

Bt Cotton Adoption: A Double-hurdle Approach for North Indian Farmers

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This article adds to the existing literature by identifying determinants of the Bt cotton adoption decision, as well as what influences the extent (or level) of adoption. Econometric results show that information is a vital factor behind adoption and level of adoption. Experience is a barrier to Bt cotton diffusion, while available credit encourages farmers to adopt. As farmers consider Bt cotton a remedy for the negative implications of pesticide application in non-Bt production, those with higher health costs are more likely to adopt. Higher profit potential is an incentive for farmers with relatively little farm area to adopt Bt cotton. Farmers with poor-quality soil are more likely to adopt, and their level of adoption is also greater. This is due Bt cotton being more suitable for areas with such soils, as compared to crops like rice. Thus, Bt cotton diffusion is more likely to be successful among relatively small farms and those in less fertile areas.

Key words: Bt cotton, adoption, Cragg model, Tobit model, probit model, North India.

Introduction

Cotton is an important cash crop in India. India has the largest area under cotton, but it is the world's second-largest producer. This occurs since the average yield in India (526 kg per hectare) is much lower than the world average (779 kg per hectare; Subbiah & Jeyakumar, 2009). Lower productivity is a real concern for India, especially with high population pressure and increasing demand for land for non-agricultural activities; it is quite difficult to increase cotton area in the country. Cotton production also faces several other challenges. Cotton is highly susceptible to pest attacks. Nearly half of the cotton crop in India is damaged by pests and diseases, compared to 24.5% world average. More than half of the technical-grade pesticides produced in the country are used in cotton production (Gandhi & Namboodiri, 2006). After continuous application of pesticides for several years in cotton fields, bollworms become resistant, making cotton production risky and non-profitable (Gandhi & Namboodiri, 2006). In addition, environmental and health hazards have slowly risen due to increasing pesticide application in cotton fields. In this situation, Bt cotton technology was introduced to India in 2002. Higher yields and lower pesticide costs that ultimately result in more profit encouraged farmers to adopt Bt cotton (Barwale, Gadwal, Zehr, & Zehr, 2004; Bennett, Kambhampati, Morse, & Ismael, 2006, Kiresur & Manjunath, 2011; Qaim, 2003; Qaim & Zilberman, 2003). Mal, A.V., Bauer, and Ahmed (2011) found that in North Indian

farming conditions, Bt cotton is more efficient in input use and has a lower environmental impact quotient, which indicates less damage to the environment than non-Bt cotton. Government policies, especially price interventions, helped adoption in India (Arora & Bansal, 2011).

Bt cotton is widely accepted by Indian farmers. Until 2010, more than 80% of total cotton area came under Bt cotton production (James, 2010). Though the adoption rate is quite impressive in all of India's regions, there are variations among them. At the beginning of Bt cotton introduction, North India had a poorer performance than other regions. The rate of adoption in the region was about 35% during 2007, whereas it was about 80% in some states of the southern and western regions. Later, Bt cotton adoption in North India crossed 80% of cotton area, which is even higher than some states like Gujarat and Madhya Pradesh in the western and central regions, respectively (Arora & Bansal, 2011; Choudhary & Gaur, 2010). In our work we try to identify farm-level factors that encouraged early adoption of Bt cotton. Understanding these factors could be helpful in planning new technological interventions.

With very few exceptions, available empirical studies on cotton production in India address profitability and productivity issues. The issue of adoption is not very common. We could access two studies on Bt cotton adoption in India. One is a paper (presented at a seminar) by Arora and Bansal (2011). Their work is at the macro level to identify the effects of seed prices and

technological development on adoption. By using different dynamic logistic regression models, they found that reductions in seed price and technological developments enhance diffusion rates. Though this macro-level study is quite useful for designing policy regarding seed price and technology development, it may not be useful while designing micro-level policy. In certain situations an individual farm's characteristics can become more important than macro policies (i.e., if a technology contradicts social norms or if farmers find it difficult to practice a new technology, it may never catch on, despite government interventions or attractive profits). As under the same policy framework some farmers adopt Bt cotton and some do not, it is quite logical to assume that there are farm-level characteristics which may influence adoption decisions; we will explore these in this article. Another study was conducted by Kiresur and Manjunath (2011) to identify the Bt cotton adoption factors in northern Karnataka state, which is situated in the southern region of India. According to their logit model, costs of seed and plant protection chemicals work against adoption, but yields of Bt cotton positively influence the decision in favor of adoption.

There are several ways in which our work differs from these studies and may contribute to the existing pool of literature. First, unlike previous studies, we not only analyze the farmer decision on adoption, but also the factors that influence the level of adoption. Our findings should not only be helpful in increasing the number of adopters, but also individual farmers' land shares in Bt cotton. Secondly, until now, literature does not account for the factors of health costs and soil quality in adoption, though these might have notable influence. Finally, to date, no study has been done to better understand and explain the factors responsible for the impressive Bt cotton adoption rate in northern India. Because in India policies regarding Bt cotton do not notably vary across regions, the relatively remarkable adoption rate in the North might be an outcome of certain farm-community-level characteristics.

The article is divided into four sections. This introductory section is followed by a methodological section where data and econometric models are described. This is followed by the results section which contains the findings of the study and discussions. Finally, the results are summarized and presented in the conclusion.

Methodological Aspects

Data and Survey

A total of 200 cotton farmers belonging to eight different villages in two North Indian states (Haryana and Punjab) were interviewed about their cotton farming experience in the 2007-2008 cropping year. The farmers were selected through a multi-stage sampling technique. The selection criteria for states, districts, and villages were purposeful in our study to find areas with the highest cotton production. At the village level, farmers were selected randomly using a list of cotton growers available from the State Agriculture Department. This is a complete list of farmers in each village kept by the department. The list is updated annually, as it serves as one of the major sources of agricultural census.

Empirical Models

Among our sample farmers, some cultivate Bt cotton and some non-Bt cotton. Also, there are differences in level of adoption among the adopters. Some of the adopters utilized all their available land for Bt cotton, whereas others used only a share of their land. Hence, we have two questions to answer: why are some adopting and some not, and why does the level of adoption vary among the adopters? We use a Cragg's double hurdle model to answer these two questions. Use of Cragg's model for analyzing adoption and level or intensity of adoption is common in agricultural economic literature (Cooper & Keim, 1996; Gebregziabher & Holden, 2011; Shiferaw, Kebede, & You, 2008; Teklewold, Dadi, Yami, & Dana, 2006). Another alternative here might be the Heckman selection model. According to Jones (1989), one of the important differences between these two models concerns the sources of zeros. In the Heckman model, the non-adopters will never adopt under any circumstances. On the other hand, in a double hurdle model, non-adopters are considered as a corner solution in a utility-maximizing model. In the case of Bt cotton, the assumption of Heckman's seems to be too restrictive. Changes in input price or extensive extension programs may encourage non-adopters to adopt. Hence, we used Cragg's double hurdle model instead of Heckman's.

According to Cragg's model, a farmer faces two hurdles while deciding on Bt cotton cultivation. The first is to decide whether to cultivate Bt cotton. The second hurdle is related to the level of adoption, or how much land or capital to allot to Bt cotton production. The most important underlying assumption of the model is that

these two decisions are made in two different stages. At the beginning of a cropping season a farmer may decide to cultivate Bt cotton without making exact plans about the quantity of land. Many factors can influence a farmer's decision afterwards, i.e., price and availability of inputs, potential to cultivate competing crops, information about production technology, etc.

The first stage of Cragg's model is a probit model to analyze determinants of adoption, and the second stage is a truncated model for determinants of the level of adoption (Cragg, 1971). If d_i^* is the latent variable describing a farm's decision to adopt, y_i^* is the latent variable describing its decision on the level of adoption, and d_i and y_i are their observed counterparts, respectively. Based on the specification by Cragg (1971) and Moffatt (2005), the two hurdles for a farmer can be written as

$$d_i^* = \alpha z_i + v_i \tag{1}$$

$$y_i^* = \beta x_i + \varepsilon_i, \tag{2}$$

where

$$d_i = \begin{cases} 1, & \text{if } d_i^* > 0 \\ 0, & \text{if } d_i^* \leq 0 \end{cases} \text{ and } y_i = \begin{cases} y_i^*, & \text{if } y_i > 0 \text{ and } d_i^* > 0 \\ 0, & \text{if otherwise} \end{cases},$$

where z_i is the vector of variables explaining whether a farmer adopts Bt cotton technology, x_i is a vector of variables explaining level of adoption, and v_i and ε_i are the error terms.

The dependent variable in the first stage is the farmer's adoption decision. This variable is binary in nature, taking numeric value 1 for adopters, and 0 for non-adopters. In the second stage, the dependent variable is the Bt cotton land ratio (the ratio of quantity of land under Bt cotton production to total farm land). As the variables explaining adoption can also explain level of adoption, the same set of independent variables are used in both stages. The list of explanatory variables include number of cotton information sources; farming experience (years); education of the farmer (years of formal schooling); farmer's access to credit facilities available in the locality (dummy, 1=farmers have access);¹ log of annual off-farm income earned by the members of the family who are not engaged in farming, i.e., profit from petty business, investment dividends, salaries and remittance (Rs.);² log of farm area (acres); membership in a farmer's club or society that provides useful information regarding farming (dummy, 1=mem-

ber);³ log of annual health costs resulting from pesticide use, before adopting Bt (Rs.);⁴ and soil fertility (dummy, 1 for farms with fertile soils; 0 for farms with poor soil).⁵

According to Carroll, McCarthy, and Carol (2005), Equations 1 and 2 are assumed to be independent, and therefore the error terms are randomly and independently distributed, $v_i \sim N(0,1)$ and $\varepsilon_i \sim N(0,\sigma_\varepsilon^2)$. The log-likelihood function for this version of Cragg's model assumes the probit and truncated regressions to be uncorrelated and is given as

$$L = \prod_{y_i=0} \left[1 - \Phi(z_i\alpha)\Phi\left(\frac{x_i\beta}{\sigma}\right) \right] \prod_{y_i>0} \Phi(z_i\alpha)\sigma^{-1}\phi\left(\frac{y_i - x_i\beta}{\sigma}\right), \tag{3}$$

where Φ and ϕ are the standard normal cumulative distribution function and density function, respectively. The log-likelihood function is estimated using the maximum likelihood estimation (MLE) technique.

The double-hurdle model is reduced to the Tobit model when the probit mechanism ($d_i^* > 0$) is absent in Equation 2. This can also be seen in the log-likelihood function presented in Equation 3, when $\Phi(z_i\alpha) = 1$. The Tobit model arises if $\alpha = \beta/\sigma$ and $x = z$ (Martínez-Espínora, 2006). Absence of the probit mechanism implies that the decision about adoption and level of adoption are made simultaneously. We also develop a Tobit

1. *During the survey, a farmer was asked whether he was eligible for credit by fulfilling different requirements (i.e., collateral of the credit, interest rates, etc.) of the credit institutions. The enumerators explained the requirements to the respondents. Farmers who believed they were capable of fulfilling these requirements were treated as having access to credit facilities.*
2. *One may suspect endogeneity with this variable, as Bt adoption affects labor use and hence there might be reverse causality. But we do not think such reverse causality exist in our estimation, as we did not include agricultural labor income while calculating the off-farm income.*
3. *Mostly, these are clubs or societies organized by governmental and non-governmental organizations (NGOs) working in the field of agriculture. These clubs or societies introduce and encourage the use of new farming technologies. They also provide advice services when a farmer faces any specific farming problem. Some cooperative societies also have clubs or societies for their members. Very few of these clubs or societies are self-organized by the farmers to share their experience.*

model and do a standard likelihood ratio test between the Tobit and double-hurdle model to know how these decisions are made. Following Gujarati (2003), the Tobit model for our specific case can be written as

$$y_i = \begin{cases} \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \dots + \beta_k x_{ki} + \mu_i & \text{if Bt cotton land} \\ 0 & \text{ratio} > 0 \text{ otherwise} \end{cases} \quad (4)$$

where $\beta_0 \dots \beta_k$ are the unknown parameters to be estimated and $x_{1i} \dots x_{ki}$ are the same set of explanatory variables used in the second stage of the Cragg model. Using MLE, the Tobit model is estimated. According to Maddala (1992), the likelihood function for the Tobit model can be written as

$$L = \prod_{v_i > 0} \frac{1}{\sigma} f\left(\frac{y_i - \beta x_i}{\sigma}\right) \prod_{v_i \leq 0} F\left(-\frac{\beta x_i}{\sigma}\right). \quad (5)$$

Through maximizing the function with respect to β and σ , we get the MLE estimates of these parameters.

As the Tobit model is nested in the Cragg model, it is possible to compare these two models through a standard likelihood ratio test when the determinants in both hurdles are the same (Buraimo, Humphreys, & Simmons, 2010). The test statistics can be computed as (Greene, 2000)

$$\Gamma = -2 [\ln L_T - (\ln L_P + \ln L_{TR})] \sim \chi_k^2, \quad (6)$$

where L_T , L_P , and L_{TR} are log-likelihoods of the Tobit, probit, and truncated regression models, respectively. Rejection of the null hypothesis ($\Gamma > \chi_k^2$) argues for superiority of the double-hurdle model over the Tobit model and establishes that the decisions about adoption and level adoption are made in two different stages.

4. Health costs include medical expenses and loss of earnings due to illness caused by pesticide use. Loss of earnings is calculated through opportunity cost. Different farmers adopted Bt in different years. An inflation rate is used to make different years' health costs comparable to 2007-2008.
5. Soil quality is based on soil type. We considered sandy and sandy loam as poor fertile land; whereas clay, clay-loam, red soil and black soil are fertile (Koning, 1994). When farmers were not sure about type of soil, assistance from an agriculture inspector was asked. Our sample farmers mostly cultivated Bt cotton in a single plot; in case of multiple plots, the geographic distance between plots within a farm was little and, hence, quality differences were not notable.

Table 1. Comparison of costs and returns from Bt and non-Bt cotton production.

Items	Bt cotton (N=160)	Non-Bt cotton (N=40)
Seed (Rs./acre)	1,364.5 (207.5)	256.5 (73.4)***
Fertilizer (Rs./acre)	1,739.5 (1,040.6)	915.1 (486.2)***
Pesticide (Rs./acre)	867.3 (458.70)	1,690.3 (721.87)***
Irrigations (Rs./acre)	1,024.8 (334.2)	567.0 (281.2)***
Labor (Rs./acre)	4,192.0 (546.3)	3,672.0 (595.6)***
Other operational cost (Rs./acre)	1,916.5 (244.1)	1,823.2 (247.2)***
Total variable cost (Rs./acre)	11,104.9 (1,672.0)	8,924.1 (1,377.3)***
Yield (kg/acre)	973.75 (199.8)	665.00 (157.8)***
Gross income (Rs./acre)	22,328.1 (4,840.3)	14,799.3 (3,684.41)***
Profit (Rs./acre)	11,223.2 (4,150.3)	5,874.7 (3,126.37)***

Note. Figures in parentheses are standard deviations.
 *** indicates that mean differences between the adopters and non-adopters are significant at the 1% confidence level.
 Exchange rate: 1 Rs. = US\$0.021 (approximately)

Results and Discussions

Costs and Returns from Cotton Production

A comparison of costs and returns from Bt and non-Bt cotton production are presented in Table 1. Costs of all inputs except pesticides are relatively higher for Bt growers and these ultimately result in higher variable costs for them. The most notable difference exists in the case of seed cost. Due to higher seed prices, Bt growers bear more than five times higher seed costs than non-Bt growers. Costs of fertilizer and irrigation are almost double for the Bt-growing farms, as Bt growers used higher quantities of these inputs. Irrigation charges include electricity/fuel and canal charges. It is worth mentioning that in Haryana and Punjab, cotton is cultivated almost exclusively with irrigation (Singh, 2009). One reason for increased inputs use could be that Bt cotton seed is more expensive than non-Bt cotton, and therefore Bt farmers pay close attention to crop management (Qaim, Subramanian, Naik, & Zilberman, 2006). Higher production costs for Bt growers are compensated by higher yields. Bt growers earn roughly 33% and 50% more gross income and profit than non-Bt cotton,

Table 2. Summary statistics of the explanatory variables used in econometric models.

Variables	Adopter (N=160)	Non-adopter (N=40)
No. of information sources	3.72 (1.12)	2.85 (1.37)***
Membership of any club/society (1=member)	0.46 (0.49)	0.05 (0.22)***
Experience (years)	21.46 (9.14)	28.25 (7.85)***
Education (years)	6.60 (5.00)	3.15 (3.59)***
Annual off-farm income (Rs.)	158,616.00 (67,752.22)	136,800.00 (53,000.32)**
Access to credit (1=farmers with access)	0.27 (0.45)	0.15 (0.36)*
Farm size (acre)	10.87 (5.85)	9.83 (5.04)
Annual health cost (Rs.)	882.82 (430.55)	710.51 (225.05)**
Soil fertility (1=fertile)	0.24 (0.43)	0.57 (0.50)***

Note. Figures in parentheses are standard deviations. *, **, and *** indicate that mean differences between the adopters and non-adopters are significant at the 10%, 5%, and 1% confidence levels, respectively.

respectively. Relatively higher production costs and profitability for Bt growers are also reported in the works of Naik (2001), Bennett et al. (2006), Qaim et al. (2006), and Mal et al. (2011).

Summary Statistics of Variables Used in Econometric Models

Table 2 presents summary statistics of different explanatory variable used in the econometric models. According to the table, significant differences between the adopters and non-adopters exist in all the variables except farm size. Adopters have more information sources than non-adopters. In the study area, farmers get information from formal sources, such as extension workers, agricultural departments, seed companies, input dealers, and agricultural universities. They also get information from informal sources, such as neighboring farms and friends. A relatively high proportion of adopters are members of a farmer club or society. Adopters are more educated but less experienced than non-adopters. Compared to non-adopters, the adopters earn more off-farm income. The proportion of farmers with access to credit facilities is significantly higher in the group of adopters. Annual health cost due to pesticide use is also significantly higher for Bt adopters. The

Table 3. Determinants of adoption level (dependent variable: Log of Bt cotton land share to total land).

Variables	Probit ^a coef. (S.E.)	Truncated ^b coef. (S.E.)
No. of information sources	0.37*** (0.11)	0.008 (0.007)
Membership of any club/society (1=member)	1.48*** (0.43)	0.081*** (0.019)
Experience (years)	-0.045*** (0.02)	-0.002** (0.001)
Education (years)	0.043 (0.03)	-0.006*** (0.002)
Log of annual off-farm income (Rs.)	0.70 (0.48)	0.068** (0.033)
Access to credit (1=farmers with access)	0.67** (0.33)	0.051*** (0.024)
Log of farm size (acre)	0.04 (0.35)	-0.064*** (0.024)
Log of annual health cost (Rs.)	0.85** (0.44)	-0.016 (0.024)
Soil fertility (1=fertile)	-1.16** (0.58)	-0.132*** (0.039)
Interaction of farm area and soil fertility	-0.01 (0.05)	0.006*** (0.003)
Constant	-14.56*** (6.18)	-0.154 (0.390)

Notes. ^a Probit estimate, which is Tier 1 of Cragg’s “two-tier” model

^b Tier 2 of the Cragg’s double-hurdle model.

Figures in parentheses are standard errors.

*, **, and *** indicate significance levels of 10%, 5%, and 1%, respectively.

proportion of farmers with poor soil on their farms is relatively higher in the group of Bt cotton growers.

Factors Influencing Adoption Decision and Level of Adoption

Factors influencing a farmer’s decision about adopting Bt cotton technology and its level of adoption are presented in Table 3. The determinants of adoption are identified through a probit model, which is the first stage or Tier 1 of Cragg’s double-hurdle model. Probability of adoption is found to be positively influenced by number of information sources, membership in a club/society, access to credit, and log of annual health costs. But adoption probability is less among experienced farmers and in those with fertile land. Tier 2 of Cragg’s model estimates determinants of adoption level. A Tobit model is also developed for the same reason. As we developed two models with two different hypotheses, here it is important to know which model is superior to

the other. To determine this, we conducted a log-likelihood test as presented in Equation 6. The calculated test statistic is $\Gamma = 91.88$ and is well above the tabulated value [$\chi_k^2(10) = 23.21$] at a 1% level of significance. Hence we can say that the Cragg's model better fits our data than the Tobit model. This implies that a farmer's decision about adoption and level of Bt cotton adoption are made in two different stages. Hence, from here on discussions are based on the findings of the Cragg's model. Findings of both the Tobit and Tier 2 of the Cragg's model in terms of associated signs of explanatory variables are similar. Some differences exist in levels of significance. Variables having a significant positive coefficient in both the models are membership in a club/society, log of annual off-farm income, and access to credit; whereas experience, soil fertility, and the interaction of farm area and soil fertility are found to have negative significant impacts on level of adoption. The coefficients of education and farm size have negative signs in both models but are significant only in Tier 2. The number of information sources has a positive and significant impact in the Tobit model. Log of annual health cost is negative and insignificant in both models. As the findings of both the Tobit and Tier 2 are similar, and the log-likelihood test statistics argue that a farmer's decision about adoption and level of adoption are made in two different stages, the Tobit model results are not presented in details.

Farmers' probability of making a decision in favor of adopting Bt cotton increases significantly when they have more information sources and become members of a farmers' club or society. These two variables also positively contribute to level of adoption, but only the membership variable has a significant impact on adoption level (Table 3). Interaction with different information sources and societies or clubs helps farmers gather information and knowledge about cultivating and performance of Bt cotton. Information reduces doubts about the performance of a technology, which may change judgment from subjective to objective (Caswell, Fuglie, Ingram, Jans, & Kascak, 2001).

Experienced farmers are less likely to adopt, and even if they do, their level of adoption is lower than that of younger farmers (Table 3). This may happen because the more experienced farmers have invested several years using particular practices and may not want to bear challenges or risks by trying a new method. According to available literature, experience can have either a positive or negative effect on adoption. Matuschke and Qaim (2009) found that since the experi-

enced farmers in India do not want to change their traditional or conventional seed varieties, they have a lower probability of adopting pearl millet hybrids. On the other hand, Thirtle, Beyers, Ismael, and Piesse (2003) found farming experience increases the likelihood of Bt cotton adoption in South Africa.

Education affects adoption probability positively, but the effect is insignificant. In the second stage of the Cragg's model, this variable shows a negative and significant impact (Table 3). Generally, studies argue for positive correlation between education and adoption (Adeogun, Ajana, Ayinla, Yarhere, & Adeogun, 2008; Feder, Just, & Zilberman, 1985). Maurice, Wilfred, and Yesuf (2010) argued that education of household increases the probability of adoption because an educated farmer is more competent and able to access and assimilate information regarding various technologies, their advantages, and disadvantages. In India, Bt cotton does not always produce a good reputation due to incidences like farmer suicides and crop failures. Groups of researchers and academics, different media, civil society's organizations, and NGOs are vocal and active against Bt cotton. Educated farmers are more likely to be aware of these issues, and they may affect the farmer's probability of adoption. But this may not sufficiently explain the lower adoption level of the educated. There are other possibilities; for example, educated farmers are more likely to have off-farm income-generating activities, and they might rely less on income from agriculture. Hence, higher profit potential may not be that interesting to them as it is for less-educated farmers. Educated farmers also like to balance the use of land with different crops. They are well informed about the economics and price trends of different crops like oil-seeds, cluster bean, etc.; therefore, they diversify crop production. Risk aversion through crop diversification is more likely to be practiced by educated farmers.

Access to credit facilities is another variable that significantly influences the probability of adopting Bt cotton. Access to credit also significantly effects level of adoption (Table 3). As Bt cotton requires relatively more capital (Table 1), access to credit may help farmers decide in favor of adoption. For resource-poor farmers in India, fulfilling the entire capital requirement for Bt cotton from their own sources is very difficult. Assurance of some financial support may encourage farmers in this regard. The positive impact of credit on adoption is well documented in literature (Aikens, Havens, & Flinn, 1975; Langyintuo & Mekuria, 2005; Smale, Just & Leathers, 1994).

The effect of farm size on level of adoption is negative and highly significant (Table 3). This implies that with increasing farm land, farmers tend to allocate a relatively lower share of their land to Bt cotton. According to available literature, farm size and adoption do not have single type of relationship. Some literature reports a positive relationship (Abara & Singh, 1993; Feder et al., 1985; Fernandez-Cornejo, 1996; Kasenge, 1998; McNamara, Wetzstein, & Douce, 1991), whereas other studies observed a negative relationship (Harper, Rister, Mjelde, Drees, & Way, 1990; Yaron, Dinar, & Voet, 1992). Generally it is argued that technology adoption is less likely on small farms associated with high fixed costs (Abara & Singh, 1993). But adopting Bt cotton technology does not require any such investment. A counter argument regarding the effect of farm size is offered by Yaron et al. (1992). To them, little land area may also act as incentive to adopt a technology, especially in the case of an input-intensive innovation such as a labor-intensive or land-saving technology. Small farms face more challenges for their livelihood than do large farms, and they might be more aggressive towards new technology if they assume it to offer higher profit potential. Large farms might earn enough for their livelihood and thus not be willing to take on challenges associated with new technology. Moreover, in our study areas, there is less potential for expanding farm size, as demand for non-agricultural land is continuously increasing. Hence, for farmers, the most likely option for betterment of their livelihood is to increase input-productivity, and small farmers are most likely to explore such potential.

Compared to Bt cotton, non-Bt cotton requires a relatively higher quantity of pesticides and its inherent implications, hence the cost is also higher for them (Table 1). Bollworms are becoming resistant to certain insecticides and non-Bt growers observe expanding budgets for insecticides (Gandhi & Namboodiri, 2006). Use of insecticides also introduces health hazards and costs. Bt cotton provides a solution for farmers, as it has resistance to bollworms. Bt growers apply less insecticide and experience fewer health problems. The health cost variable is included in the adoption model with the assumption that farmers who experience higher health costs are more likely to adopt. We also observe a positive correlation between health cost and level of adoption, but the relationship is significant only in the adoption model (Table 3). Higher health costs associated with non-Bt cotton production may encourage farmers to turn to Bt cotton, as Bt cotton has the poten-

tial to keep health costs at relatively lower levels due to relatively less use of pesticides.

The negative sign of the soil fertility variable in our adoption model indicates that a farmer's probability to adopt Bt cotton increases when available land (or certain portions of land) is not fertile enough. In such situations, farmers also cultivate Bt cotton on relatively higher portions of land (Table 3). Rice is the major competitor of Bt cotton in the study areas. Cash crops like cotton will have priority over rice only if the farmer's motive is profit maximization. This is very unlikely to be true for our sample farmers, as most of them operate small- or medium-size farms and whose economic situation is not very solid. Hence, we can easily assume that after ensuring a supply of adequate and high-quality inputs for rice, a farmer plans for Bt cotton. Furthermore, compared to Bt cotton, rice production requires relatively good land. In this study, sandy and/or sandy loam types of soil are considered non-fertile, as water-holding capacity and mineral content is lower in these soils (Koning, 1994). Growing rice in these soils is very difficult. Alternatively, Bt cotton requires less water; hence, a farmer with poor soil is more likely to use that land for Bt cotton. A farmer may also be aware of the debate regarding negative impacts of Bt cotton on soil quality (Institute of Science in Society [ISIS], 2009) and may not be willing to take risks with his best/quality soil. Moreover, compared to rice, Bt cotton production is a risky enterprise for several reasons, including production uncertainty, reliance on input-output markets, high seed prices, less familiarity with Bt cotton, difficulties in storing, etc. A higher probability of producing Bt cotton on relatively low-quality land may also be an outcome of a farmer's risk aversion.

Conclusion

This article is an attempt to empirically identify factors that influence early adoption of Bt cotton and level of adoption in Northern India. These findings are useful for increasing Bt cotton production through enhancing adoption and level of adoption. The empirical findings show that the members of different farmers' clubs or societies are more likely to adopt and their level of adoption is also higher. A farmer increases his land under Bt when he gets information from different sources. Compared to experienced farmers, early adoption was more common among younger farmers. A lower proportion of experienced farmers adopted Bt cotton and they used relatively lower portions of land compared to young farmers. Farm families with additional

income from non-farm sources adopted more, as they have additional income to meet Bt production costs. Access to credit helps in Bt adoption and enhances the level of adoption. Bt is more likely to be adopted in relatively less fertile land. Level of adoption is also higher in these types of land. The relatively higher suitability of Bt cotton compared to rice in poor quality land and farmers' risk-averse character are the underlying reasons here. Due to higher profit potential, farmers with relatively little land are more likely to adopt.

In this article, we argue for Bt cotton adoption since it is the most likely option for increasing cotton production and farm profit; Indian government policies are also along this line. But along with profit potential, Bt cotton also has brought controversy. Academics, policymakers, NGOs, and civil-society organizations have expressed their concerns over possible threats of Bt cotton. Addressing all these issues is beyond the scope of the present study. The ecological impacts of Bt cotton need to be considered while designing policy. Therefore, we recommend studies considering both the economic and environmental aspects of Bt cotton in India.

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