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Technical efficiency and reduction in input costs in agriculture: case of genetically modified cotton

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Abstract Adoption of labour-saving agricultural technologies is often determined by peak-season labour scarcity and uncertainty in labour supply, besides the need to reduce overall cost of production. Adoption of labour-saving technological innovations could also be justified on efficiency grounds. Technology-led agricultural growth is believed to ensure economic gains to cultivators, increase in real wages and creation of employment opportunities. This paper estimates changes in mean technical efficiency in herbicide-tolerant cotton, vis-à-vis conventional Bt cotton crops. Analysis indicates that use of herbicide-tolerant technology is technically more efficient, as it reduces wastage of purchased farm inputs due to absence of crop-weed competition, in addition to ease of cultivation related operations termed in literature as non-pecuniary benefits.

Keywords Agricultural Technology, Labour use, Cotton, Herbicide tolerance, Technical Efficiency, Female employment.

JEL classification J43, O33, Q12, Q16

1 Background

Labour availability is an important factor influencing farmers' decisions to adopt new agricultural technologies. Often, peak-season labour scarcity (at the time of sowing, harvesting and weeding operations) causes operative constraints in crop cultivation. This finds support in literature on labour bottlenecks and labour supply uncertainty. Uncertainty in labour availability can also often explain the adoption of new labour-saving crop technologies (Feder et al. 1985). In addition, the adoption of labour-saving technological innovations is justified on efficiency grounds, as hired labour accounts for the lion's share in cost of cultivation (Binswanger 1982). Farmers in developing countries adopt, often in stealth, the new labour-saving chemical and agro-mechanical innovations originating in the developed countries, due to their private cost-reducing characteristics (Jayasuriya & Shand 1986; Herring 2007).

The widespread adoption and successes associated with Bt cotton has resulted in a tendency among cotton cultivators for closer spacing of cotton plants. This restricts intercultural and weeding operations. Weeds compete with crops for moisture, nutrients and space; which results in output losses. It also leads to higher production costs due to additionalities and cause contamination of the final output (Benson 1982). Besides, there also exist critical periods of weed/crop competition as well as efficacy of weed control methods. To maximize yields, the weeds have to be managed before the critical period begins (Hall et al. 1992; Zimdahl 2004). Due to their ability to appropriate soil moisture, weeds often cause serious water-deficits for crops under drought-prone conditions. Farmers have to increasingly rely on manual weeding, despite labour becoming increasingly expensive and labour scarcity being common. Farmers, therefore, look for an efficient solution for weeds that would reduce fertilizer consumption and expenditure on other inputs.

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In this context, the use of glyphosate and herbicide tolerant (HT) cotton has emerged as the desired technological choice for cotton growers. As the immediate concern of farmers is to reduce the dependence on manual weeding, the use of HT cotton becomes a preferred option for the farmers to the extent that it precedes their concerns such as the use of HT trait fostering seed monopolies or enhancing technological dependence on a company.

Herbicides can be broad-spectrum (non-selective) whose application reduces weed growth before the crop germinates. Narrow-spectrum (selective) herbicides are applied to weeds that emerge during the growing season. Since weeds of different types may occur in a field, a large number of selective herbicides are commonly used, making weed control an expensive operation. Thus, it has been postulated that weed management can be made simpler by spraying a single broad-spectrum herbicide (such as glyphosate) during the growing season (James 2012). In developed countries like the US, herbicides constitute 70% of all pesticides used, as against the world average of around 49%. In India 20% of the pesticides are herbicides/weedicides; but their use is on the rise (Kuruganti 2011).

Genetically modified HT cotton was first cultivated commercially in the US in 1997 and is now being planted on nearly three-quarters of the total cotton holdings globally. There are net environmental impacts associated with HT cotton relative to the conventional technology (Brookes & Barfoot 2013). While the adoption of HT crops does not lead to reduction in herbicide quantities *per se*, the selective (toxic) herbicides are substituted by less toxic broad-spectrum herbicides (Dong et al. 2016). In addition, glyphosate is compatible with conservation tillage as it reduces fuel consumption and greenhouse gas emissions (Brookes & Barfoot 2008; Duke & Powles 2008). The economic gains of HT crops stem from the fact that farmers adopting these benefit in terms of lower herbicide expenditures and costs associated with manual weeding by hired workers. HT technology as such is yield neutral with no major yield gains (Brookes & Barfoot 2008). Crop yield is more a function of genetics and effectiveness of weed control due to substitution of multiple herbicides by the broad-spectrum glyphosate. Glyphosate controls nearly 300 weed species, including broad leaf and grass weeds.

The use of a single broad-spectrum herbicide simplifies management decisions and is time saving.

Evidence shows that since 2007, of the total farm income impact derived from using HT cotton, 87% can be subscribed to cost savings and 13% to yield gains (Brookes & Barfoot 2013). In the context of benefits of labour-saving technologies, Jayasuriya and Shand (1986, p.425) stressed that, “. more productive new technology (even when it has a direct employment reducing effect) can lead to higher employment and real incomes through effects such as higher demand for labour-intensive goods and services and lower food prices.” Adoption of crops bearing HT trait also results in certain hard-to measure benefits such as simplicity, convenience and flexibility in applying herbicide, safety issues, scope for saving management time, etc. (Frisvold & Reeves 2010; Bonny 2009). These benefits can be broadly categorised as ‘unmeasurable technology shifters’ that contribute to overall efficiency gains. Reduction in the involvement in weeding related activities can be positively associated with part-time farming, and increase in off-farm work of farm households.

In India, HT cotton trait was undergoing the regulatory process. However, the application for approval of its commercial use to the Genetic Engineering Approval Committee (GEAC) was withdrawn by the parent company (Mahyco-Monsanto Biotech Ltd) in 2016. Despite this, illegal Bt cotton seeds stacked with the HT trait are being sold and cultivated widely in several cotton-growing belts of India. Samples from Andhra Pradesh, Telengana, Maharashtra, Karnataka and Gujarat have tested positive for this yet unapproved transgenic cotton (Kuruganti 2011; Jishnu 2015; Anon. 2017). Jadhav (2018) reported that the seeds were being mass produced secretly in central and northern Gujarat and Telengana and then smuggled into other states. In Gujarat, HT cotton has made forays and the seeds are being used mostly in Kutch region, where there is an acute shortage of labour. In Saurashtra districts too, notably in Amreli, such seeds are available in the market (Bhattacharya 2012). It has been reported that in the agricultural season of 2017-18 (*kharif*) nearly 35 lakh packets of HT incorporated cotton seeds have been planted in the country, sold at an average price of Rs. 1200 to 1500 per packet. This can be translated into nearly 22 lakh ha (at the rate of 1.5-1.7 packet/acre) (Damodaran 2017).

Clearly this trait is being increasingly preferred by the cotton cultivators in the country. In this context, the findings of a study by Brookes et al. (2017) are worth noting. The authors, using a computable general equilibrium model, estimated the potential welfare and efficiency losses and changes related to terms of trade (ToT) with the disuse of HT technology across the countries. The study indicated that by banning the use of glyphosate resistant crops, India was likely to suffer efficiency losses (crop production costs and reduction in crop yields) to the extent of 52% and total welfare impacts by 5%, nullifying the ToT gains to the tune of 47%. The study indicates that, the world over, efficiency losses associated with shifting away from GM HT technology to inferior conventional production technology are greater than the terms of trade welfare gains.

The implications of herbicide tolerance in Indian situation are unknown. This is crucial as “weeds” are often used for food and fodder. The use of labour for manual/mechanical weed control continues to be high and the female workforce engaged in agriculture derives largest number of employment days from manual weeding operations. Under these circumstances, deployment of HT technology in Indian conditions merits thorough assessment and precautions. Even otherwise, in the Indian context, technology-led agricultural growth has a dominant role in economic welfare and in reducing poverty through its direct impact on real wage rates and indirect impact on increased employment (Swaminathan 2010).

Against this background, the specific objectives of the paper are: (i) to provide an overview of labour absorption pattern and labour cost in the overall cost of cultivation of cotton under two technology scenarios, i.e., conventional Bt technology vis-a-vis HT technology; and, (ii) to assess technical efficiency and changes therein with introduction of technology; in this case, cultivation of herbicide tolerant cotton, as compared to the conventional Bt cotton. This would enable understanding if HT cotton technology offers greater scope for input-use efficiency and productivity gains on account of labour saving. These objectives are achieved through the assessment of data generated from a primary survey of Bt and HT cotton cultivating farmers in the state of Gujarat. At this juncture, a brief

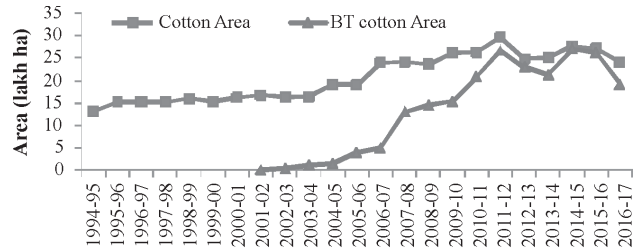


Figure 1. Expansion of cotton area in Gujarat, 1990-2017

Source: Government of Gujarat, Directorate of Agriculture and Socio-Economic Review of Gujarat State (various years).

explanation is called for on the selection of the sample cultivators. Analyses are based on a primary survey of 350 Bt cotton farmers and adopters of HT seeds that are sold in stealth. The sample farmers belonged to seven cotton-growing districts of Gujarat state, viz., Ahmedabad, Sabarkantha, Baroda, Bhavnagar, Surendranagar, Rajkot and Kutch. Technical efficiency in cotton cultivation was estimated for 211 farms using Bt cotton, and for 23 farms cultivating HT cotton. Cost of cultivation and technical efficiency were calculated from the farm-level data that include detailed input-output budget for all the plots cultivating cotton. While the primary survey was carried out in 2013-14, the information was collected for the agricultural year 2012-13. Before proceeding with the analysis, the next section provides a brief review of the cotton scenario in the state of Gujarat. Following this, Section 3 deals with the input use and labour absorption patterns on the sample cotton farms. Section 4 is devoted to a discussion on the technical efficiency aspects in cotton traits. The last section provides a summary and policy implications.

2 Growth experience of cotton in Gujarat

Bt cotton, aided by increased water availability, revolutionized Gujarat’s agricultural sector. It replaced hybrids and ‘desi’¹ varieties of cotton to a great extent. Whereas the area under hybrids and ‘desi’ varieties declined from 99% (2002-03) to 21% (2010-11) and further to 3.5% (2015-16) (figure 1), the area under non Bt cotton increased to 20%, in 2016-17. Recently, Bollgard III or herbicide tolerant cotton has also been made available to farmers (Government of India 2017).

Prior to the early 1990s, cotton area in Gujarat had been declining at the rate of 4.2%/annum. However,

¹ ‘Desi’ stands for indigenous or local varieties.

Table 1. Growth rates in area, production and yield of cotton in Gujarat (% per annum)

	Area	Production	Yield
1980/81 to 1990/91	-4.24*** (0.57)	-2.78 (0.09)	1.17 (0.02)
1990/91 to 2000/01	4.54** (0.89)	10.05* (0.44)	5.05** (0.25)
2001/02 to 2009/10	6.38** (0.89)	12.44* (0.68)	5.36*** (0.33)
2010/11 to 2017/18	-0.89 (0.09)	2.14 (0.15)	3.09*** (0.34)

Source: Government of Gujarat, Department of Agriculture.
Notes: R² is shown in parenthesis. *, ** and *** significant at 1, 5 and 10 % respectively.

during the 1990s, the cotton acreage increased at the rate of 4.5% and output grew at 10 %/annum, due to significant increase in yield levels of cotton (table 1). Between 2001-02 and 2009-10, the period during which Bt cotton was introduced on a large scale, cotton acreage accelerated at the rate of 6.4% annum and expanded to 24 lakh ha in 2009-10. The area further expanded to 26 lakh ha by 2017-18, although the area after 2010-11 declined. In the post-Bt era, output and yield of cotton have also taken significant strides. With large scale adoption of Bt cotton (Bollgard I and II) during 2001-02 to 2009-10 the cotton production accelerated to 12.4%/annum. However, it may be noted that after 2009-10, cotton output growth decelerated to 2.1%/annum.

Overall, farmers' response to Bt-hybrids was extremely positive, as these reduced expenditure on plant protection and also saved the crop from insect-pest infestation (e.g., from American bollworm). Nonetheless, the state offered a competitive market for cotton seeds. Farmers experimented with an array of risk assumptions in deciding on the use of cotton seeds (official Bt, loose Bt, branded but illegal Bt) and often preferred mixing of the varieties. Roy et al. (2007, p.71) also noted that "...most Gujarati cotton farmers have naturalised transgenics, fitting them into traditional strategies of conceptualizing and managing risk and assuring a livelihood."

The spread of Bt cotton was, however, marred by considerable information asymmetries; and, farmers

selected seeds after experimenting with several varieties. They had little knowledge of Bt traits, refuge use and targeted pests. They also received little extension support. As a result, bio-safety measures were not effectively followed (Lalitha & Viswanathan 2018). Moreover, the pesticide use scenario could have been different if it was ensured that sucking pest resistant hybrids were approved for commercial cultivation. Despite this, Gujarat continues to be a leader in cotton acreage, second only to Maharashtra. The state's intervention in reducing Bt cotton seed prices helped in its wider adoption and large gains leading to overall surpluses.

It is well documented in literature that Bt cotton adoption led to increase in acreage, yield and welfare gains. However, some sceptics attribute these to lower incidence of pests, good monsoons, better irrigation facilities and use of fertilizers, besides large scale shift from desi to hybrid cotton; and, not solely due to the gene technology (Kuruganti 2009; Bennett et al. 2006; Ramasundaram & Vennila 2013). With the universal adoption of Bt cotton, while the American bollworm infestation in cotton diminished, the untargeted pests (sucking pests) emerged, necessitating increased pesticide use (Ramasundaram et al. 2014). The adoption of Bt cotton stabilized by the end of the 2000. In fact, the reported 'technology depreciation' of Bt cotton set in during 2007, even though it continues to retain its edge in acreage over the non Bt counterparts.

3 Input use pattern in cotton on sample farms

The experience with Bt cotton in India, especially in terms of employment generation or labour absorption has not been very encouraging (Rao & Dev 2009). Studies have reported mixed results. While a few researchers report higher labour requirement due to increased yields and greater use of labour in harvesting/picking (Qaim et al. 2006; Qaim 2003), a few others reported ambiguous results mainly in regions where cotton is picked manually (Rao & Dev 2009; Qaim & Matuschke 2005). Reduced labour requirement was reported due to reduction in pesticide sprayings. The increase in labour use in harvesting was set off by the decline in labour use in sprayings of pesticides.

Mehta (2015) summarised labour absorption pattern and variable costs for Bt cotton vis-à-vis HT cotton. She observed that human labour (family and hired) was nearly 17% lesser in HT cotton compared to Bt cotton.

Of this, hired/casual labour (including piece-rate workers) was saved to the extent of 43%. Use of family labour in HT cotton, however, was higher by 15%. The withdrawal of women from agriculture, as casual workers, could be a reflection of the larger trends related to the effect of growth factors, led by the shrinkage in labour demand due to increase in rural wages as also owing to growing mechanization of agriculture (Himanshu 2011; World Bank 2012; Chand & Srivastava 2014). In this context, adoption of herbicide tolerant cotton is likely to enhance availability of women for non-farm jobs.

Table 2 examines the cost structure of Bt and HT cotton. The cost of hired labour, followed by cost of fertilizers, constitutes the largest share of the variable cost for both types of cotton. There was a significant reduction in hired labour cost in the case of HT cotton (35%) over Bt cotton, and its share in total cost (cost A2+FL) declined from 53% to 42%. Predictably, due to the decline in use of hired labour, the cost of tractor and other machinery recorded an increase of 13%. As stated earlier, use of family labour increased in HT cotton cultivation. The imputed cost of family labour increased from 23% to 29%.

With adoption of HT cotton, except cost of weedicides that increased by 44 %, all other input costs showed a

significant decline over the conventional Bt cotton. The share of purchased inputs in total cost obviously increased due to decline in labour costs. Share of insecticides remained unchanged, but the share of weedicides rose from close to 1.5% to about 2.6%. Farmers growing HT cotton reported higher number of pesticide sprays (5.8 per acre) as compared to 5.4 per acre in the case of Bt cotton. However, the average sprays of weedicides reportedly remained unchanged at 2.2 per acre in HT cotton (Mehta & Pareek 2015). While the application of weedicides/herbicides did not witness major changes with the adoption of HT cotton, their costs reportedly escalated. The cost of production for HT cotton was lower by 18% than for Bt cotton. Considering only the paid out costs (i.e. A2 cost) the savings in the cost of production per acre was close to 25% for HT cotton over Bt cotton. The cost of herbicides/weedicides increased, and it was reported in the survey that about 95% of HT cotton cultivators were using Monsanto's Roundup herbicide. It could be because the weedicide was more expensive than the other weedicides/glyphosate products that were being traditionally used by Bt cotton cultivators. It was also reported in the primary survey that nearly 68 % of all the sample farmers sprayed herbicides/weedicides. The relationship between the size of farms and the weedicide sprays reveals that the small and marginal

Table 2. Cost structure for Bt cotton vis-a-vis HT cotton for the sample farmers

Item	Bt Cost in Rs. per acre	HT	Bt Percentage of total cost	HT	% Change (col 3- col 2/col 2)
(1)	(2)	(3)	(4)	(6)	(7)
Hired labour	19818	12901	53.4	42.4	-34.9
Animal & machine labour	1573	1769	4.2	5.8	12.5
Family labour (imputed cost)	8385	8841	22.6	29.1	5.4
Labour cost	29776	23511	80.2	77.3	-21.0
Seed	1444	1295	3.9	4.3	-10.3
Fertiliser	2403	2124	6.5	7.0	-11.6
Insecticide	1638	1441	4.4	4.7	-12.1
Weedicide	546	789	1.5	2.6	44.4
Irrigation	1308	1271	3.5	4.2	-2.8
Paid out Costs (Cost A2) *	28731	21589	77.4	70.9	-24.9
Cost A2+FL	37116	30430	100.0	100.0	-18.0

Source: Derived from Table 8, Mehta (2015) and author's computation from primary data. Costs are at current prices.

Note: * Cost A2 is the cost the farmer actually pays out of her pocket for buying various inputs ranging from seeds, fertilisers, pesticides, hired labour, hired machinery or even leased-in land. Cost A2+FL is imputed cost of family labour added to the cost A2.

farms, comprising of 12.7% of cotton plots, accounted for 20% of the weedicide sprays, the medium farms comprising 59% of the plots showed 60% of the weedicide sprays. The large farms that comprised of 28% of the plots accounted for only 20% of the sprays (Mehta & Pareek 2015). It may be noted that the cultivation of HT cotton was predominant for medium and large farmers who faced labour constraints. This was also reflected in the larger expenditure on weedicide sprays in HT cotton. However, the challenge of sucking pest infestation was reportedly high in both the cases, though relatively higher in the case of HT cotton growers. About 64 % of the farmers cultivating Bt (Bollgard II) cotton and 71% of the farmers cultivating HT cotton reported high level of the sucking pest infestation. HT cotton being an expensive crop, farmers possibly strive for higher output and hence guard their crops more aggressively. This situation was akin to Bt cotton, wherein farmers in the initial years sprayed more pesticides, although the number of sprays decreased after the Bt event was transferred to a larger number of hybrids. It is also apparent that the susceptibility of sucking pests was reportedly higher in the hybrids incorporating HT traits, thereby necessitating a higher number of insecticide sprays. Since the seeds/hybrids that are more vulnerable to sucking pests are being used for the purpose of trait incorporation, possibly the technology needs to be transferred to the better suited genotypes of cotton.

It would also be useful to know if it is justified to cultivate HT cotton as it saves significant labour cost in the crucial cultivation related tasks. Cotton picking, weeding and land preparation are more labour-intensive tasks that call for increased use of hired labour (Mehta 2015). In fact, the share of hired labour cost for manual weeding activity, on an average, nearly halved from 19% to 8% with the adoption of HT cotton. On the other hand, share of labour cost for picking increased from 44% to 49%. Removal of crop residues and land preparation accounted for around 5% of all the labour costs in case of Bt cotton. This nearly halved to 2.5% in the case of HT cotton vis-a-vis Bt cotton. In fact, with the adoption of herbicide-tolerant cotton, farmers experienced a reduced burden of weeds and reduced deployment of labour for weeding. While cost of labour for chemical weed application increased only marginally, in the case of fertilization and pesticide application it increased by nearly 8 and 3 percentage

points, respectively. The task-wise distribution of family labour cost followed a similar pattern. Studies have indicated that applying glyphosate on HT maize is a quick operation, and it is possible to manage weeds prior to their critical growth period despite labour constraints (Kalaitzandonakes et al. 2015).

The creation of employment opportunities owing to widespread adoption of Bt technology was a big gain for the rural economy and was a boon for rural employment growth in the past decade. However, increasing urbanization, migration, shift towards rural non-farm jobs, along with higher enrolment in education, besides exposure to outside world owing to all pervading electronic media, are leading to altogether different kind of aspirations among rural youth (Mehta 2018). Such trends are also a reflection of the current disenchantment with farm related activities and the prevailing distress conditions in the agricultural sector. Labour-saving (mainly hired labour) possibilities offered by HT cotton technology bode well for strengthening the process of occupational diversification and economic transformation that is already visible in predominantly cotton growing regions.

4 Technical efficiency- comparison of cotton traits

Technical change implies increase in agricultural productivity at lower unit costs, that translates into reduction in the prices of farm commodities. Raising agricultural productivity through biotechnology is crucial in smallholder dominated farming systems. It is, therefore, often argued that higher growth in crop productivity is likely to enhance growth in non-farm sectors, in turn pushing the wages upwards (Dev & Rao 2009). By targeting crops grown extensively by the resource poor farmers, biotechnology can yield positive results through reduction in input costs, and thus raising profitability, provided there are no price distortions.

Yield gains from HT technology (maize) have been widely reported in Philippines, Indonesia and South Africa. *Ex ante* economic impact assessment of HT crops include quantification of input-use and yields, assessing intrinsic value of such impacts and changes in farmers' adoption patterns, environmental impacts, market impacts (changes in aggregate supply, demand

and prices), aggregate economic impacts and their distribution amongst producers and consumers. Studies have assessed the economic gains of adopting HT technology (Qaim 2009; Brookes & Barfoot 2011; Gouse et al. 2009; 2016). Several studies have used partial equilibrium models (Moschini et al. 2000; Falck-Zepeda et al. 2000; Qaim & Traxler 2005; Horna et al. 2009; Kalaitzandonakes et al. 2015), computable general equilibrium models (Hareau et al. 2005; Brookes et al. 2017) and total factor productivity analysis (Jones 2011) of HT crops. A number of empirical studies have shown that HT crops can lead to ‘non-pecuniary’ benefits (managerial ease, time savings) and non-market effects such as environmental safety (Marra & Piggott 2006). Significant value is assigned to such benefits by many producers.

In addition, the potential welfare losses can be ascertained through estimation of input efficiency, for instance by quantifying the upper bounds of potential yield-saving from effective weed control, and avoidance of input losses due to less weed-crop competition. Theoretically, efficiency of herbicide-tolerant crops will indicate the potential yields from the fields that have been prepared and planted using HT technology versus yields from fields that have used the conventional technology. Econometric formulations have been widely used to estimate agricultural productivity (partial and total) and compare technology and efficiency indicators. Farrell (1957) in his seminal study estimated technical and allocative efficiency (price efficiency) in production through the use of a ‘frontier’ production function. In this study, the production function is used to define maximum output that a farm can achieve by using HT technology vis-à-vis conventional Bt hybrids. Thus, efficiency of post-emergence glyphosate herbicide tolerant cotton (Roundup Ready RR Flex) is compared with the performance of cotton farms using manual weeding and conventional tillage. If a farm is producing sub-optimal output due to certain constraints (including technology depreciation), its production function can be specified as:

$$\gamma_i = f(\chi_1^i, \chi_2^i, \dots, \chi_n^i) \exp(u_i) \quad \dots(1)$$

Where, u represents combined effects of managerial and organizational factors that pose constraints to the

cotton production. Thus $\exp(u_i)$ reflects the farm’s ability to produce at the present level of technical efficiency (TE). TE of a farm is thus:

$$\exp(u_i) = \frac{\gamma_i}{\gamma_i^*}$$

Where, γ^* is the maximum possible output, and it has been measured variously including the stochastic production function based on composed error model of Aigner et al (1977), Meeusen & Van den Broeck (1977), Battese & Coelli (1992), Kalirajan et al. (1996), Kalirajan & Shand (1997, 1999), Greene (2008), Kumbhakar & Lovell (2000). In this section² the technical efficiency of the two cotton traits (HT and Bt) is estimated through a frontier production function using the ‘‘FRONTIER’’ programme. It enables maximum likelihood estimation of stochastic frontier production through error components specification (Battese & Coelli 1992). It assumes that all deviations from the frontiers of output result from technical inefficiency associated with weeding costs, conventional tillage and labour related expenses, besides unmeasured managerial constraints. The response coefficients of the inputs (specifically area, labour, machinery, fertilizer, irrigation) are ascertained from the OLS estimates, using a Cobb-Douglas production function:

$$\gamma_i = \alpha + \sum \beta_j \chi_j^i \quad \dots(2)$$

where, γ is the observed output and $i = 1, 2, \dots, n$ number of inputs.

The maximum output reached by a production unit or the stochastic frontier is specified by the coefficients ($\sum \beta_j \chi_j^i$), and each unit’s/farm’s output is bounded by a deterministic quantity for each combination of inputs. This is expressed after taking log on both sides as:

$$\gamma_i = \alpha + \sum \beta_j \chi_j^i + u_i \quad \dots(3)$$

where, u is the non-negative random technical inefficiency component or the amount by which the farm fails to achieve its optimum.

The response coefficients are given in table 3. All the coefficients in both the cases have expected signs, except the vector for purchased farm inputs (fertiliser and farm chemicals) in case of HT cotton. The response

² The methodology for efficiency estimation in this section has been borrowed from Mehta (2011).

Table 3. Frontier production functions for total cotton output (in quintals)

Variables	Bt Cotton	HT Cotton
Area (in bigha)	1.89 (7.146)*	0.18 (4.065)*
Labour (in '00)	0.16 (2.488)*	0.23 (1.300)***
Machine cost ('000 Rs)	0.19 (2.745)*	0.27 (2.198)**
Fertilizer & farm chemicals ('000 Rs)	0.34 (4.771)*	-0.004 (-0.015)
Irrigation cost ('000 Rs)	0.07 (1.041)	0.47 (1.976)**
Mean square error	0.93 (0.417)*	0.35 (2.458)**
Gamma	0.78 (0.514)*	0.94 (10.538)*
Log likelihood function (LR test of one sided error)	-216.7 (3.318)	-8.68 (2.715)

Source: Authors' calculations

Notes: The numbers in parentheses are the t-ratios. *, ** and *** denote significant at 1, 5 and 10%, respectively

of Bt cotton is more elastic to area and purchased inputs (fertilizer and farm chemicals). All the coefficients are highly significant, except the one for irrigation cost. The elasticity of HT output, on the other hand, is higher with respect to irrigation cost, followed by cost of farm and machine labour. The negative response to purchased inputs (fertilizer and farm chemicals) perhaps captures the fact that there are significant information asymmetries accompanying the use of stealth but expensive HT seeds particularly related to the appropriate dosage of herbicides, pesticides, etc. To guard against production losses, farmers use inputs more intensively. Moreover, Roundup Ready herbicide is expensive. The use of pesticides is also higher due to increased infestation of pink bollworm and sucking pests. Since most of the HT cotton farmers belong to the arid tracts, the elasticity in terms of irrigation costs is the highest. All the coefficients are statistically significant, except purchased inputs.

The frontier production function estimates are used to measure degree of technical efficiency as:

$$TE = \exp(-u_i) * 100 \quad (4)$$

In order to compare the two technological regimes in cotton, the relative efficiency levels estimated through Eq. (4) at farm level are aggregated to derive the mean technical efficiency for conventional Bt cotton and HT cotton. Since there is a sample bias or disparity in sample numbers for the two varieties, a t-test was carried out to compare the means. The results of the analysis are given in table 4.

The technical efficiency on HT farms ranged from 0.99 to 0.71 vis-à-vis 0.97 to 0.54 in the case of Bt cotton

farms. Overall, technical efficiency is higher on farms cultivating HT cotton (0.90), than on Bt cotton cultivating farms (0.84). This indicates that improvement in farming practices with the adoption of HT cotton has contributed positively to the total factor productivity. It is also estimated that if Bt cotton farms achieved the maximum efficiency levels they could realize 13% of incremental output; this discrepancy being higher than that for HT cotton farms (i.e., 10%). In other words, the difference between frontier and the mean actual output due to technically inefficient input use is larger for Bt cotton.

It is quite apparent that the inter-farm variation in technical efficiency is not significantly different. The diffusion of technical information, to that extent, is observed to be nearly uniform across the two cultivars.

Table 4. Estimated technical efficiency of Bt and HT cotton on sample farms

Item	Bt cotton	HT cotton
No. of farms	211	23
Maximum TE	0.97	0.99
Minimum TE	0.54	0.71
Mean TE	0.84	0.90
Standard deviation	0.089	0.099
Coefficient of variance	0.106	0.111
Variance	0.008	0.009
t- statistic	2.759	df 232
p value	0.0063	

Source: Authors' calculations

Notes: df is degree of freedom

However, there seems to be some scope to increase Bt cotton output with the current input use. It may also be noted that HT trait is likely to cause a decline in the variable costs owing to reduced deployment of the crucial labour input, resulting in greater efficiency. In fact, more judicious use of inputs and not the yield enhancement is the cause of increased output and net profit, without any augmentation of resources. To substantiate the point, one could cite the over-exploitation of ground water in the state, which is not only inefficient but is threatening sustainability of resources. Given the severe peak season labour constraints and labour supply uncertainty, savings in labour use can tide over with the introduction of this technological trait. The widespread use of HT cotton is possibly an outcome of these advantages that the crop offers. The non-pecuniary benefits of labour savings in herbicide tolerant technology are manifested in the reduction in drudgery associated with manual weeding and saving in individual time for greater engagement in more remunerative non-farm activities. In addition to the reduced expenditure on labour, efficiency in the use of purchased inputs due to absence of crop-weed competition causes decline in the overall cost of cultivation. Moreover, the effect of unexplained causes that shift frontiers, such as simplification of management decisions, cannot be ruled out.

It is pertinent to note here that while Bt cotton adoption is nearly complete in the state, the HT cotton seeds are used in stealth. Precisely for this reason, the respondents were not forthcoming about its usage. In addition, the use of HT cotton across districts and farm sizes in the state is not uniform as in case of Bt cotton. Consequently, it constrained the sample size of HT cultivators (for details, see Mehta & Pareek, 2015). Given the biased nature of the sample for the two cotton traits, the estimated mean technical efficiency for both was subjected to the t-test that assesses whether the means of two groups are *statistically* different from each other. As shown in table 4, the t-value was statistically significant, indicating that the difference between the groups not a chance occurring; and that the difference between the means of efficiency levels for the two crops is significant.

5 Conclusion

The macro-economic trends indicate that particularly agricultural male workers are finding enhanced

employment in non-agricultural sectors viz. construction, services and manufacturing. This trend has led to shortage of farm hands for crucial farming operations during peak seasons; and also pushed the farm wages upwards, resulting into significant increase in the variable cost of cultivation. In such a situation, interest of the vulnerable groups, notably resource poor farmers, is jeopardized. The large-scale shift of agricultural workers from primary to other sectors and from rural areas to rural towns and intermediate cities was evident from Census 2011. It indicates that growth of agricultural labour productivity depends on the pace of technical progress, that in turn raises the growth of output. It is argued that introduction of labour-saving technologies, even if that might displace labour initially, would raise the rate of production/output growth. By targeting the crops grown extensively by the income and the resource poor farmers, biotechnology can yield positive results. For example, enabling reduction in input use would invariably enhance profitability.

Besides the changing contours of rural economy and preference for non-farm jobs, marginal farmers carry out cultivation activities, including the time consuming and labour-intensive activities such as weeding, with the help of family labour. Use of HT cotton would reduce the labour-time spent on these operations, which would enable their engagement in the activities that have significant productivity advantages. The analysis also indicates that the burden on female family workers reduces noticeably with the adoption of HT technology. It may be surmised that technological innovation and adoption is likely to accelerate such trends and enable greater participation of women in non-farm activities and also in education.

In a liberalised agricultural trade regime, the domestic commodity production is usually linked to highly unstable global prices. Under these changed conditions, in addition to the increased spending on infrastructure, agriculture would gain far more from non-price factors such as technological innovations and better management practices. It is, therefore, imperative to step up investment on research and dissemination activities that stimulate adoption of efficient farming practices and avoid wasteful use of resources. International competitiveness of agriculture would have to be ensured through technological change and identification of efficiency shifters. The experience garnered from our limited sample indicates that HT

trait in cotton raises the total factor productivity and possesses potential for output enhancement. Besides saving on labour costs, it raises the efficiency of input use, which is a critical concern for sustainability. Such findings reiterate the need to focus on technological innovations, dissemination of scientific knowledge and ensuring its adoption, to enhance the efficiency levels in agriculture, within a robust IPR/IWR regime and stringent regulatory mechanism. The government has to play a pivotal role in this process. Presently, agriculture sector in the country is facing distress. It is heading towards avoidable waste, as agricultural output growth is overwhelmingly driven by increased use of purchased inputs. The latter has been contributing significantly in making agriculture non-remunerative for large sections of the farming population and must be tackled through timely infusion of appropriate technology.

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