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Analysis of cotton productivity gains with the adoption of Bt-cotton in India

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Abstract
The paper analyses the impact of Bt cotton on productivity gains of cotton productivity in India. The analysis finds that there has been significant change in productivity due to the adoption of Bt cotton and it is also found that there has been structural break in terms of productivity gains from conventional seeds to Bt cotton seeds.

Keywords: Cotton, commercial crop, productivity, Bt, adoption, growth, agriculture

Introduction
Cotton is an important commercial crop of India and plays a key role in the national economy. About 60 million people get employment either directly or indirectly in the agricultural and industrial sectors of cotton production, processing, textiles and related activities and by way exports, the foreign exchange earnings of cotton amounts Rs.3837.33 crores (Agriculture Statistics at a glance, 2021) [2]. With economic liberalization and globalization sweeping the world there is a scope for our country to play a leading role in the cotton production and export. If increasing production trend continues in years to come, India can become a major exporter of cotton. Researchers have shown that with the adoption of new technologies on farmer's fields, it is possible to increase the average productivity beyond 600 kg lint per hectare to meet the increasing cotton demand (CICR, Nagpur). As per 2014-15, 95% of India cotton cultivation area is under Bt cotton crops (Clive, 2015) [15] but it wasn't always so. Bt cotton was the first genetically modified crop to be approved for cultivation in India in 2002, with the introduction of Monsanto's GM cotton seeds. Bt stands for Bacillus thuringiensis, a bacterium that produces toxins harmful to a variety of insects, including bollworms that attack cotton. Bt cotton was created by introducing genes from the bacterium Bt into cotton seeds.

The introduction of Bt cotton led to a dramatic increase in production across the cotton producing states and soon Bt cotton took over most of the acreage under cotton cultivation. Cotton production rose from 13 million bales in the pre-Bt year of 2001-02 to 39 million bales in 2013-14, a rise of almost 200%. India's cotton imports fell, exports grew and as of 2015-16 India overtook China as the biggest cotton producer in the world (Clive, 2015) [15]. In India, cotton exports increased from 0.05 million bales in 2002-2003 to 8.5 million bales in 2007-2008, with earnings increasing from US$ 10.4 million in 2002-2003 to US$ 2.2 billion by 2007-2008. During the same period, cotton imports decreased from 2.5 million to 0.7 million bales. Cotton textile exports also increased in value from US$3.4 billion in 2002-2003 to US$4.7 billion in 2007-2008 (Anchal Arora and Sangeeta Bansal, 2011) [3]. Although partly a result of increased yields, export increases are generally attributed to changes in domestic and international agricultural trade regulations.

In this paper, we wish to analyse empirically the growth on cotton productivity with adoption of Bt cotton since 2002. Specifically, our aim is to estimate the difference between productivity of Bt cotton vis-à-vis non-Bt (conventional) cotton seeds for which we will first estimate a probable production function. We are also interested in finding structural break in cotton productivity trend, if any. Moreover, we wish to decompose the difference in productivity gains in two parts: due to Bt seeds directly and due to change in other inputs with Bt adoption.

Literature Review

Genetic engineering has been revolutionary in the recent past due to its staggering impact on the targets concerned. Bt cotton is one of the engineered varieties of cotton that has lured many researchers due to its precise impact on targeted insect, bollworm which had choked the yield of cotton. Today, the technology is widely accepted across the world as far as short run analysis of the technology is concerned. A number of research work has been done related to the technology touching various dimensions. Here, we review some of the influential papers in this field in order to have some insight to our work in progress.

In India, Bt technology has added significantly in terms of pest resistance and this is apparent from the recent productivity growth observed in major cotton producing states. Bt cotton yields are found to be higher and the yield increase is statistically significant in all the states under both irrigated and rain-fed conditions. Hence, given the good market acceptance of the product, the value of output per hectare is higher in all the states and conditions. (Vasant P. Gandhi and N.V. Namboodiri, 2006) [14]. Therefore, there is no doubt that Bt technology has worked wonders in India as far as bollworm control adds to the returns in terms of yield gains are concerned. But there has been constant chirps about the rate of adoption that was observed in India and competing developing economies like China and South Africa. Researchers have suggested that a ceiling on Bt seed price can increase the rate of adoption and therefore can multiply the yield gains and thus raise profits of the farmers. But in case of China, it seems to help only on productivity grounds but doesn't add to farmers' pocket in later years as the benefit from lowered seed price is nullified by the controlled procurement by Chinese government (C.E. Pray and L. Nagarajan, 2011) [5]. Even in case of South Africa the price intervention doesn't better the agronomic aspects as the farmers are already using the technology at its optimum (Anchal Arora and Sangeeta Bansal, 2011) [3]. In Indian context, on the other hand, there indeed is some scope of price intervention as a decline in seed price through government intervention leads to increased rate of diffusion of the Bt technology. Moreover, the diffusion rate also increases as a consequence of introduction of newer Bt varieties showing that increased competition in market of seeds benefits farmers (Anchal Arora and Sangeeta Bansal, 2011) [3]. On similar lines P. Sadasivappa and M. Qaim (2009) [10] found that the price caps introduced in 2006 by Indian government have further increased the profits to farmers, and they probably also contributed to the decrease in use of illegal Bt seeds, which were rampant in India until recently. But the impact of the price controls on aggregate technology adoption is relatively small - the take-off phase for Bt cotton in India had already started before 2006, and today's adoption rates would not be much lower even without the interventions.

Turning to the agronomic effects, Bt technology has proved to be useful on this count too. Bt has led to reductions in pesticide use and higher effective yields and thus, significantly higher profits for Bt growers, willingness to pay rose for cotton growers because of this high profits. Each additional hectare of Bt cotton was shown to produce 82% higher aggregate incomes than obtained from conventional cotton. Therefore, profit differences between Bt and non-Bt-cotton have increased over time (P. Sadasivappa and M. Qaim, 2009) [10]. In China, adoption of this technology has helped farmers fight the pests cost effectively and has also aided the farmers' health (Pray *et al.*, 2002) [4]. The large farmers definitely have benefited from the technology but whether the benefits reach the smallholders is a concern as hetrogeniety among farmers causes significant variability in impacts (Qaim and Subramanian *et al.*, 2006) [9]. Though, some research has found that in developing countries, gains seem to spillover to small farmers too (B. Shankar *et al*, 2004) [11]. Moreover, farmers with small holdings appeared to have benefited proportionately more in South Africa. Thus, this has positive agronomic effect of improving equality in the developing countries and the results found are stable and are expected to prevail (Jonas Kathage and Matin Qaim, 2012) [7].

All these literatures have taken Cobb-douglas production function. The literatures show that the adoption of Bt cotton seeds reduces the insecticides used especially for ballworms and this results in lower costs, higher yields and increased profits. Here, we are to estimate the effect of Bt cotton on yield via pest control and in addition, we are to estimate the rate of growth of yield due to Bt adoption and hence to check the region of production possibility. We would be estimating the effects on pesticides use with adotion of Bt cotton seeds as well. The effect of inputs varies with the amounts of variable inputs used and hence to assure this, we take a special translog function rather than Cobb-Douglas production function. We estimate the structural break, if any, in the productivity of cotton. Here, we also estimate total factor productivity growth with the adoption of Bt seeds which none of the researchers did before.

Data and Methodology

Data Sources

- Cotton Advisory Board
- Cotton Corporation of India
- Central Institute of Cotton Research
- International Service for the Acquisition of Agri-biotech Applications
- Agricultural statistics at a glance 2016, Ministry of agriculture, GoI
- Input Survey of India
- Agricultural Research Data Book, IASRI
- Directorate of Economics and Statistics
- Handbook of statsistics on Indian Economy, Reserve Bank of India
- Central Insecticides Board and Registration

The paper uses time-series dataset compiled from various mentioned sources. We have estimated data for insecticides use for cotton before the Bt adoption as a fraction of total pesticides used in agriculture in India which according to Tulsi Bhardwaj and J.P. Sharma (IARI Pusa, 2013) [13] is 36% on an average.

For the fertilizers data over the study period specific to cotton, we have used the level of recommended fertilizers use in cotton as per Central Institute of Cotton Research assuming that farmers follow the recommended level of the fertilizers. This is based on ground that most of the farmers cultivating cotton seem to be well informed as apparent from rapid Bt technology adoption rate that reached from 0% to almost 100% in just 12 years. The more productive varieties consume more fertilizers. We have taken a weighted average of the Bt and non-Bt types with weights being their respective proportion in cropping. The recommended level of fertilizers use in non-Bt type is 140 kg/hec and that for Bt type is 208kg/hec. Therefore, we have.

$$F_t = [(1- \lambda_{Bt}) * 140 + \lambda_{Bt} * 208] * A_t$$

Where,
F_t = Fertilizers used in cotton cultivation in India in year t
λ_{Bt} = Proportion of Bt cotton
A_t = Total Area of cotton cultivation in India in year t

In the present paper we analyse the cotton productivity trends in India from 1980-81 to 2014-15. We study the productivity gains by fitting the production function as:

$$Y = f(S, I, F, W, \varepsilon)$$

Where,

- Y is the yield rate of cotton
- S is the adoption rate of Bt seeds
- I is the total amount of insecticides used for cotton cultivation
- F is the total amount of fertilisers used for cotton cultivation
- W is the cotton cultivation area under irrigation
- ε is the catch-all variable

In the literatures studied earlier, researchers have assumed Cobb-Douglas functional forms. But we want to have a more flexible functional form imposing lesser a priori restrictions therefore, here we take a more general trans-log form as defined below.

$$ln\, ln\, (Y) = \beta_0 + \beta_S\, ln\, ln\, S + \beta_I\, ln\, ln\, I + \beta_F\, ln\, ln\, F + \beta_W\, ln\, ln\, W + \beta_{SI} S)(lnI) + \beta_{SF} S)(lnF) + \beta_{SW} S)(lnW) + \beta_{IF} I)(lnF) + \beta_{IW} I)(lnW) + \beta_{FW} F)(lnW) + \varepsilon_i$$

Here, we have yield rate of cotton per hectare as the dependent variable. Our explanatory variables are adoption rate of seeds, irrigated area under coton cultivation, insecticides applied for cotton cultivation and fertilisers used for cotton. We have tried the kitchen-sink approach to reach a final workable model that support the data at hand. We have tried a number of models six of which are more preferred over others.

Our most preferred model turns out to be Cobb-Douglas model estimated as

$$lnY = \beta_0 + \beta_I lnI + \beta_S lnS + \beta_W lnW + \beta_D D + \varepsilon,$$

Where D is trend Dummy taking value 0 for pre adoption era and 1 for post adoption. Coefficient of D is expected to incorporate the productivity difference that has occurred over time and if this coefficient turns out to be statistically significant, we can conclude that there indeed is a structural break at the specified year otherwise not.
We have estimated this production function for the study period using OLS method. In our analysis, use of fertilisers comes out to be highly correlated with seed adoption rate and hence in our analysis assuming that bt and non-bt crops both had similar effects of using same quantity of fertilisers, we dropped this variable and proceeded further for estimation with the other variables that are expected to explain the variability in the yield. The regression results and interpretations are shown in Results section.
We are interested in finding the productivity growth in cotton yield that accrues to Bt technology. For this we have used methodology suggested in the paper by Subash C. Ray and Lai Chen (2010) [12]. For yields and the inputs in the two periods we have taken the geometric mean of the yield over the years.
As per the methodology suggested by Subhash C. Ray and Lei Chen (2010) [12], we estimate total factor productivity using the formula:

$$TFP_j = \left(\frac{Y_j}{S_j}\right)^{\beta^S} \left(\frac{Y_j}{I_j}\right)^{\beta^I} \left(\frac{Y_j}{W_j}\right)^{\beta^W}$$

Where,
j = {pre, post}
$\beta^S = b_S + b_D$, geometric weights of adoption rate of Bt seeds on yield
$\beta^W = b_W$, geometric weights of percentage of irrigated area
$\beta^I = b_I$, geometric weights of percentage of insecticides sprays
For the growth of productivity over the two periods we calculate the ratio of the productivities using above equation for the two periods.

Empirical results

As per the data, we get that there has been significant rise in the yield with adoption of Bt seeds and the increase in yield is due to effective pest control. The table below gives the comparison of the competitive models.

Our preferred model is MODEL 6 which captures the effect of inputs on the productivity in pre and post Bt adoption periods. We applied Kitchen-sink approach to estimate our production function. In the first model we have taken all the relevant variables and their interaction terms. In second model, we added trend dummy as well. In Models 3 & 4, we dropped irrigation % because its contribution to the yield rests the same for both conventional and Bt seeds even after the genetic modifications specific to pests. In Models 5 & 6, we dropped all the interaction terms. Models 1, 2 & 3 give unexpected signs and insignificant coefficients. In Model 4, the interaction terms of insecticides are statistically insignificant and the coefficients are positively biased. In Model 5, the coefficient of Insecticides is highly insignificant. The stated reasons justify our model selection. Before ending in a Cobb-Douglas model, we have also tested for the statistical significance of the restrictions imposed on the more general Translog function. The F-test gives results in favour of Cobb-Douglas model as we fail to reject the null-hypothesis.

Table 1: The table below shows the comparison between different models

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Ln I	-140.1941 (290.2157)	202.026 (337.4242)	-5.9442** (2.869816)	4.9834 (4.703208)	-1.2231 (.1226124)	0.3586** (0.1468343)
Ln S	6.9780 (8.059175)	7.5945(7.69936)	-0.0694* (0.0405532)	0.0825 (0.0657271)	0.0067*** (0.00181393)	0.0079*** (0.0066131)
Ln S*ln S	0.0042 (0.0032302)	0.0045 (0.0030866)	0.0000409 (0.0001196)	-0.0002* (0.0001539)	-	s-
Ln I*ln I	-0.1056 (0.4819076)	-1.2975 (0.8136133)	1.0327** (0.4945684)	-0.7433 (0.7786298)	-	-
Ln I*ln S	-0.1213 (0.2377754)	0.1170 (0.2636705)	0.0342** (0.0142458)	-0.0214 (0.0237724)	-	-
Ln W	12.0112 (35.64187)	-6.5444 (35.58473)	-	-	0.0394*** (.0107485)	0.03441*** (.0086123)
Ln W*ln W	-0.0015 (0.0050805)	-0.0008 (0.0048645)	-	-	-	-
Ln I*ln W	0.2561*** (0.0689172)	0.2153* (0.0696833)	-	-	-	-
Ln S*ln W	0.0126 (0.0287905)	-0.0031 (0.0288714)	-	-	-	-
D	-	0.5268* (0.2966917)	-	0.7047** (0.2533955)	-	0.5001*** (0.1144189)
const.	25.3941*** (5.36877)	11.0474 (9.566904)	13.82869** (4.145276)	-2.9276 (7.088007)	4.4296*** (0.50953)	3.1113*** (0.5045085)
Adj. R sq.	0.9181	0.9254	0.7953	0.8338	0.8103	0.8803

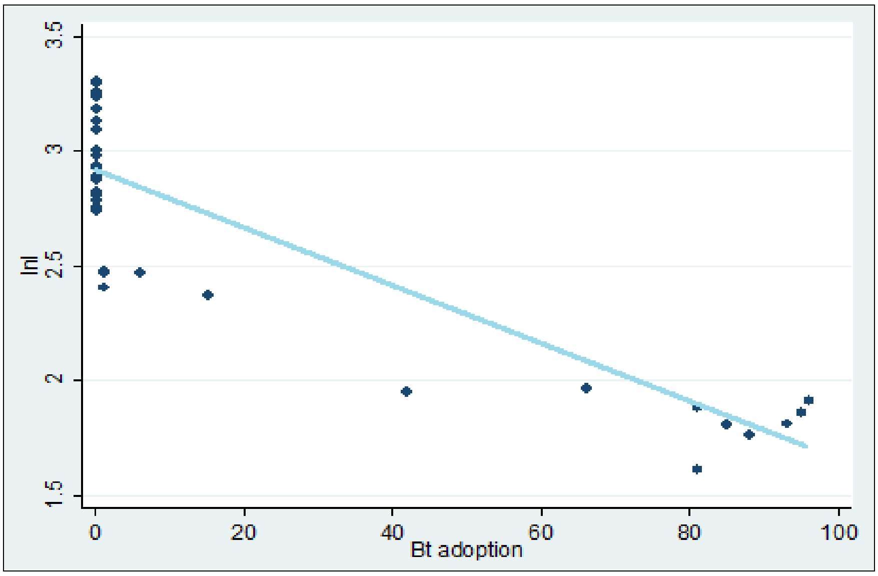

Fig 1: Effect of Bt seeds adoption on insecticides use

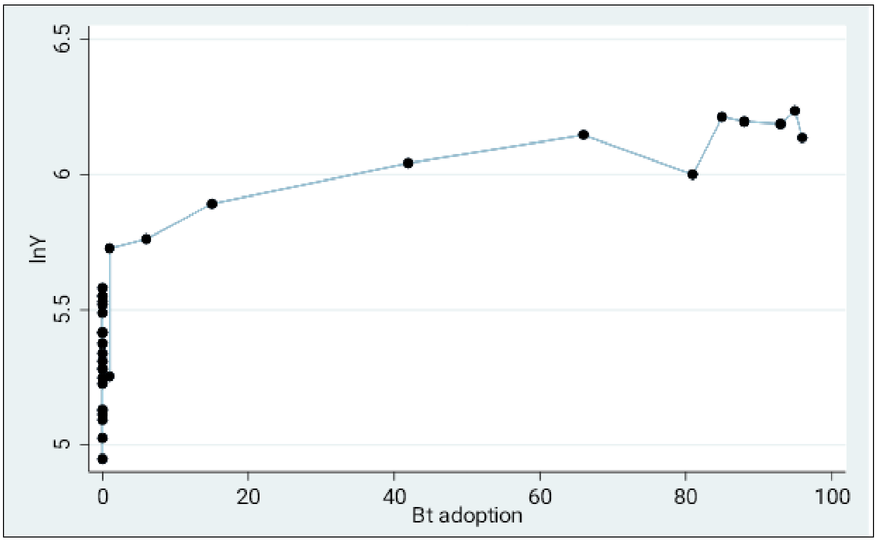

Fig 2: Effect of Bt seeds adoption on cotton yield

The positive coefficient of insecticides shows increase in yield rate because Bt seeds are able to control bollworm pests only but pesticides are still useful for fighting other pests which, in turn results in rise in production through control of secondary pests. The effect of adoption rate of Bt vis-à-vis conventional seeds shows around 50% increase in yield per hectare per year. Moreover, we get that the rate of increase of yield remains constant. The regression is robust to changes. Our study also finds the coefficient of the trend dummy to be highly significant emphasising the fact that Bt technology has led to a structural break in the yield of cotton.

Figure 1 shows that with the adoption of Bt seeds, use of insecticides declined significantly which implies that Bt seeds are pest resistant as expected. It's interesting to see that the insecticides use is marginally increasing in later period of the study which might be because of biological adaptation of bollworm pests.

Figure 2 shows that there has been significant rise in yield with increase in the adoption of Bt seeds. In later yaers of study, the productivity is almost constant. This is due to Bt adoption rate touching cent percent. The slight fluctuations in yield reflects bad harvest due to natural calamities or environmental changes.

As per our calculations[1] total factor productivity in pre adoption period is 1.269 while that in adoption period is 1.74.

$$TFP_{growth} = (TFP_{post} - TFP_{pre})/TFP_{pre}$$

$$= \frac{1.74-1.269}{1.269} = 0.37$$

Hence, the total factor productivity growth with the adoption of Bt seeds is found to be 37%. This is the total aggregate effect with the adoption of Bt seeds.

Conclusion

Cotton is one of the most important cash crops of India. To meet the rising demand due to population increase and affluence, it is required to prevent the cotton bolls from pest attacks. In this paper, we have tried to estimate the effects of transgenic Bt cotton seeds on productivity and yield. As per the genetic modifications, Bt seeds are resistant to bollworm pests and the effect is seen with lower applications of insecticides. As we know, insecticides are chemicals and have hazardous effects on health of farmers, soil productivity/fertility and friendly worms like earthworms and redworms. Hence, we can say that the decline in requirements of insecticides application has indirect positive agronomic effects contributing to Integrated Pest Management Program. In terms of productivity, the effect of gene modifications may decline in future due to its zero resistance against secondary pests and lower pesticides consumption. This can be minimized with targeted insecticides spread for secondary pests.

As per economic perspective, we can see the contribution of Bt seeds on higher yields. As per our estimates, the total factor productivity of Bt seeds is 37% higher to total factor productivity of conventional seeds. This growth has helped significantly to meet the rising demands of cotton. The effect of Bt seeds is mainly through lower pesticides attack by bollworms on cotton bolls which results in higher production. The lower pesticides requirement results in lower pesticides sprays which adds to lower costs and hence higher profits to the farmers. In the initial years of Bt seeds adoption, the prices of Bt seeds were quite higher due to monopoly of Mahyco Monsanto Biotech and farmers were reluctant to reap benefits of the transgenic seeds. In later years, with government interventions the prices declined which resulted in higher adoption rate of Bt seeds contibuting to higher benefits of farmers.

With falling effects of Bt seeds on bollworms control and thus increased pesticide use in later period of study the researchers need to rethink of its usefulness in future. Moreover, due to its zero resistance to secondary pests, it is required to develop verieties to control the secondary pests and sustain the effects of Bt seeds.

[1] See Appendix

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Appendix

Total factor productivity for yield of cotton under this study we use the methodology suggested by Subhash C. Ray and Lei Chen (2010).

As per their suggestion the total factor productivity in our context can be calculated using the formula.

$$TFP_j = \left(\frac{Y_j}{S_j}\right)^{\beta^S} \left(\frac{Y_j}{I_j}\right)^{\beta^I} \left(\frac{Y_j}{W_j}\right)^{\beta^W}$$

Where,

j = {pre, post}

$\beta^S = b_S + b_D$, geometric weights of adoption rate of Bt seeds

$\beta^W = b_W$, geometric weights of percentage of irrigation area

$\beta^I = b_I$, geometric weights of percentage of insecticides sprays

The regression results found for our model are reproduced below.

Estimated coefficients	Pre	Post
b_0	2.9151	3.1113
b_I	0.3018	0.3586
b_S	0.0455	0.0344
b_W	-	0.0079
b_D	-	0.5001

For the two periods i.e., pre and post Bt. adoption we calculated separate average total factor productivity and for averaging over the time period we have use geometric mean of yield and that of the inputs in that period. Empirically, we found geometric mean of the variables in two periods as tabulated.

	Pre	Post
Ln Y	203.5	396.8
Ln S	-	29
Ln I	20.35	7.65
Ln W	32.54	34.45

To find the geometric weights, we have normalized the coefficients by dividing the individual coefficients by the sum of the coefficients given as.

$$b_i^j = \frac{\beta_i}{\sum_{i=1}^{n} \beta_i}$$

The corresponding estimated values of geometric weights β's i.e., b's for j (=pre, post) are

Coefficients	Geometric weights (pre)	geometric weights (post)
b_0	0.8935	0.7754
b_I	0.0925	0.0894
b_S	0.0139	0.0086
b_W	-	0.0020
b_D	-	0.1246

Empirically, we found geometric mean of the variables in two periods as tabulated.

	Pre	Post
Ln Y	203.5	396.8
Ln S	-	29
Ln I	20.35	7.65
Ln W	32.54	34.45

The corresponding average factor productivity is found using the formula.

$$AFP_i^j = \frac{y^j}{f_i}$$

Where, j, as above, represents the two periods.

	Pre	Post
AFP_S	-	13.68
AFP_I	10	52.45
AFP_W	6.25	11.52

As per the methodology suggested by Subhash C. Ray and Lei Chen (2010), we estimate total factor productivity using the formula.

$$TFP_j = \left(\frac{Y_j}{S_j}\right)^{\beta^S} \left(\frac{Y_j}{I_j}\right)^{\beta^I} \left(\frac{Y_j}{W_j}\right)^{\beta^W}$$

Where,

j = {pre, post}

Substituting the respective values, the total factor productivity as given by above formula for the two periods are.

$TFP^{pre} =$ 1.269

$TFP^{post} =$ 1.74

Therefore, the growth in total factor productivity is found to be.

$$TFP_{GROWTH} = \frac{1.74 - 1.269}{1.269}$$

=0.37

Hence, the total factor productivity growth over the two periods is found to be 37%.