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## **Welfare Gains from Application of First Generation Biotechnology in Indian Agriculture: The Case of Bt Cotton<sup>§</sup>**

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### **Abstract**

The study has quantified the welfare gains from adoption of Bt cotton in India. The adoption of Bt cotton has increased income levels and generated substantial gains due to higher yields and lower cost of production through lower cost on plant protection. During the period 2002-15, the total benefit has been estimated to be of ₹ 220 billion with 85 per cent share accruing to the producers and 15 per cent to the private seed companies/ marketing firms. The welfare gains have been found to vary across states, depending upon the extent of penetration of Bt technology and agronomic performance of the crop. In India, Bt gene is embedded in hybrids as a value-capturing mechanism, necessitating seed purchase by farmers every season afresh. One policy option to improve the producer surplus could be development of the open pollinated Bt varieties in the country that may provide higher benefits to the adopters in resource-poor regions, which are generally more suited for varieties than hybrids. The study has also highlighted some indirect gains in terms of soil health, green house emission, human health, to cite a few.

**Key words:** Biotechnology, Bt cotton, economic surplus, technological change, welfare gains

**JEL Classification:** O33, Q16

### **Introduction**

In India, the introduction of Bt cotton for commercial cultivation is a major technological landmark after the advent of green revolution in the late-1960s. Since its introduction, the technology has transgressed sizes and agro-ecologies resulting in significant economic gains, and has transformed the landscape of India's cotton economy (Ramasundaram *et al.*, 2011). The direct benefits of Bt cotton include reduced insecticide-usage, lower farming risks and

production costs, higher yields and profits, expanded opportunities to grow cotton and a brighter economic outlook for the cotton industry (Edge *et al.*, 2001; Gandhi and Namboodiri, 2006; Pray and Naseem, 2007). These benefits have provided increased returns to labour and household income, thereby a reduction in rural poverty (Subramanian and Qaim, 2010).

The noticeable feature of the impact of Bt cotton in India is its regional variation (Bennett *et al.*, 2006; Qaim *et al.*, 2006). The variation is more pronounced when the prescribed norms for Bt cotton cultivation, for example maintenance of refuge crops, are not strictly followed (Sadashivappa and Qaim, 2009). Further, Bt seeds in India are available only in hybrids, produced and marketed by private firms. Accordingly, some of the state governments have intervened into the Bt cotton seed pricing by declaring maximum retail

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price for Bt cotton seed. These factors have affected the relative performance of cotton in terms of yield growth, pesticide saving and seed costs. However, there is only a limited literature that deals with the *ex-post* assessment of impact of Bt cotton at the national level in India, as in the case of many other non-industrialized countries (Falk-Zepeda *et al.*, 2007). Even scarcer are studies that address regional variations in technology adoption and agronomic performance.

The present study has estimated the welfare gains from the adoption of Bt cotton in India and their incidences across states. This study has contributed to the existing literature in two ways: first, as noted earlier, there are only a few *ex-post* studies in India that have documented the welfare gains of Bt cotton at the national level, taking into consideration the regional heterogeneity. Most studies have used trial data or field level data on the agronomic and economic performances, collected from experimental farms or a limited number of farmers from specific location at a particular point of time. This study, on the other hand, has combined the field level data with the macro level data on actual performance of cotton using secondary data for all the major cotton-growing states in the country. Second, the study has estimated the private sector surpluses taking into account the changes in input (seed) markets.

### Extent of Bt Cotton Cultivation and its Impact in India

In 2009-10, cotton was cultivated in 10.3 Mha of area by 4-5 million farm households, yielding 5.5 Mt of raw cotton (GoI, 2010). It is cultivated in most of the agro-ecologies, mainly under the rainfed conditions, except in the northern states where it is cultivated with assured irrigation (Sundaram *et al.*, 1999). Maharashtra, Gujarat and Andhra Pradesh account for more than three-fourths of the total cotton area. Cotton has undergone continuous shifts in technology and policy during the past few decades. The notable shift has been in the in species-mix. At the dawn of independence, about 96 per cent of the cotton area was under *desi* (indigenous) varieties (Sundaram *et al.*, 1999). The commercial hybrid in cotton was first developed by India in the late-1960s. By 2000, the area under the American cotton varieties and hybrids

reached 75 per cent. However, the yield advantage associated with varietal changes started showing the signs of fatigue in the past two decades or so. One of the major reasons was the increased biotic stress, particularly, insect pest attack. The most devastating pest on cotton is bollworm (*Helicoverpa armigera*), causing yield loss up to 50 per cent (CICR, 1998). As a result, the share of plant protection in the total cost of cultivation increases tremendously. For example, in Punjab the share of pesticides in the operational costs increased from four per cent in the triennium ending (TE) 1978-79 to 34 per cent in TE 2001-02 (Shetty, 2004). The total loss due to the infestation of bollworm has been estimated to be ₹ 20 billion to ₹ 120 billion<sup>1</sup> (Wahab, 1997; Chandra, 1998; BIRTHAL *et al.*, 2000), despite about half of the total pesticide-use being on cotton alone (Sundaram *et al.*, 1999; Qaim, 2003). The human health implications of high chemical-use in cotton cultivation were also enormous. These developments had created a perfect stage for the introduction of transgenic cotton in India. After the introduction of Bt hybrids in 2002-03 *kharif* season, its adoption has been unparalleled.

### Economic Impacts of Bt cotton

Several recent studies have examined the economic impact of Bt cotton in the developing countries, including India (Qaim, 2003; Qaim and Zilberman, 2003; Barwale *et al.*, 2004; Bennett *et al.*, 2006; Gandhi and Namboodiri, 2006; Qaim *et al.*, 2006; Dev and Rao, 2007; Pray and Naseem, 2007; Vitale *et al.*, 2007). These studies have adopted different approaches such as enterprise budgeting technique, production function approach, social accounting matrix and economic surplus model, to estimate the economic impact of Bt cotton. These have used primary data (collected from the farmers/ plots), and have provided varying estimates of the economic gains. The increase in benefits at the farm level has been attributed to the savings in insecticide-use and higher yields, despite higher seed prices (*see* Subramanian and Qaim, 2010).

The yield advantages of Bt cotton being quite large, the area under Bt cotton increased from about 29 thousand ha in 2002 to over 9.4 M ha in 2010 (James, 2010) and was accompanied by the increase in yield from 213 kg/ ha during 1998-2001 to 430 kg/ ha during

<sup>1</sup>The exchange rate for Indian currency, One US\$ = ₹ 48.60 (in 2002)

**Table 1. State-wise area under Bt cotton in India, 2002-2009**

('000 ha)

State	2002	2003	2004	2005	2006	2007	2008	2009
Andhra Pradesh	4 (0.5)	5 (0.6)	71 (6.0)	90 (8.7)	657 (67.6)	1000 (88.2)	1143 (81.7)	1264 (86.2)
Gujarat	9 (0.6)	42 (2.6)	126 (6.6)	149 (7.8)	407 (17.0)	1300 (53.7)	1450 (61.6)	1372 (55.7)
Haryana	0 (0.0)	0 (0.0)	0 (0.0)	11 (1.9)	42 (7.9)	279 (57.8)	380 (83.5)	448 (88.4)
Karnataka	2 (0.5)	3 (0.9)	34 (6.5)	29 (7.0)	80 (21.3)	146 (36.2)	172 (42.1)	262 (57.3)
Madhya Pradesh	1 (0.2)	13 (2.3)	86 (14.9)	136 (21.9)	302 (47.3)	471 (74.8)	514 (82.3)	593 (97.1)
Maharashtra	12 (0.4)	22 (0.8)	161 (5.7)	509 (17.7)	1655 (53.3)	2562 (80.2)	2572 (81.8)	3150 (90.1)
Punjab	0 (0.0)	0 (0.0)	0 (0.0)	70 (12.6)	281 (46.3)	575 (95.2)	476 (90.3)	513 (100.0)
Rajasthan	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.4)	5 (1.4)	38 (10.3)	121 (40.0)	265 (59.6)
Tamil Nadu	0 (0.0)	8 (8.2)	12 (9.3)	17 (12.1)	32 (31.9)	60 (60.4)	72 (62.9)	26 (25.0)
India	28 (0.4)	93 (1.2)	491 (5.6)	1014 (11.7)	3461 (37.8)	6431 (68.3)	6900 (73.4)	7892 (80.0)

Note: Figures within the parentheses indicate percentage to total

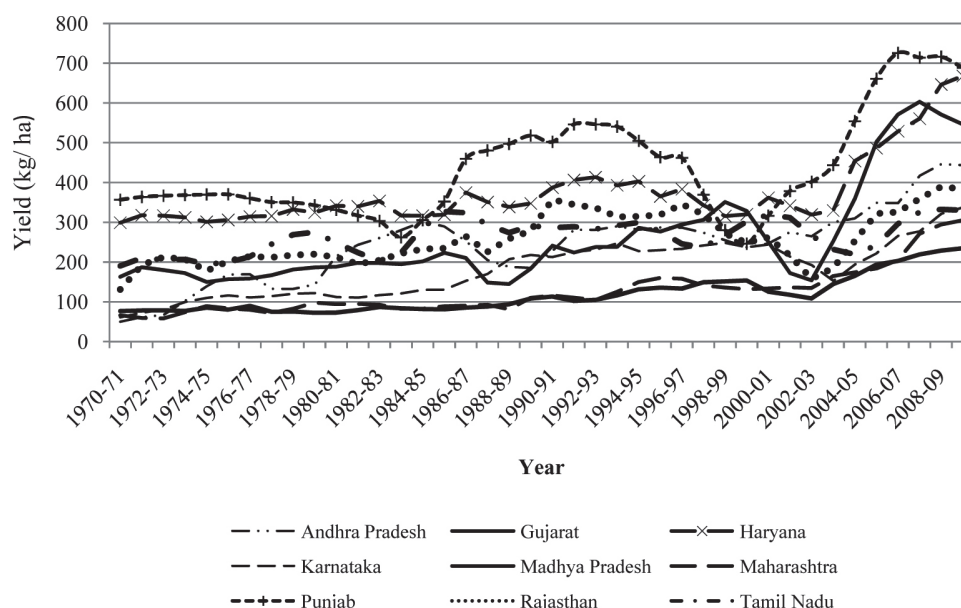
Source: Compiled from Indiatat.com, ISAAA; Gruère and Sengupta (2011) and *Agricultural Statistics at a Glance* (various issues) GoI

2006-07 to 2008-09. The adoption of Bt cotton in major states of India has been shown in Table 1. The replacement of area under non-Bt cotton coincided with a significant yield increase in all the states.

The productivity trend in cotton in India since 1970 has been depicted in Figure 1. All the states have posted sharp yield increase post-Bt cotton introduction. This could lead to the increase in national cotton production from 1.83 Mt in 1970-71 to 4.0 Mt in 2008-09 at an annual growth of about 13 per cent. This is in contrast to its growth performance before the introduction of Bt cotton (0.7%). The growth in production, as expected, was propelled by yield improvements (James, 2008) though wide regional variations exist in the growth performance.

The growths in area, production and yield during the Bt period (2002-03 to 2009-10) and the preceding decade (1992-93 to 2001-02) have been presented in Table 2. The yield growth was significant during the Bt period (from 2002-03 onwards) — from 3.2 per cent in Tamil Nadu to 17.4 per cent in Gujarat — causing a

significant growth in production in most states. The low growth in production in some states, viz. Karnataka and Tamil Nadu, could be attributed to the decline in cotton area. The impact of Bt technology has been succinctly brought out by Gruère and Sengupta (2011). The average cotton yield level reached almost 400 kg/ha in 2003-04 (the second year of Bt cotton introduction) and then exceeded 500 kg/ha in 2006-07. It took just three years to increase yield by 100 kg/ha in the post-introduction of Bt, while previously, a similar increment took 15 years — from 200kg/ha in 1982 to 300 kg/ha in 1997. They have also estimated that under the alternate scenario of continuing at the historical growth rates, the production of cotton would have been around 13-14 million bales at the yield level of less than 300 kg/ha as against 526 kg/ha during 2009-10. Likewise, the total pesticide consumption in the Indian agriculture would have been around 60 thousand tonnes as against 42 thousand tonnes in 2010-11. It is pertinent to mention that improvements in the quality of pesticides have also contributed to the reduction in pesticide quantity (Ramasundaram *et al.*, 2011).



**Figure 1. Average cotton yield level by state (kg/ha), 1970-71 to 2009-10**

Source: GoI (2010)

**Table 2. A comparison of growth in area, production and yield of cotton during Bt period and the preceding decade**  
(in per cent)

State	Area		Production		Yield	
	Pre-Bt (1992-93 to 2001-02)	Bt (2002-03 to 2009-10)	Pre-Bt (1992-93 to 2001-02)	Bt (2002-03 to 2009-10)	Pre-Bt (1992-93 to 2001-02)	Bt (2002-03 to 2009-10)
Andhra Pradesh	4.40	-0.90	1.70	9.40	-2.80	10.20
Gujarat	4.30	4.90	4.40	22.20	0.40	17.40
Haryana	1.90	-3.10	0.01	8.80	-1.70	11.70
Karnataka	-1.60	-5.90	-3.20	-0.30	-1.80	6.20
Madhya Pradesh	-0.10	4.10	2.50	12.80	2.60	8.80
Maharashtra	1.60	-0.90	3.70	10.00	2.20	10.90
Punjab	-3.60	1.80	-6.80	17.70	-3.20	15.70
Rajasthan	1.90	-8.50	-3.10	2.40	-4.80	11.00
Tamil Nadu	-3.90	-8.80	-5.90	-6.00	-1.80	3.20
India	1.70	-0.01	0.70	13.00	-1.00	13.00

Note: Pre- Bt period and Bt period correspond to 1992-93 to 2001-02 and 2002-03 to 2009-10, respectively

Source: Adapted from VPAGe (2012)

Many other studies have estimated the beneficial role of Bt cotton employing field level data. Based on farm level data from the states of Andhra Pradesh, Karnataka, Maharashtra and Tamil Nadu in 2002, Qaim *et al.* (2006) have reported that with Bt cotton, yield was higher to the extent of 34 per cent and the number of insecticide sprays was lower by 2.6-times. Subramanian and Qaim (2009) surveyed the same

farmers again in 2004-05 and then in 2006-07, and reported that on an average, Bt cotton recorded 37 per cent higher yields than the conventional cotton and 41 per cent lower insecticide applications. The profit realized from the cultivation of Bt cotton is substantially higher (80%) owing to higher yields and lower cost on plant protection (Narayanamoorthy and Kalamkar, 2006; Bennet *et al.*, 2006; Dev and Rao, 2007).



Some studies are, however, skeptical about the impact of Bt technology in India. According to Kuruganti (2009), the high yield growth in cotton in Gujarat was due to the low incidence of target pest, consistently good monsoon for a long period, increasing area under irrigation, and high application of chemical fertilizers. Further, it is argued that the shift to cultivation of hybrids itself brought in large yield improvement.

Naik *et al.* (2005), while exploring the paradoxes reported in some studies, have found that, on an average, the Bt technology generates economic benefits, but heterogeneity across farmers needs to be addressed. The appropriateness of Bt technology depends on the local pest pressure, individual crop management, local suitability of the germplasm into which Bt gene is transferred and the information flow. Gruère and Sengupta (2011), while agreeing to the proposition that the Bt cotton technology has played a significant role in raising cotton production, have also pointed to the differing marginal effects of the technology across states. Some researchers attribute such differences to the enabling paraphernalia of technology adoption like development of irrigation infrastructure (Shah *et al.*, 2009; VPAGE, 2012), besides the variations in the agro-ecological and socio-economic conditions (Bennett *et al.*, 2006; Qaim *et al.*, 2006). This fact becomes more evident on looking at the irrigation development *vis-a-vis* cotton yield. According to Ramasundaram and Vennila (2013), the post-Bt cotton production gains cannot be solely attributed to the gene technology.

## Empirical Methodology

### Economic Surplus Model for Welfare Estimation

Economic surplus model has been widely used to quantify the welfare effects of genetically modified crops. It details how markets would respond to the introduction of the technology, by analysing new equilibrium using a demand-supply framework. It is based on the premise that whenever new technologies are adopted on a large scale, the productivity increase will cause the crop supply curve to shift downwards, leading to changes in producer and consumer surpluses, which are measured in standard monetary units (Alston *et al.*, 1995). The consumers derive their surplus from purchasing their bundle of goods at lower prices,

whereas producers obtain surplus out of selling higher quantities in the market and by reducing production costs. Consumer surplus, in that context, represents the free resources that can be transferred to other sectors of the economy, whereas the producer surplus is the sum of additional rents that accrue to farmers' internal resources (Vitale *et al.*, 2007). The magnitude and distribution of the economic benefits depend on factors such as price elasticity, volume of production, trade issues, and nature of innovative changes induced by the technology, innovator rent, and technology fee, among others. The model follows comparative static approach, and doesn't detail the dynamics of establishment of the new equilibrium. In this study we have used partial equilibrium model.

As the technology is developed and commercialized by the private sector, the accrued technology rent also needs to be considered (Moschini and Lapan, 1997) in estimating the total welfare gains. The Bt technology in India was developed by Mahyco-Monsanto Biotech, but the company has sub-licensed the marketing rights to four other firms as well. Therefore, the appropriation of the benefits of seed industry goes to all the firms involved in the entire business process, including the innovators and the marketing companies as per the license agreements and respective market shares. We have, however, restricted our analysis to the benefits accrued to the entire private sector without attempting to analyse the firm-level benefit appropriation.

### Model Empirical Structure

India is a net exporter of raw cotton and cotton yarn. India exported 1.4 million tonnes of cotton (including raw cotton, cotton yarn, lint and waste) worth US \$ 2.0 billion in 2009. This accounted for 21 per cent of the world cotton trade (FAO, 2011). Considering this significant share in cotton export, we modelled the economic impact of Bt cotton in an open-economy framework with no technology spill overs (though, there could be some across the border transfer), and assumed linear supply and demand and a parallel shift in supply from the new technology (Alston *et al.*, 1995). The spill over effect was neglected considering the large size of India as an agrarian economy and negligent impact that the changes in factors of production would bring about in other sectors. The cotton market is regulated by the

Government of India, which guarantees purchase of cotton at a minimum support price. However, in practice, the domestic market price is generally higher than the minimum support price, rendering the government operations redundant in most of the years and states. The Bt cotton seeds in India are marketed by Mahyco-Monsanto, the holders of patent for the technology and marketing rights. Due to the monopoly power that the company enjoys, it is able to set the seed prices above the marginal cost of production. Therefore, the welfare estimation undertaken in this model had two components, viz. changes in the producer surplus and benefits to the private sector.

The change in producer surplus ( $\Delta PS$ ) resulting from Bt technology in the year  $t$  can be calculated by Equation (1):

$$\Delta PS = P Q K (1 + 0.5 K \epsilon) \quad \dots(1)$$

where,  $P$  and  $Q$  are the prices and quantities of cotton, respectively and  $\epsilon$  is the price elasticity of supply.  $K$  is the technology induced supply shift of cotton, calculated based on the actual change in the yield level of cotton as indicated in Equation (2):

$$K = \left[ \frac{E(Y)}{\epsilon} - \frac{E(C)}{1 + E(Y)} \right] \rho A_t (1 - \delta_t) \quad \dots(2)$$

where,  $E(Y)$  is the proportionate yield change per hectare,  $E(C)$  is the proportionate change in input costs per hectare to achieve the expected yield changes,  $\rho$  is the probability of the success of the research (assumed as one as the technology is *fait accompli* and the analysis is *ex-post*),  $A_t$  is the adoption of Bt cotton in percentage of total acreage and  $\delta_t$  is the annual rate of depreciation. The technology depreciation in the case of Bt cotton was noted in the form of emergence of non-target pests, thereby necessitating increased pesticide application. It was observed that once the Lepidopteron pests, like American cotton bollworm infestation diminished, new problems emerged in the form of increased infestation by the sucking pests. The value of technology depreciation was decided in discussion with the subject matter specialists and the promoter company, as progressive increment over the life of technology.

As the performance details of the technology were available, the field data with respect to yield advantage, cost reduction and adoption rate were used for estimation. The private sector benefit (PB) accruing to

the innovators and marketeers was analysed using the method propounded by Moschini *et al.* (2000):

$$PB = A[(1 - \theta)(P_{Bt} - P_{non-Bt})] \quad \dots(3)$$

where,  $A$  is the coverage of Bt cotton in hectares,  $P_{Bt}$  is the price of the  $B_t$  seeds and  $P_{non-Bt}$  is the price of non-Bt seeds. Here, it is safe to assume that the conventional seed market is competitive and cost of production of Bt cotton is equal to that of the non-Bt conventional hybrids available in the market, and difference between these two prices is the gross technology revenue (GTR). However, distribution, marketing and extension costs of the Bt seeds are somewhat higher than the conventional hybrids. Qaim *et al.* (2006) have used the value of 0.1 to account for this expenditure and was represented by  $\theta$  in Equation (3). By adjusting the GTR with  $\theta$ , it translates into net private benefit. Though this cost pertains to the initial years of the technology development, it was assumed that the expenditure under this head would continue to retain the market composition and introduction of new hybrids with Bt gene. The company R&D expenditure has not been accounted for in the analysis, as it is considered as sunk cost. Welfare gains have been estimated for major the cotton-growing states of India, and were summed up to arrive at the national level estimates. Table 3 lists major assumptions used in estimating the model.

## The Data

Gruère and Sengupta (2011) have reported that a majority of Indian farmers gained substantially by adopting Bt cotton; however, the gains in the Bt cotton cultivation cannot be generalised for all cultivators, regions and seasons. The range of reduction in the number of sprays was 30-36 per cent with the associated cost reduction of 35-52 per cent. The yield gain was in the range of 34-42 per cent with no clear effect on seed cotton prices. The overall rise in the net return was to the extent of 50-94 per cent. But, there were considerable inter-state variations as well. Notwithstanding the deficiencies of these studies, we have adopted the means of the agronomic performance parameters compiled by Gruère and Sengupta (2011) to compute state-wise economic surpluses. The technology life reckoned for the computation was assumed to be 14 years, based on the discussions with crop scientists and seed companies.

**Table 3. Some of the major assumptions used in estimation in the study**

Assumption	Parameter/ Values	Source
Technology life	14 years	Discussions with experts
Price elasticity of supply	0.43	Qaim (2003)
Yield improvement and agronomic performances	Mean values for the states	Gruère and Sengupta (2011)
Technology fee	52%	Discussions with experts
Social discount rate	5.2%	Kula (2004)

Acharya and Agarwal (1994) have estimated the supply elasticity of cotton in southern India to be 0.31 in the short-run and 0.54 in the long-run. Since the state-wise disaggregated elasticity of supply is not available, we have taken the average elasticity of 0.43 as the medium-run elasticity to calculate the reduction in marginal costs. The medium-run supply elasticity of 0.43 was used by Qaim (2003). Another important parameter used in the estimation process was the technology fee, which is the cost difference between Bt and non-Bt seeds. Though the price of Bt seeds was on a higher side in the initial years, subsequent government interventions, brought it down considerably (Sadashivappa and Qaim, 2009). Based on discussions with seed dealers and farmers, it was assumed to be 52 per cent. The actual technology adoption rates were used for the estimation of benefits up to 2010 and the end-year values were retained for the remaining period of 2011 to 2015. It is pertinent to mention here that this assumption seems quite tenable as the adoption of Bt cotton almost stabilized by the end of previous decade.

Another important parameter is ‘technology depreciation’. Discussions and literature enabled our assumption that technology depreciation in Bt cotton has been since 2007 and would continue even during the projection period, though would retain the edge over non-Bt counterparts. The counterfactual cotton prices were calculated as the three-year weighted average prices based on the data during the pre-Bt period, 1999-00 to 2001-02. For an open economy, the usage of international prices is more relevant than national prices; however, in view of the less than full transmission of the international prices to the domestic market, the domestic prices were used for the analysis. The impact assessment needs to take into account the growth not accounted for by the technology; therefore, the output was adjusted by using the exogenous output growths. These were estimated based on the business

as usual principle, by compound annual growth rate of cotton production over a decade covering 1990-91 to 2001-02, the period closer to the introduction of Bt cotton. Since the benefits are accruing over a period, the future benefits need to be discounted. The selection of a proper discount rate assumes importance in this context. Kula (2004) has reported the social discount rate for evaluating agricultural projects as 5.2 per cent. We have adopted this rate to calculate the present value.

## Results and Discussion

The welfare gains generated by the adoption of Bt cotton in different states are reported in Table 4. The total gains at national level amounted to ₹ 220 billion, consisting of ₹ 188 billion producer surplus and ₹ 32 billion private sector surplus. In US dollars (at 2002 exchange rates), these benefits were US\$ 5.67 billion with per annum benefit of \$ 404 million. Similar results were reported for other countries as well. Price *et al.* (2003) have reported an annual surplus of about US\$ 164 million in the United States with farmers,

**Table 4. Distribution of estimated welfare gains in of Bt cotton cultivation in major cotton-cultivating states of India, 2002-2015**

(in million ₹)			
State	Producer	Private sector	Total
Andhra Pradesh	545	4500	5045
Gujarat	57942	9170	67112
Haryana	4663	1474	6137
Karnataka	4265	853	5118
Madhya Pradesh	13803	2039	15842
Maharashtra	62873	10981	73854
Punjab	36889	1929	38818
Rajasthan	6247	692	6939
Tamil Nadu	1177	317	1494
Total	188405	31955	220360



consumers and producing companies sharing 37 per cent, 18 per cent and 45 per cent, respectively. For China, the reported surplus was US\$ 140 million in 2009 (Pray *et al.*, 2001). Qaim (2003) estimated the total producer and innovator surplus for India to be ₹ 15 billion in 2005, starting from ₹ 0.30 billion in 2002, ₹ 2.1 billion in 2003 and ₹ 6.0 billion in 2004, when the area under Bt cotton was very less. Our estimates were pegged at a slightly lower level — ₹ 0.64 billion for 2002, ₹ 0.85 billion in 2003 and ₹ 1.37 billion in 2004. This deviation could be due to less than expected reductions in pesticide consumption in some states.

The realization of surpluses across the states has varied widely in proportion to the penetration of Bt hybrids, their agronomic performance and variations in pre-Bt cotton performance (base effect). The highest benefit was recorded in Maharashtra (₹ 74 billion), which was about one-third of the country's total surplus, followed by Gujarat (₹ 67 billion). These two states together accounted for 57 per cent of the total cotton area in India. Andhra Pradesh, with its meagre share of only two per cent in the surplus (pegged at about ₹ 6.3 billion) is conspicuous as its share in the crop acreage is as high as 15 per cent (1.4 Mha). The state appropriated only 0.29 per cent of the total producer surplus generated in India, while its share in the total private sector surplus was 14 per cent. The lower performance of the producer surplus despite higher adoption rates may be due to the negligible cost reduction and high pre-Bt growth performance experienced in the state. Punjab, a state where cotton is cultivated under assured irrigated condition, realized a producer surplus of ₹ 0.37 billion, accounting for about 19 per cent of the national producer surplus, despite a meagre area-share of about 5.6 per cent. The introduction of Bt cotton hybrids has fitted well with the prevailing cotton-wheat crop rotation system of the state (Ramasundaram, 2005). Short-duration cotton could be cultivated during the *kharif* season (summer, starting from June-July), and harvested by October, and the land preparation for the succeeding *rabi*-wheat crop (winter) could be undertaken from late-October. Before 2005-06, the hybrid cotton area in the state was less 3-4 per cent, as open pollinated varieties were more preferred. But, Bt hybrids, with synchronized flowering, limited picking and early termination,

enabled timely sowing of wheat. Besides, the dismal pre-Bt performance of cotton, the yield growth during the previous decade being negative (−3.2 %) due to severe pest infestation (VPAGe, 2012), also facilitated a higher surplus. The large reductions in costs on pesticides and the resultant high yield advantage during the post-Bt period helped the state to emerge as a high performer.

It was noted that almost 85 per cent of the total generated surplus was by the producers, and the rest by the private sector. Barring Andhra Pradesh, the share of producer surplus across states ranged between 76 per cent in Haryana and 90 per cent in Rajasthan. It is worthwhile to recall that in both these neighbouring states, cotton is cultivated under the irrigated condition<sup>2</sup>. Still, their better performance in cotton cultivation can be adduced to higher yield gains and lower pesticide-use. The extent of surplus realization and distribution between the producers and the private sector would have been different, but for intervention of the states in rationalising the seed prices (Ramasundaram *et al.*, 2011). The intervention to reduce the seed prices in many states helped in its wider adoption, generating higher producer surplus, and boosting the private sector surplus through volume of trade. It can be surmised that the percentage of benefit appropriation was more than the corresponding area share under Bt cotton in Gujarat, Punjab and Rajasthan. While in Punjab and Rajasthan, large yield increase and lower pesticide-use favoured the increase in the benefits, in Gujarat it was triggered by the large area increase. Though cotton is cultivated under irrigated conditions in Haryana also, its share in benefits could not surpass area share, probably due to less than proportionate reduction in input application compared to the non-Bt era (the pest infestation was more severe in Punjab than Haryana).

## Conclusions

One decade has elapsed since the Bt cotton was introduced in the crop season 2002-03 for commercial cultivation in India. This study has analyzed the impact of Bt technology on Indian cotton economy through the economic surplus model and examining the distribution of gains across states. The study has

<sup>2</sup> The bulk of cotton cultivation in Rajasthan is in the Sri Ganganagar district, contiguous to cotton belts of Punjab and Haryana, and is 100 per cent irrigated. Cotton in this district constitutes bulk of the crop area in the state.

combined the field level meta data on the agronomic performance of Bt cotton with the macro data on technology adoption, seed prices and exogenous growth rates for all the major states of the country.

The Bt cotton phase has increased income levels and generated substantial social gains due to higher yield and lower cost of production through reduced cost on plant protection. During the period 2002-2015, the total benefit has been projected to be of ₹ 220 billion with 85 per cent accruing to the producers. The study has observed wide inter-state variations which are due to differences in the penetration of Bt hybrids, their agronomic performance in the fields and variations in pre-Bt cotton performances. The highest total surplus has been recorded in Maharashtra, followed by Gujarat. Andhra Pradesh and Punjab have depicted contrasting performance because of the differences in agronomic performances and the exogenous technology growth. While the lower reduction in insecticide-usage combined with positive exogenous technology growth have yielded a lower producer benefit (in absolute terms and in comparison with the acreage) in Andhra Pradesh, the significant reduction in insecticide-usage and lower exogenous production growth have provided higher and more than proportionate benefits in Punjab.

The private sector benefits have been found to constitute only 15 per cent of the total benefits because of the seed market regulations. It has also been pointed out that the relatively strong intellectual property rights regulations in India have helped in the generation of substantial private benefits and innovation rents, thereby promoting private investment in cotton research and development. The study has highlighted that in India the vehicle for Bt technology in cotton is hybrids, whereas in other countries, the Bt technology is incorporated in open-pollinated varieties obviating the need to purchase seed every year (Ramasundaram *et al.*, 2011). The development of the open pollinated Bt varieties may help in realization of higher benefits to cultivators in the resource-poor regions not conducive to hybrids and enhancement of the producer surplus.

Finally, it may be mentioned that the benefits of Bt technology adoption would remain under-estimated by as much as the un-estimated positive externalities and indirect benefits in terms of health benefits due to reduction in pesticide use and reduced exposure to pesticides, possible surge in population of predators and parasites, improvement in soil health and clean

water bodies, reduction in emission of greenhouse gases, increase in employment generation and reduction in poverty, which could not be captured due to paucity of data. On the flip side, new challenges have emerged in cotton pest scenario in India in the past few years, in terms of negative externalities like surge in minor pests calling for more plant protection expenditure for their control than earlier, reduction in biodiversity by elimination of cotton open pollinated varieties, to cite a few. This study has not taken into account these complex changes at the field level.

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