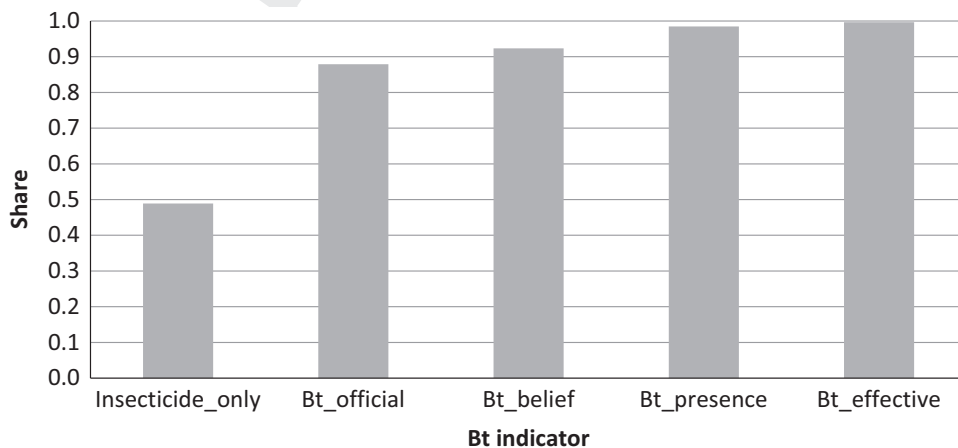


Figure 2. Average predicted damage abatement of different Bt indicators

*Source:* Authors.

that she believes to be Bt, then together with insecticide, 92% of cotton yield is protected. If a real Bt variety has been planted, as measured by Bt presence, no matter how effective the gene, then together with insecticide, 98% of yield is protected. A real and *effective* Bt variety will protect almost 100% of the yield based on our estimates.

In summary, we find that the integrity of Bt cotton varieties in Pakistan is closely associated with the abatement of damage to cotton from lepidopteran pests in Pakistan, and thus to maximum yield that can be obtained in the presence of pest pressures. These findings highlight the need for researchers – and, more generally, proponents of Bt technology – to use greater caution in measuring the yield impacts of Bt cotton in Pakistan, and in making the case that Bt cotton can contribute to yield improvement. These findings also highlight the utility of specific laboratory tests to measure the presence and efficacy of Bt gene expression when studying the economic impact of Bt cotton or other GM crops.

## 5. Conclusions and Implications

Since its introduction in 1996, Bt cotton has diffused rapidly and broadly across cotton-growing regions of the world. Its adoption by smallholder farmers has been most impressive in poorer countries, where accumulated evidence demonstrates its profitability, labour savings and substantial reduction of damage from *lepidopteran* insects.

One recurring, yet relatively unexplored thematic thread in the literature has been the recognition that smallholder cotton growers in poorer countries are not well informed about Bt cotton or how to grow it. Proponents of the crop might argue that certain types of knowledge are of no real importance if the crop benefits farmers; those observers who are concerned about the ethics argue that empowering poorer farmers with knowledge is a social imperative.

The term ‘variety integrity’ is often used to characterise a variety that grows true to its type or true to its label. We use this concept here. We take a pragmatic view that when a farmer does not know whether the seed he or she planted is Bt or not, and has no firm expectations concerning its effectiveness against pests, production plans are most likely to be suboptimal. In the aggregate, we would consider that such decision-making has both private and social costs in terms of output and savings foregone, potential contributions to future epidemics related to the buildup of genetic resistance to Bt toxin, and negative externalities from continued, excessive use of pesticides despite the adoption of Bt varieties.

Pakistan’s experience is particularly well-suited for a test of hypotheses concerning farmer knowledge of Bt expression. In Pakistan, Bt cotton was disseminated to farmers before it was officially approved, and the Bt cotton industry is highly competitive, with a large number of small-scale firms selling seed in local markets. The analysis in this paper contributes to the existing literature by testing the effects of various definitions of Bt cotton on productivity and damage control. We follow closely the work of major previous studies in our overall specification of the models, but introduce four definitions of Bt cotton in addition to variety name: (1) farmers’ belief; (2) official approval status; (3) presence of Bt; and (4) Bt effectiveness. The last two measures are based on measurements from laboratory tests, and the effectiveness variable is based on a combination of a continuous score and a threshold value from a bioassay. To our knowledge, previous studies, with the notable exception of work by Pemsil *et al.* (2005), have relied entirely on variety name.



The estimation of the Cobb-Douglas production function generates results that are broadly consistent with economic theory. The yield-enhancing inputs (fertiliser and labour) have a strong effect on cotton productivity. By contrast, insecticides, which are damage-controlling, have no discernible influence on productivity. None of the Bt measures, except 'Bt belief', has a significantly positive effect on yields in the standard production model. Believing that a cotton variety is Bt may be associated with better management practices which are not already controlled for in our covariates, or 'intrinsic' management characteristics. The insignificance of other Bt measures attests to the notion that the genetic backgrounds do not differ systematically between Bt and non-Bt varieties in Pakistan, so that there is no independent yield effect due to background. This last possibility echoes what has already been stated in the literature: it is difficult to distinguish the Bt effect when the backgrounds into which the Bt gene is placed may differ. Observed yield effects may be the Bt gene, the genetic background or the interaction of the two.

However, because of the potential for bias in estimated coefficients, the damage abatement framework is the preferred method for estimating the effects on productivity of inputs that maintain yields against pests and disease rather than directly enhancing yield. Using a damage abatement framework, we find that all Bt variables reduce yield losses alongside insecticide use, and by a relatively large magnitude. However, the models with the biophysical measures are the most complete. That is, these retain the strong positive effects of conventional inputs as well as the effects of Bt gene expression. The marginal effects of these measures are also considerably stronger than that of Bt belief. Our predicted average effects suggest that Pakistani farmers benefit greatly from adopting Bt cotton varieties, which potentially prevent more than half of the yield loss. However, the officially approved Bt varieties are considerably less effective than true Bt varieties (those which display the trait and those which are effective).

To our knowledge, our general finding regarding the variants of Bt and how these may differentially affect both farmers' capacity to control damage effectively are unique in the applied economics literature about GM crops. Our approach has highlighted the importance of measuring input in productivity analyses, and particularly in the study of biotech crops. Based on our analysis, we recommend measuring Bt toxin expression using biophysical methods if accuracy in assessing impacts is the objective and variety integrity is questionable. Farmer's self-reported status may be appropriate when variety identity is known by farmers. Our findings also have implications for the design and management of Pakistan's regulatory system governing both GM crops and seed more generally. The issues associated with seed and varietal integrity evidenced here suggest, first, the need for more effective monitoring systems. While there is little to suggest that seed certification systems are effective in ensuring seed quality for farmers, there is likely more that can be done with point-of-sale monitoring and other forms of market surveillance (Rana, 2014). This may be especially true if laboratory tests are used more routinely and if they become cheaper and faster to use. Second, our findings suggest that social welfare could be substantially increased by improving information dissemination to farmers – perhaps through engagement of farmer-based and/or private information channels.

These results are also applicable to the many lower income countries beyond Pakistan where seed quality is an issue. In his insightful review of the global evidence on Bt cotton, Tripp (2009) concluded that adopters of Bt cotton will not be the poorest of the poor, but those with more assets and knowledge. He emphasised that biosafety regimes and more investment in cutting edge research are necessary but not enough

for the crop to benefit poorer farmers, arguing the need for strong input markets and institutional design, and more germane to this study, empowering farmers through provision of information. Our results confirm this view. Believing a variety is Bt cotton when it is not is likely to be a utility-enhancing situation, let alone a profit-maximizing one, for smallholder farmers.

A number of years after the publication of Tripp's (2009) collection of studies, the results shown here for Pakistan suggest some crucial differences. There is no evidence here that Bt cotton farmers are more advantaged than other cotton farmers in Pakistan, and the prices they pay for seed are relatively low by global standards. Yet, there is considerable evidence that the integrity of the Bt cotton varieties they grow is questionable and that many do not know with certainty whether the varieties they are growing are Bt or not. While this may be cause for concern, our results confirm that no matter which definition we use, Bt cotton *per se* reduces damage significantly. On the other hand, none of the definitions except 'Bt belief' is positively associated with cotton productivity in the conventional production model. Thus, although better provision of information seems to be an ethical imperative, this may not necessarily improve cotton productivity.

### Supporting Information

Additional Supporting Information may be found in the online version of this article:

**Table S1.** Mean comparison of farm and farmer characteristics, final sample vs. dropped sample

### References

- Abedullah, S. K. and Qaim, M. 'Bt cotton, pesticide use and environmental efficiency in Pakistan', *Journal of Agricultural Economics*, Vol. 66, (2015) pp. 66–86.
- Ali, A. and Abdulai, A. 'The adoption of genetically modified cotton and poverty reduction in Pakistan', *Journal of Agricultural Economics*, Vol. 61, (2010) pp. 175–192.
- Ali, S., Shahid, H., Shahid, M., Ali, G. M. and Yusuf, Z. 'Status of Bt cotton cultivation in major growing areas of Pakistan', *Pakistan Journal of Botany*, Vol. 42, (2010) pp. 1583–1594.
- Ali, S., Shah, S. H., Ali, G. M., Iqbal, A., Asad, M. and Zafar, Y. 'Bt Cry toxin expression profile in selected Pakistani cotton genotypes', *Current Science*, Vol. 102, (2012) pp. 1632–1636.
- Areal, F. J., Riesgo, L. and Rodríguez-Cerezo, E. 'Economic and agronomic impact of commercialized GM crops: A meta-analysis', *Journal of Agricultural Science*, Vol. 151, (2013) pp. 7–33.
- Chambers, R. G., Karagiannis, G. and Tzouvelekas, V. 'Another look at pesticide productivity and pest damage', *American Journal of Agricultural Economics*, Vol. 92, (2010) pp. 1401–1419.
- Cheema, H. M. N., Khan, A. A., Khan, M. I., Aslam, U., Rana, I. A. and Khan, I. A. 'Assessment of Bt cotton genotypes for the Cry1Ac transgene and its expression', *Journal of Agricultural Science*, Vol. 153, (2015) pp. 1–9.
- Feder, G. and Slade, R. 'The acquisition of information and the adoption of new technology', *American Journal of Agricultural Economics*, Vol. 66, (1984) pp. 312–320.
- Fox, G. and Weersink, A. 'Damage control and increasing returns', *American Journal of Agricultural Economics*, Vol. 77, (1995) pp. 33–39.
- GOP (Government of Pakistan). *Census of Agriculture 2010* (Lahore: Agriculture Census Organization, 2012). Available at: <http://www.pbs.gov.pk/content/agricultural-census-2010-pakistan-report> (last accessed 30 May 2015).

- 1 GOP (Government of Pakistan). *Pakistan Economic Survey 2012–13* (Islamabad: Ministry of  
2 Finance, 2013). Available at: [http://www.finance.gov.pk/survey/chapters\\_14/02\\_Agriculture.pdf](http://www.finance.gov.pk/survey/chapters_14/02_Agriculture.pdf) (last accessed 30 May 2013).
- 3 Gruère, G. P. and Sun, Y. *Measuring the Contribution of Bt Cotton Adoption to India's Cotton*  
4 *Yields Leap*, Working Paper No. 01170 (Washington, DC: International Food Policy  
5 Research Institute, 2012).
- 6 Guan, Z., Lansing, A. O., Wossink, A. and Huirne, R. 'Damage control inputs: A comparison  
7 of conventional and organic farming systems', *European Review of Agricultural Economics*,  
8 Vol. 32, (2005) pp. 167–189.
- 9 Horna, D., Smale, M., Al-Hassan, R., Falck-Zepeda, J. and Timpo, S. *Insecticide Use on*  
10 *Vegetables in Ghana: Would GM Seed Benefit Farmers?* Working Paper No. 00785 (Washing-  
11 ton, DC: International Food Policy Research Institute, 2008).
- 12 Huang, J., Hu, R., Rozelle, S., Qiao, F. and Pray, C. 'Transgenic varieties and productivity of  
13 smallholder cotton farmers in China', *Australian Journal of Agricultural and Resource Eco-*  
14 *nomics*, Vol. 46, (2002) pp. 367–387.
- 15 James, C. *Global Status of Commercialized Biotech/GM Crops in 2014* (Ithaca, New York: Inter-  
16 national Service for the Acquisition of Agri-biotech Applications, 2014).
- 17 Klümper, W. and Qaim, M. 'A meta-analysis of the impacts of genetically modified crops',  
18 *PLoS ONE*, Vol. 9, (2014) pp. 1–7.
- 19 Kouser, S. and Qaim, M. 'Bt cotton, damage control and optimal levels of pesticide use in  
20 Pakistan', *Environment and Development Economics*, Vol. 19, (2014) pp. 704–723.
- 21 Lichtenberg, E. and Zilberman, D. 'The econometrics of damage control: Why specification  
22 matters', *American Journal of Agricultural Economics*, Vol. 68, (1986) pp. 261–273.
- 23 Liu, E. M. and Huang, J. 'Risk preferences and pesticide use by cotton farmers in China', *Jour-*  
24 *nal of Development Economics*, Vol. 103, (2013) pp. 202–215.
- 25 Mitchell, P., Shi, G., Ma, X. and Lauer, J. G. *Effect of Prices, Traits and Market Structure on*  
26 *Corn Seeding Density*, Selected paper, Annual Meeting of the Agricultural and Applied Eco-  
27 nomics Association, July 26–28, 2009, Milwaukee, Wisconsin. Available at: [http://agecon-](http://ageconsearch.umn.edu/handle/49520)  
28 [search.umn.edu/handle/49520](http://ageconsearch.umn.edu/handle/49520) (last accessed 30 May 2016).
- 29 Nazli, H., Orden, D., Sarker, R. and Meilke, K. *Bt Cotton Adoption and Well-being of Farmers*  
30 *in Pakistan*, Pakistan Strategy Support Program Working Paper No. 004 (Washington, DC:  
31 International Food Policy Research Institute, 2012).
- 32 Pemsl, D., Waibel, H. and Gutierrez, A. P. 'Why do some Bt-cotton farmers in China continue  
33 to use high levels of pesticides', *International Journal of Agricultural Sustainability*, Vol. 3,  
34 (2005) pp. 44–56.
- 35 Qaim, M. and de Janvry, A. 'Bt cotton and pesticide use in Argentina: Economic and environ-  
36 mental effects', *Environment and Development Economics*, Vol. 10, (2005) pp. 179–200.
- 37 Qaim, M. and Zilberman, D. 'Yield effects of genetically modified crops in developing coun-  
38 tries', *Science*, Vol. 299, (2003) pp. 900–902.
- 39 Rana, M. A. *The Seed Industry in Pakistan: Regulation, Politics and Entrepreneurship*, Pakistan  
40 Strategy Support Program Working Paper No. 19 (Washington, DC: International Food Pol-  
41 icy Research Institute, 2014).
- 42 Saha, A., Shumway, C. R. and Havener, A. 'The economics and econometrics of damage con-  
43 trol', *American Journal of Agricultural Economics*, Vol. 79, (1997) pp. 773–785.
- 44 Shankar, R. and Thirtle, C. 'Pesticide productivity and transgenic cotton technology: The  
45 South African smallholder case', *Journal of Agricultural Economics*, Vol. 56, (2005) pp.  
46 97–116.
- 47 Shi, G., Chavas, J. P., Lauer, J. and Nolan, E. 'An analysis of selectivity in the productivity  
48 evaluation of biotechnology', *American Journal of Agricultural economics*, Vol. 95, (2013)  
49 pp. 739–754.
- 50 Showalter, A. M., Heuberger, S., Tabashnik, B. E. and Carrière, Y. 'Development, agronomic  
51 performance and sustainability of transgenic cotton for insect control', in: R. Tripp (ed.),

- 1 *Biotechnology and Agricultural Development: Transgenic Cotton, Rural Institutions, and*  
2 *Resource-Poor Farmers* (New York: Routledge, 2009).
- 3 Smale, M., Niane, A. and Zambrano, P. 'Impact économique des cultures transgéniques sur les  
4 producteurs dans l'agriculture non-industrialisée: La première décennie', *Économie Rurale*,  
5 315, (2010). Available at: <http://economierurale.revues.org/index2512.html> (last accessed 30  
6 August 2015).
- 7 Sperling, L., Osborne, T. and Cooper, D. *Towards Effective and Sustainable Seed Relief Activi-*  
8 *ties*. FAO Plant Production and Protection Working Paper No. 181 (Rome: Food and Agri-  
9 culture Organization of the United Nations, 2004).
- 10 Spielman, D. J., Nazli, H., Ma, X., Zambrano, P. and Zaidi, F. 'Technological opportunity,  
11 regulatory uncertainty, and Bt cotton in Pakistan', *AgBioForum*, Vol. 18, (2015) pp. 98–112.
- 12 Tripp, R. *Biotechnology and Agricultural Development: Transgenic Cotton, Rural Institutions,*  
13 *and Resource-Poor Farmers* (New York: Routledge, 2009).
- 14 Xia, L., Xu, Q. and Guo, S. 'Bt insecticidal gene and its temporal expression in transgenic cot-  
15 ton plants', *Acta Agronomica Sinica*, Vol. 31, (2005) pp. 197–2002.
- 16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49

# Author Query Form

Journal: JAGE

Article: 12174

Dear Author,

During the copy-editing of your paper, the following queries arose. Please respond to these by marking up your proofs with the necessary changes/additions. Please write your answers on the query sheet if there is insufficient space on the page proofs. Please write clearly and follow the conventions shown on the attached corrections sheet. If returning the proof by fax do not write too close to the paper's edge. Please remember that illegible mark-ups may delay publication.

Many thanks for your assistance.

Query reference	Query	Remarks
1	<b>AUTHOR: A running head short title was not supplied; please check if this one is suitable and, if not, please supply a short title of up to 40 characters that can be used instead.</b>	
2	<b>AUTHOR: Please confirm that given names (red) and surnames/family names (green) have been identified correctly.</b>	
3	<b>AUTHOR: Qaim, 2009 has not been included in the Reference List, please supply full publication details.</b>	
4	<b>AUTHOR: Finger <i>et al.</i>, 2011 has not been included in the Reference List, please supply full publication details.</b>	
5	<b>AUTHOR: Crost <i>et al.</i>, 2007 has not been included in the Reference List, please supply full publication details.</b>	
6	<b>AUTHOR: GOP, 2014 has been changed to GOP, 2013 so that this citation matches the Reference List. Please confirm that this is correct.</b>	
7	<b>AUTHOR: Pemsl <i>et al.</i> (2011) has been changed to Pemsl <i>et al.</i> (2005) so that this citation matches the Reference List. Please confirm that this is correct.</b>	



8	<b>AUTHOR:</b> Figure 1 has been saved at a low resolution of 195 dpi. Please resupply at 600 dpi. Check required artwork specifications at <a href="http://authorservices.wiley.com/bauthor/illustration.asp">http://authorservices.wiley.com/bauthor/illustration.asp</a>	
---	---	--