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Technical Efficiency and Environmental Impact of Bt Cotton and Non-Bt Cotton in North India

Puran Mal, Manjunatha A.V., Siegfried Bauer, and Mirza Nomman Ahmed
Justus Liebig University Giessen, Germany

Bt cotton technology has emerged as an advantageous alternative to traditional cotton varieties by inhibiting bollworm attack, thereby improving farm production and income. This study focuses on analyzing the technical efficiency and environmental impact (via insecticide use) of Bt cotton farms compared to non-Bt cotton farms using the stochastic frontier approach and the Environmental Impact Quotient (EIQ), considering primary data from agriculturally progressive states of India. The results indicate that average technical efficiency is higher in Bt cotton farming. Roughly 80% of Bt cotton farms fall in the efficiency category of 80-95%; this percentage falls to 60% in non-Bt farms. In addition, Bt cotton demonstrates a lower EIQ value than non-Bt cotton, indicating less damage to the environment. The results can provide positive insights to the Indian Government for pushing this efficient technology towards expansion.

Key words: Bt cotton, Environmental Impact Quotient, India, stochastic frontier approach, technical efficiency.

Introduction

Cotton is an important cash crop in India and in many parts of the sub-tropical world. Cotton and its value-added products are major export earners for India's national income. It is the most important raw material for the Indian textile industry. The Indian cotton industry provides employment to more than 15 million people, contributing 20% to the Gross National Product and 30% to the total agricultural exports. India annual exports of cotton yarn, thread, fabrics, and apparel earn to the tune of US$10-12 billion as foreign exchange. It accounts for more than 75% of the total fiber that is converted into yarn by spinning mills in India and 58% of the total textile fabric materials produced in the country (Subbiah & Jeyakumar, 2009). Both the area cultivated and production of cotton started increasing in 1990-1991 and continued to do so until 2001-2002. In 2002-2003, both the cotton cultivated area and production decreased because of high insect infestation in general and bollworms in particular. But after 2003-2004, cotton area and production again increased because of the introduction of genetically modified cotton in March 2002 (Singh, 2009). In 2008-2009, the area under cotton amounted to 9.4 million hectares with production of 4.93 million tonnes, having increased at a compound growth rate of 1.2% and 12% in the past decade, respectively, indicating the contribution of Bt cotton in increasing productivity (Singh, 2009). Historically, Indian farmers have incurred huge losses due to bollworm infestation, to the extent of 20-50% in production (Bose, 2000). In this regard, Bt cotton technology has emerged as a substitute for the traditional cotton varieties, reducing bollworm attack and thereby improving farm production and income. Despite the beneficial role of Bt cotton in improving production and reducing insecticide use, its application and use remains a rigorously discussed topic; mainly two research views exist: (i) Bt cotton farmers have higher yields and higher returns, and their practice is considered better to the environment than conventional cotton growers (Barwale, Gadwal, Zehr, & Zehr, 2004; Morse, Bennett, & Ismael, 2006; Qaim, 2003; Qaim & Zilberman, 2003), and (ii) Bt cotton farmers have lower yields and lower returns and impose greater damage to the environment relative to conventional cotton (Institute of Science in Society [ISIS], 2005; Qayum & Sakkhari, 2005; Shiva & Jafri, 2004). With this background, the current study aims at clarifying the doubts about the role of Bt cotton by analyzing the technical efficiency and the environmental impact of Bt and non-Bt cotton farming using the stochastic frontier approach (SFA) and the Environmental Impact Quotient (EIQ), respectively, considering primary data (2007-2008) from the most agriculturally progressive states of India, Haryana, and Punjab.

In this article, we next present a theoretical review, followed by the methodology. Then, we discuss the results before the final section concludes the article by presenting the implications.

Theoretical Review of Bt and Non-Bt Cotton

The introduction of Bt cotton to the Indian market has reduced the dependency on agro-chemicals for crop protection, thereby dramatically changing the cotton scenario in India. There have been a number of studies before and after the approval of Bt cotton varieties reporting that Bt cotton is more profitable than conventional cotton. Naik (2001) found a 78.8% profit increase due to better yields and a 14.7% reduction in pesticide costs through the use of Bt cotton in India. Qaim (2003) and Qaim and Zilberman (2003) came to similar findings. They reported that Bt cotton generates 80-87% higher yield than non-Bt cotton, owing to the availability of the Bt gene, which is effective for controlling the bollworm species in different cotton-growing areas. An average increase in yield to a tune of 30% and revenue increases of Rs.18,000 per hectare compared to non-Bt cotton have been reported (Barwale et al., 2004; Smale, Zambrano, & Cartel, 2006). Similarly, several empirical studies carried out in Maharashtra, Andhra Pradesh, Karnataka, Tamilnadu, Gujarat, and Madhya Pradesh by Ramagopal (2006); Qaim, Subramanian, Naik, and Zilberman (2006); Gandhi and Namboodiri (2006); Associate Chambers of Commerce and Industry of India (ASSOCHAM, 2007); and Subramanian and Qaim, (2009) indicate that Bt cotton farmers are benefiting from higher yields and reduced pesticide expenses in comparison with non-Bt cotton farmers.

These findings are being criticized on the grounds of higher costs of production (Sahai & Rahman, 2003) and in this regard, private companies have falsified the performance of Bt cotton in reducing pesticide use and increasing yields (Venkateshwarlu, 2002). From the price point of view, it was also reported that Bt cotton received prices 10% lower in the local market (Business Line, 2002). Other studies have reported that new pests and diseases have been found in Bt cotton varieties, and in some instances the Bt gene failed to provide protection from the bollworm (Research Foundation for Science, Technology, and Ecology, 2002). Shiva and Jafri (2004) observed that Bt cotton is unsuitable for developing countries, causing negative impacts in the small farming sector. This was clearly stated in the study by ISIS (2005), which reported that Bt cotton has totally failed in India and non-Bt cotton farmers earned 60% higher income than Bt cotton farmers due to the damage caused by root rot disease. Along similar lines, Qayum and Sakkhari (2005) concluded that Bt cotton is not favorable for smallholder farmers and rain-fed areas, reporting nearly 30% less yield than non-Bt cotton. Despite these concerns, the area under cultivation with Bt cotton is steadily increasing and farmers' willingness to adopt this technology to increase yield and reduce pest damage is reportedly growing. In view of this controversy, this study follows a systematic and empirical approach in order to provide useful information to policymakers.

Methodology

Data Collection and Study Area

Data were collected through random sampling from two agriculturally progressive states of North India for the agricultural year 2007-2008. The Punjab and Haryana states were chosen, as they are the main cotton producers, contributing more than 72% to the total cotton production of North India. Within each state, four villages from two districts were selected using a multi-stage sampling technique for data collection. From each village, primary data was collected through random sampling of 25 farmers from eight villages of four districts, comprising a total of 200 cotton farmers. The cotton farmers interviewed consisted of 160 Bt cotton and 40 non-Bt cotton farmers. Detailed information from the cotton-producing farmers on socio-economics and farming profile, input use and output, costs, and returns were collected using structured questionnaires.

Concept of Efficiency and Stochastic Frontier Approach to Measure Efficiencies

The concepts of efficiency and productivity are commonly used to replace each other in spite of their different meanings. Productivity can be used as the ratio of output to input of a given firm, whereas efficiency is defined as the ratio of the maximum possible output on the production frontier to a given level of input (Coelli, Rao, O'Donnell, & Battese, 2005). The estimation of efficiency began with the work of Farrell (1957), who explained the concept of a firm's efficiency considering multiple inputs. According to him, efficiency consists of two components: (i) technical efficiency, which gives the capacity of the firm to achieve highest output with the given level of inputs, and (ii) allocative efficiency, which reveals the capacity of the firm to apply the inputs in optimal quantities at given prices. A combination of technical and allocative efficiency presents a measure of economic or cost efficiency (Coelli, 1996a).

Efficiency analysis can be carried out using deterministic and stochastic approaches. The deterministic approach is called Data Envelopment Analysis (DEA). It is non-parametric in nature and applies mathematical programming to measure efficiency, not imposing restrictions on the dataset (Coelli, 1996a, 1996b). The SFA, which is parametric in nature, applies random production, cost, or profit functions to measure efficiency (Andreu & Grunewald, 2006; Subhash, 2004). These two methods estimate the firm's relative position to the efficiency frontier (Johansson, 2005). The DEA method has been criticized in the past due to its inability to account for errors and to test for significance of the efficiency measures. Later, Banker (1993) and Fare and Grosskopf (1995) revealed a number of statistical tests that have made DEA a powerful tool for analyzing efficiencies. SFA has drawbacks because of a priori assumption of the functional form and the distribution of the one-sided error term (Forsund, Lovell, & Schmidt, 1980). But it accounts for measurement errors such as technical inefficiency and random disturbances due to climate factors, chance, etc. (Coelli, 1996b; Lilienfeld & Asmild, 2007). In this study, SFA is used for calculating the efficiency of cotton farming because of its advantages over DEA.

The Cobb-Douglas production function is the most commonly used functional form for analyzing agricultural production data. The major reasons for using this functional form are due to its mathematical properties, simplicity of computation, and interpretation (Heady & Dillon, 1961). The Cobb-Douglas production function can provide a better approximation for the production processes for which factors of production are imperfect substitutes over the entire range of input values. In addition, the Cobb-Douglas production function is relatively simpler to estimate because of logarithmic transformation into linear form (Beattie & Taylor, 1985).

The stochastic Cobb-Douglas production frontier model assuming truncated normal random variables can be expressed as (Coelli, 1996b)

$$Y_{it} = f(X_i\,\beta)\exp(V_i - U_i);\ i = 1, 2\ldots \text{N}, \tag{1}$$

where Y_{it} is the output at a given time, the stochastic production frontier is $f(X_i\,\beta)\exp(V_i - U_i)$, and V_i follows symmetric distribution that captures the random effects of exogenous shocks and measurement error. The technical inefficiency relative to the stochastic production frontier is captured by the one-sided error component $U_i > 0$. The explicit form of the stochastic Cobb-Douglas production frontier can be expressed as

$$Y = a\prod_{i=1}^{k} X_i^{bi}\exp(\varepsilon), \tag{2}$$

where Y is the frontier output, X is physical input, b the elasticity of Y with respect to X, a is the intercept, and $\varepsilon = V - U$ is a composed error term. The model can be transformed into logarithmic form:

$$LnY = b_0 + \sum_{i=1}^{k} b_i\,LnX_i + V_i - U_i\,, \tag{3}$$

where $b_0 = Ln(\alpha)$.

The technical efficiency, using a Cobb-Douglas production function, is estimated using the $\exp(-U_i)$ and is expressed as (Coelli, Rao, & Battese, 1998)

$$\text{Technical Efficiency (TE)} = \frac{Y_i}{\exp(X_i{}'\beta + V_i)} = \exp(-U_i) \tag{4}$$

This study calculates technical efficiency (on a per-acre basis) considering yield as the output variable and labor, fertilizers, insecticides, and number of irrigations as input variables in an efficiency analysis using FRONTIER 4.1 statistical program. In order to test for a statistically significant difference in average technical efficiencies between Bt and non-Bt cotton farms, the Mann-Whitney test is used.

Environmental Impact Quotient (Insecticide Use)

Measuring the environmental impact of pesticide is a challenging task (Morse et al., 2006), and there are several methods to do so. These methods can only be applied when active ingredients are known. Environmental impact is popularly assessed through the Biocide Index and Environmental Impact Quotient (EIQ). For this study the EIQ is applied, considering the average effect of each pesticide on farm workers, consumers, and ecological components. A lower EIQ value means less damage to the environment and a higher EIQ value indicates more damage.

The EIQ was developed by Kovach, Petzoldt, Degnil, and Tette (1992) and is commonly applied to estimate the environmental impact of pesticide application in commercial agriculture. Herein a modified version is applied for the calculation of field-level EIQ values for Bt and non-Bt cotton farming using the active ingredients of applied insecticides. The field EIQ value per acre is calculated as

Table 1. Socio-economic profile of sample farmers.

Particulars	Mean: Bt cotton (n=160)	Mean: Non-Bt cotton (n=40)	Mean: Mann-Whitney test (p-value)
Age (years)	41.04	47.03	0.0001
Education level (schooling years)	6.89	3.65	0.0001
Family size (number)	5.7	5.75	0.5330
Cotton area (acres)	6.15	4.19	0.0004
Total area (acres)	10.83	9.83	0.2088

Note: one acre is equivalent to 0.4 hectares

Field EIQ/acre = [EIQ value × Active ingredients of insecticide application (kgs)/acre] (5)

Results and Discussion

Socio-Economic Profile of Bt and Non-Bt Cotton Farmers

Significant differences in age, education, and cultivated area exist within the sample group, whereas total area and family size are not statistically significant among Bt and non-Bt cotton farmers. Bt cotton farmers are younger than non-Bt farmers, indicating that younger farmers show a greater readiness to adopt the new technology than older ones, a point confirmed by Kiresur and Manjunath (2011) in their study in the Karnataka state of India. Average family size is 5.75 for non-Bt cotton and 5.7 for Bt cotton. The average education levels for Bt and non-Bt cotton farmers are 6.89 and 3.24 schooling years, respectively. Non-Bt cotton farmers limit their education level to 10 years for schooling, leaving 50% of non-Bt farmers illiterate. On the other hand, more than 50% of the Bt farmers have 10 or more years of schooling. The average farm sizes for Bt and non-Bt cotton farmers are 10.83 and 9.83 acres, respectively, indicating that Bt cotton farmers on average have greater land than non-Bt cotton farmers. The area used for cotton cultivation by Bt and non-Bt cotton farmers is 56.82% and 42.68% of their total land, respectively (Table 1).

Efficiency Analysis Considering Input Use and Yield on Per Acre Basis

Considering the yield levels in Bt and non-Bt cotton, the average yield is 32% higher with Bt cotton. Considering input use in Bt cotton, labor, and insecticide use are relatively lower, and fertilizer and water use are relatively higher than with non-Bt cotton. The yield variation was higher in the case of Bt cotton with the minimum at 400 kgs and the maximum at 1,600 kgs per acre, whereas in the case of the non-Bt cotton farms, the minimum yield was recorded at 300 kgs and the maximum amounted to 1,000 kgs, indicating less variation in non-Bt cotton yields (Table 2). In addition to the variations observed in the average input and yield, technical efficiency analysis might give more clarity on the differences between Bt and non-Bt cotton farms.

Table 2. Variable inputs and output per acre used in stochastic frontier approach.

Input/output	Bt cotton: Mean	Bt cotton: SD	Non-Bt cotton: Mean	Non-Bt cotton: SD
Yield (Kgs)	973.95	199.84	665	157.79
Labor (days)	17.21	2.24	18.23	2.90
Fertilizer (Kgs)	163.06	30.72	125.5	24.67
Insecticides (gms)	1054.69	217.32	2525.86	921.38
No. of irrigations	4.61	0.71	3.35	0.53

The average technical efficiency is comparatively higher with Bt cotton farms as compared with non-Bt cotton farms; significance is proven using the Mann-Whitney test. The minimum level of technical efficiency is almost the same with Bt and non-Bt cotton farms, whereas the maximum level of technical efficiency is relatively higher in the case of Bt cotton farms. The differences in the technical efficiencies among Bt and non-Bt cotton farms is attributed to the significant variation in input use and output realized. In addition, the higher technical efficiencies with the Bt cotton farmers over non-Bt cotton farmers can also be attributed to the variations in the education and farm size. For instance, Bt cotton farmers have higher average education and farm size; the same farmers possess higher technical efficiencies as compared with non-Bt cotton farmers. However, the issue needs further investigation to gain clarity. The results of this study are consistent with the study of Gouse, Kirsten, and Jenkins (2003), who found in South Africa higher average technical efficiencies in the three consecutive seasons (1998-1999, 1999-2000, and 2000-2001) for Bt cotton farms as compared with non-Bt cot-

Table 3. Descriptive summary of technical efficiency (TE).

Efficiency	Bt cotton	Non-Bt cotton
Average TE	0.88	0.85
Minimum TE	0.63	0.62
Maximum TE	0.97	0.92
Mann-Whitney test (p- value)	0.001	

Table 4. Number of cotton farms in the technical efficiency categories.

Efficiency categories: Number (%)	Bt cotton	Non-Bt cotton
60-65%	1(0.6)	1(2.5)
65-70%	0(0)	0(0)
70-75%	3(1.9)	1(2.5)
75-80%	6(3.8)	7(17.5)
80-85%	19(11.9)	7(17.5)
85-90%	81(50.6)	18(45)
90-95%	49(30.6)	6(15)
95-100%	1(0.6)	0(0)
Total number of cotton farmers (%)	160(100)	40(100)

Note: Figures in parentheses indicate percentage to the total cotton farms.

ton farms (Table 3). The technical efficiency levels of farms can be explicitly understood from Table 4, which indicates the number of cotton farms in the different efficiency categories.

Roughly 31% of the Bt cotton farmers fall in the range between 90 and 100% technical efficiency, whereas this percentage reduces to less than half for non-Bt cotton farms. Around 80% of the Bt cotton farms fall in the efficiency category of 80-95%, while this percentage reduces to 60% with non-Bt cotton farms. This trend can be clearly seen in Figure 1 which indicates the cumulative technical efficiency distribution of Bt and non-Bt cotton farms. The greater cumulative share of Bt cotton farms in the higher efficiency levels become clear.

Environmental Impact Analysis Considering Insecticide Use

Bt cotton is mainly used for resistance against bollworms, therefore the environmental impact is estimated considering the use of insecticide. The quantity of insecticide application may not provide enough information about environmental impact because there are different types of insecticides—some are used in less quantity but are highly harmful to the environment and some are used in greater quantity but are less harmful to the environment. To address this heterogeneity, the EIQ method is used to assess the environmental impact of Bt and non-Bt cotton farms. Table 5 provides a comparison of the per-acre field EIQ value for Bt and non-Bt cotton varieties. It was found that Bt cotton has a lower EIQ value than non-Bt cotton and the difference is found to be significant. Bt cotton has a field EIQ of 20.48, which is 28% lower than non-Bt cotton at 28.79, indicating less harm by Bt cotton on the environment. Similar results have been found in environmental impact studies of Bt cotton. Morse et al. (2006) found similar results in South Africa. Brookes and Barfoot (2006) analyzed the United States, China, and India. In the United States, they found that in 2007 the use of Bt cotton resulted in a 19.9% reduction in field EIQ. Since 1996, the cumulative reduction in field EIQ load has been 9.2%. In China, the cumulative field EIQ load has fallen to 35.1% since 1997, whereas in India it has fallen 9.7% since 2002. Due to the generally greater levels of pesticide use associated with their cultivation, both Bt and non-Bt cotton production are relatively harmful to the environment compared to other crops. However, farmers use less insecticide to produce Bt cotton as compared with non-Bt cotton and these insecticides are less hazardous to environment.

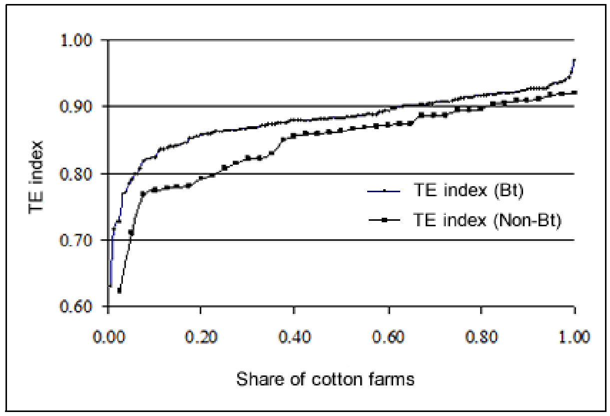

Figure 1. Cumulative technical efficiency distribution of farmers.

Table 5. Field EIQ value of Bt and non-Bt cotton.

Type of cotton	Field EIQ/acre	Standard deviation
Bt cotton	20.48	12.29
Non-Bt cotton	28.79	13.66

Mean difference = 8.31 (p-value = 0.001)

Conclusion and Suggestions

The technical efficiency of Bt and non-Bt cotton farms using a stochastic frontier approach has shown that there is considerable variation in efficiency among Bt and non-Bt cotton farms. The average technical efficiency of Bt cotton farms is higher than that of non-Bt cotton farms. The extent of technical inefficiencies were found to be higher in non-Bt cotton farms as compared with Bt cotton farms and these inefficiencies are driven by the significant variations in input use and output realized in addition to the variation in farm size and education of the farmer. However, the contribution of farm size and education to the technical efficiency needs further investigation of the issue. In the second step, an Environmental Impact Quotient analysis has shown that Bt cotton farms also have a lower EIQ than non-Bt cotton farms, indicating reduced damage to the environment. The results should provide useful insights to the Indian Government for expanding Bt cotton adoption with the goal of improving farm income levels as well as benefiting the environment.

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