# Bt Cotton in India: Development of Benefits and the Role of Government Seed Price Interventions

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While previous research has analyzed the impacts of Bt cotton in India, most available studies are based only on one or two years of data. We analyze the technology's performance over the first five years of adoption, using panel data with three rounds of observations. On average, Bt-adopting farmers realize pesticide reductions of roughly 40%, and yield advantages of 30-40%. Profit gains are at a magnitude of US $60 per acre. These benefits have been sustainable over time. Farmers' satisfaction is reflected in a high willingness to pay for Bt seeds. Nonetheless, in 2006 Indian state governments decided to establish price caps at levels much lower than what companies had charged before. This intervention has further increased farmers' profits, but the impact on aggregate Bt adoption was relatively small. Price controls might have negative long-term implications, as they can severely hamper private sector incentives to invest in new technologies.

***Key words***: biotechnology, Bt cotton, genetically modified crops, farm survey, India, seed markets, technology adoption, willingness to pay (WTP).

## Introduction

Bt cotton is one of the first genetically modified (GM) crop technologies with wide distribution in developing countries. In India and China, in particular, the area under Bt cotton has increased sharply over the last couple of years, reaching 25 million acres in 2007 (James, 2007). Most of the Bt cotton growers in these countries are small-scale farmers; several recent studies have shown that they benefit considerably from adopting the technology in terms of reductions in pesticide use and higher effective yields (Bennett, Kambhampati, Morse, & Ismael, 2006; Crost, Shankar, Bennett, & Morse, 2007; Pray, Huang, Hu, & Rozelle, 2002; Qaim, Subramanian, Naik, & Zilberman, 2006). Nonetheless, concerns persist about the development of benefits over time. Pest populations might eventually become resistant to Bt, especially when refuge strategies are not enforced, as is often the case in smallholder agriculture. Moreover, secondary pests not controlled by Bt might turn into primary pests (e.g., Wang, Just, & Pinstrup-Andersen, 2006). Both factors could potentially entail diminishing pesticide savings and yield advantages over time. In addition, given that most GM crops thus far have been commercialized by private sector multinationals, there are fears that monopolistic market structures might increasingly prevail. This could lead to excessive prices charged for Bt seeds, resulting in lower farm profits and restricted technology access, especially for resource-poor farmers (e.g., Lalitha, 2004; Qaim & de Janvry, 2003). Accordingly, some developing coun-

tries' governments have started to intervene in GM seed pricing (e.g., Basu & Qaim, 2007; Fukuda-Parr, 2007). In India, for instance, since 2006 state authorities have set official maximum retail prices for Bt cotton seeds, which are significantly lower than the prices previously charged by seed companies. The broader implications are not yet fully understood.

Our research contributes to the existing literature in two ways. First, we analyze the farm-level agronomic and economic effects of Bt cotton adoption in India over time. While previous studies for India have analyzed just one or two years of data (Bennett et al., 2006; Crost et al., 2007; Gandhi & Namboodiri, 2006; Qaim et al., 2006), we use panel data collected in three survey rounds over a period of five years. Second, we analyze and discuss the role of price interventions in the market for Bt cotton seeds. Two of the farm survey rounds were conducted before the government had set maximum retail prices, while the third round was carried out afterwards.

The rest of this article is organized as follows. The next section provides a broader background of Bt cotton adoption in India, also discussing the role of black-market seeds and the politics behind the government's price interventions. Then the farm survey data are described and the technology's impacts on input use and crop productivity analyzed. In a further section, we estimate farmers' willingness to pay (WTP) for Bt cotton seeds in the three survey rounds using a contingent valuation approach. WTP is an interesting measure to analyze

**Table 1. Development of cotton area, production, and yield in India.**

| | Cotton area (million acres) | Production (million tons) | Yield[a] (kg/acre) | Bt cotton area[b] (million acres) | Bt in % of total cotton area[b] |
|---|---|---|---|---|---|
| **2000-01** | 21.4 | 2.38 | 113 | -- | -- |
| **2001-02** | 21.8 | 2.69 | 125 | -- | -- |
| **2002-03** | 19.2 | 2.31 | 122 | 0.1 | 0.7 |
| **2003-04** | 19.1 | 3.04 | 161 | 0.3 | 1.3 |
| **2004-05** | 22.0 | 4.13 | 190 | 1.3 | 5.7 |
| **2005-06** | 21.7 | 4.10 | 191 | 3.3 | 15.0 |
| **2006-07** | 22.9 | 4.76 | 210 | 9.5 | 41.5 |
| **2007-08** | 23.8 | 5.27 | 224 | 15.5 | 65.1 |

*Sources: CAI (2008) and James (2007).*
[a] *Yield is expressed in terms of pure lint in official statistics.*
[b] *Only the area grown with officially approved Bt cotton hybrids is considered.*

farmers' level of satisfaction with the technology. Given rapidly increasing Bt adoption rates in India, we hypothesize that mean WTP is higher than the actual seed prices charged by companies in the first years of adoption and certainly higher than the maximum retail prices established since 2006. The last section concludes and discusses policy implications.

## Background

In India, cotton accounts for 30% of agricultural gross domestic product (Cotton Association of India [CAI], 2008). With more than 20 million acres, the country has the largest cotton area in the world. The area under cotton in India has grown considerably in recent years. Likewise, yield levels have increased significantly, from around 120 kg of lint per acre in the early 2000s, to more than 200 kg now (Table 1). The Cotton Advisory Board (CAB) of India estimated an all-time record cotton production of 5.27 million tons and a record high 23.8 million acres in 2007-08. As a result, India has been able to improve its position in world cotton trade from the third largest *importer* in 2002-03 to the second largest *exporter* after the United States in 2007-08. This significant increase in cotton area and production in India is attributed to better returns realized by farmers during the last few years, which are largely due to the introduction and rapid spread of Bt cotton technology (CAI, 2008; Khadi, Rao, & Singh, 2007).

The first three Bt cotton hybrids were commercially approved in India in 2002 for central and southern cotton-growing states (Qaim et al., 2006). The three hybrids had been developed by the Indian company

Mahyco in collaboration with Monsanto under their joint venture Mahyco Monsanto Biotech Limited (MMBL). Later, MMBL sub-licensed its Bt cotton technology to other seed companies in India for incorporation into their own cotton hybrids. A fourth Bt hybrid was commercialized in 2004 by Rasi Seeds. In 2005, 16 additional Bt hybrids were released, including some for the northern cotton-growing states of India. The Genetic Engineering Approval Committee (GEAC) sanctioned three new Bt cotton events in 2006, one of which has two stacked Bt genes for a broader spectrum of pest control. In the 2007-08 growing season, a total of 131 different Bt hybrids were grown in India (James, 2007).

### Illegal Bt Cotton

Even before the approval of the first official Bt hybrids in 2002, illegal Bt cotton seeds were used in India. In 2001, the unlicensed Bt cotton hybrid NB-151 (from the company NavBharat) was cultivated on more than 10,000 acres in the state of Gujarat. Testing found that this hybrid contained Monsanto's Cry1Ac gene; however, it did not have a license and nor undergone the necessary biosafety procedures. Although the GEAC had recommended stringent action to destroy the crop of NB-151, farmer opposition prevented the crop's destruction and legal prosecution of NavBharat. As a result, in subsequent years, illegal Bt cotton seeds multiplied and were sold under different names on a growing black market in different Indian states. Illegal Bt seeds were priced between 800 and 1200 Indian rupees (Rs) per packet of 450 grams (enough to plant one acre), as compared to a price of Rs 1600 (US $36.45) for official Bt cotton seeds (Murugkar, Ramaswami, & Shelar, 2007). In 2004-05, illegal seeds reached an estimated area of 2 million acres (Pray, Bengali, & Ramaswami, 2005). Since then, the lower price and wider availability of legal Bt cotton hybrids has probably contributed to a reduction in the illegal Bt area, albeit trustworthy statistics are hard to come by. Bennett, Ismael, & Morse (2005) showed that, on average, illegal Bt hybrids generate higher profits than conventional cotton hybrids, but lower profits than legal Bt hybrids.

### Government Price Interventions

As mentioned earlier, until 2006 the price for official Bt cotton seeds in India was roughly Rs 1600 per packet of 450 grams. Of this, Rs 1250 was charged by MMBL as the "trait value." The debate about Bt cotton pricing, which eventually led to the government interventions, started in late 2005 with the South India Cotton Associ-

ation urging seed companies to lower their seed prices. This idea gained popularity among various farmer organizations, which encouraged the state government of Andhra Pradesh to approach the Monopolies and Restrictive Trade Practices Commission (MRTPC), claiming that the price charged by MMBL was "exorbitant" and "unscientific." In response, MMBL said that its pricing philosophy was based on sharing the benefits of technologies with farmers. Furthermore, the company clarified that the trait value was charged to support current products in the market and also fund research for future products ("AP Government," 2006).

The pricing issue took a political turn when company officials and the state government sought intervention and support from India's federal government. When the Federal Ministry of Agriculture backed the request to reduce prices, MMBL offered to cut down the trait value to Rs 900. However, the government of Andhra Pradesh appealed to lower the trait value further. This appeal was upheld by MRTPC, directing MMBL to fix a trait value to a "reasonable level on par with the value Monsanto charged in China and the US" ("Bt Cotton," 2006). The company fought back, arguing that the case did not actually fall under the purview of the commission, and it challenged the MRTPC order in the Supreme Court. In the meantime, even though the case was still pending in court, the government of Andhra Pradesh issued a directive, mandating seed companies not to sell Bt seeds above Rs 750 per packet. Several other important cotton-growing states followed the Andhra Pradesh example. Later, the Supreme Court reiterated the MRTPC order and directed MMBL to sell Bt cotton seeds at the same price as in China. While some legal uncertainty remains, Bt cotton seed prices in India have dropped significantly since 2006. As Figure 1 demonstrates, the government interventions in the prices for official Bt seeds also affected the prices charged for illegal seeds in the black market.

Upon closer examination, the comparison of seed prices and trait values made by MRTPC between India, China, and the United States turns out to be inappropriate. Apart from the fact that the agroecological conditions are quite different across countries, Bt cotton technology is commercialized in open-pollinated varieties (OPVs) in China and the United States; in India it is incorporated in hybrids, for which seed production is more costly. Moreover, MRTPC made its price comparison per kg of seeds, although seeding rates vary dramatically. For instance, instead of the 450 grams of seeds per acre used by hybrid growers in India, Chinese cotton farmers use 6-8 kg of OPV seeds. Against this back-
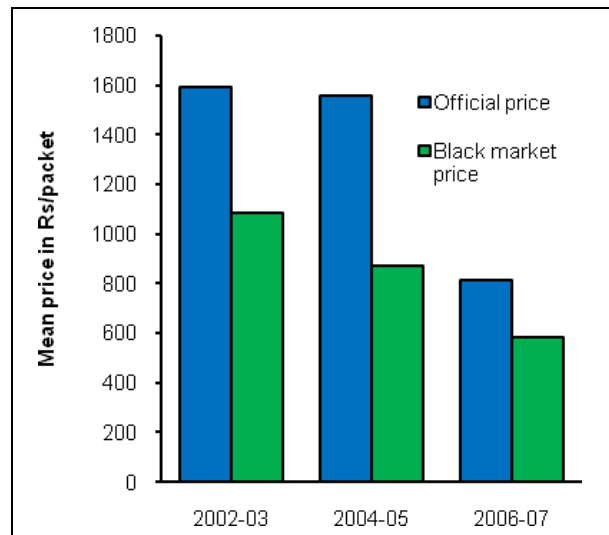


**Figure 1. Mean Bt cotton seed prices from official and black market sources.**

ground, the Bt trait value in China amounts to an equivalent of Rs 1670 per acre (Chandrashekhar, 2006), much higher than the Rs 1250 initially charged in India. In the United States, a technology fee of Rs 1405 (US $32) per acre is charged for Bt cotton (Hubbell, Marra, & Carlson, 2000). Finally, in China, Monsanto faces competition through a public sector Bt cotton technology, which was developed by the Chinese Academy of Agricultural Sciences and commercialized in some of the states where Monsanto varieties were also sold (Pray et al., 2002). This certainly restricts the company's pricing range there, besides the fact that many Chinese cotton growers reproduce their own Bt cotton seeds. Therefore, the government price caps in India appear to be the outcome of a strong political lobbying process rather than the result of an objective analysis. Further implications of the price interventions for technology adoption, impacts, and longer term innovation are discussed below.

## Farm-Level Effects of Bt Cotton

### Data

We turn now to the analysis of the farm-level effects of Bt cotton in India over time. For this purpose we carried out three rounds of a panel survey of farmers in four cotton-growing states. The four states—Maharashtra, Karnataka, Andhra Pradesh, and Tamil Nadu—are representative of cotton production in central and southern India. The first round of the survey took place in 2002-03, the first season for which Bt cotton hybrids

**Table 2. Adoption and disadoption of Bt cotton among sample farmers.**

| | 2002-03 | 2003-04 | 2004-05 | 2005-06 | 2006-07 |
|---|---|---|---|---|---|
| **Share of Bt adopters (%)[a]** | 30 | 29 | 44 | 80 | 78 |
| **Share of adopters who disadopted after the season (%)** | 51 | 26 | 17 | 24 | 16 |
| **Share of disadopters who re-adopted in any of the following seasons (%)** | 38 | 14 | 3 | 21 | n.a. |
| **Average farm size of adopters (acres)** | 16.5 | 14.3 | 15.5 | 12.0 | 12.2 |
| **Average farm size of non-adopters (acres)** | 12.3 | 13.3 | 12.0 | 9.4 | 9.0 |

[a] *The share of adopters in the sample is not representative of overall Bt cotton adoption in India, as adopters were purposely over-sampled in 2002-03.*

had been officially commercialized in India. In total, we selected 341 farmers through a stratified random sampling procedure, covering 10 districts and 58 villages in the four states. As the proportion of Bt adopters was very small in the first season, we purposely over-sampled them using complete customer lists of Bt seed sales from which we randomly selected. Hence we generated two representative sub-samples: one from the population of official Bt adopters and the other from the population of non-adopters. (For the analyses, sampling weights are used where appropriate. Further details of the sampling procedure are explained in Qaim et al. [2006].) We interviewed farmers about several aspects of cotton cultivation, including input use and output details. These data were collected at the plot level. Farmers who cultivated both Bt and conventional cotton on their farm answered the questions for both alternatives. For this reason, the number of plot observations is somewhat larger than the number of farmers in the sample. Furthermore, we collected detailed data on general farm, household, and contextual characteristics.

The second round of the survey was carried out two years later in 2004-05, and the third round again two years later in 2006-07. In these rounds, we tried to interview the same farmers as in the first round, using the same questionnaire. However, several farmers from the first round had migrated, passed away, or could not complete the interview for other reasons. In the second round, we managed to interview 318 farmers from the original sample (93%), and in the third round, 289 (85%). In order to maintain the randomness and increase the sample size, we randomly selected additional farmers in the same villages so that the total sample size was 376 and 407 in 2004-05 and 2006-07, respectively.

### Adoption Dynamics

Table 2 shows the dynamics of Bt cotton adoption in our sample—for the survey years and also the seasons in-

between. Due to over-sampling of adopters in 2002-03, the adoption rates shown are not representative for India as a whole. Nonetheless, it can be seen that adoption has increased considerably over time, which is consistent with the country-wide data shown in Table 1.

Table 2 shows that a big jump in adoption occurred in 2005-06, where adoption among sample farmers almost doubled from 44% to 80%. We consider this as the take-off phase of Bt cotton adoption, which, interestingly occurred before the state governments began controlling maximum retail prices in 2006. Obviously, farmers recognized the technology's advantages before the price caps, so government interventions were not the main thrust upward for adoption. Yet, the table also shows that adoption is not only a one-way process. Half of all Bt adopters in 2002-03 disadopted the technology after the season because they were not fully satisfied. Disadoption also occurred in subsequent seasons, although the share has declined to 16% in 2006-07. And, many of the disadopters decided to try the technology again after one or more seasons. These patterns suggest that Bt adoption is not an irreversible decision for farmers. Rather, it is a process where farmers learn whether the technology is suitable for their conditions and how to properly adjust the use of inputs, especially pesticides. Qaim et al. (2006) pointed out that there is spatial variability in Bt cotton impacts because levels of pest pressure differ. For farmers in low pest-pressure areas, the benefits of Bt are relatively small—in some cases even smaller than the seed price markup. In those cases, seed price caps could indeed lead to significant increases in adoption. But impact variability is also due to germplasm effects; especially in the first years of adoption, Bt was incorporated only in a few cotton hybrids, and these were not suitable for all agroecological conditions. As mentioned above, the number of Bt cotton hybrids has increased considerably over time.

**Table 3. Agronomic and economic effects of Bt cotton.**

| | 2002-03 | | 2004-05 | | 2006-07 | |
|---|---|---|---|---|---|---|
| | Bt (n=133) | Conventional (n=301) | Bt (n=165) | Conventional (n=300) | Bt (n=317) | Conventional (n=56) |
| | Mean (SD) | | Mean (SD) | | Mean (SD) | |
| **Number of insecticide sprays** | 4.18[***] (3.28) | 6.79 (3.64) | 4.60[***] (3.10) | 7.22 (4.71) | 3.29[*] (2.19) | 3.77 (2.49) |
| **Insecticide use (kg/acre)** | 2.07[***] (2.65) | 4.17 (3.37) | 2.05[***] (2.68) | 4.19 (10.48) | 1.22[*] (1.41) | 1.55 (1.51) |
| **Yield[a] (kg/acre)** | 659[***] (394) | 491 (336) | 743[***] (328) | 551 (292) | 842[***] (356) | 590 (335) |
| **Output price (Rs/kg)** | 20.65 (1.96) | 20.93 (2.26) | 18.63 (2.74) | 18.30 (3.17) | 19.94[*] (1.72) | 20.35 (2.92) |
| **Crop enterprise budgets (Rs/acre)** | | | | | | |
| **Seed cost** | 1573[***] (196) | 490 (286) | 1624[***] (548) | 527 (240) | 803[***] (245) | 479 (207) |
| **Insecticide cost** | 1258[***] (1469) | 2128 (1748) | 1573[***] (1633) | 2413 (1835) | 1173 (1738) | 1139 (1233) |
| **Fertilizer cost** | 1883[***] (1199) | 1658 (1073) | 1882[**] (1180) | 1665 (1286) | 1953 (2997) | 1466 (869) |
| **Manure cost** | 722[**] (834) | 590 (729) | 314 (785) | 257 (813) | 904 (1917) | 651 (1584) |
| **Labor and custom operations cost** | 1721[***] (1310) | 1406 (1080) | 1878 (1094) | 1766 (1020) | 2769 (2062) | 2728 (2163) |
| **Harvesting cost** | 1198[***] (1339) | 847 (822) | 1581[***] (747) | 1172 (676) | 1833[***] (836) | 1339 (829) |
| **Other cost** | 85 (179) | 104 (218) | 66 (399) | 124 (1471) | 225[**] (909) | 20 (69) |
| **Total variable cost** | 8441[***] (3452) | 7224 (3337) | 8919[***] (3422) | 7924 (3682) | 9662[**] (5778) | 7822 (3963) |
| **Gross revenue** | 13735[***] (8425) | 10357 (7290) | 13841[***] (6321) | 10077 (5270) | 16783[***] (7542) | 12003 (7726) |
| **Profit** | 5294[***] (8117) | 3133 (6774) | 4922[***] (6291) | 2152 (5477) | 7121[***] (7655) | 4181 (7563) |

[*], [**], [***] *Mean values are significantly different from those on conventional plots at the 10%, 5%, and 1% level, respectively.*

[a] *Yield at the farm level is expressed in terms of raw cotton (seed cotton), including lint and seed.*

Table 2 shows that Bt adopters' farm sizes were slightly larger than non-adopters' in the beginning. But, over the years, the average farm size of adopters has declined, suggesting that more and more smallholder cotton producers took up Bt technology as well. In 2005-06, the mean farm size of Bt users was reduced to 12 acres, which corresponds to the overall average in the study regions. Some of the very small cotton producers have not adopted, so that the average area of non-adopters has declined to around 9 acres. Subramanian and Qaim (2009) have shown that the indirect advantages of Bt are somewhat lower for smallholders than for larger farms in India. Nonetheless, there is clear evidence that both small and large cotton producers benefit consider-ably from the technology (Qaim, Pray, & Zilberman, 2008).

### Crop Enterprise Budgets

Based on our survey data, the agronomic and economic performance of Bt cotton at the plot level is shown in Table 3. The results are summarized in Table 4. While the sample contains a few observations of farmers who have used illegal Bt seeds, most Bt adopters had used official seeds. In all three seasons that we surveyed, the number of insecticide sprays and insecticide amounts used were significantly lower on Bt than on conventional plots. The exact reductions vary from year to year, which is partly due to seasonal variations in pest pres-

**Table 4. Comparative advantage of Bt over conventional cotton.**

|  | 2002-03 | 2004-05 | 2006-07 | Average |
|---|---|---|---|---|
| **Insecticide use** | -50% | -51% | -21% | -41% |
| **Yield** | +34% | +35% | +43% | +37% |
| **Seed cost** | +221% | +208% | +68% | +166% |
| **Total variable cost** | +17% | +11% | +24% | +17% |
| **Gross revenue** | +33% | +37% | +40% | +37% |
| **Profit** | +69% | +129% | +70% | +89% |

sure. In 2002-03 and 2004-05, insecticide quantities on Bt plots were reduced by approximately 50%. This is consistent with other studies for India (Bennett et al., 2006; Gandhi & Namboodiri, 2006).

In 2006-07, average reductions were only 21%. Yet, this lower reduction is not due to increases in insecticide sprays on Bt plots, as one might expect when Bt resistance would emerge or secondary pests would gain in importance. On the contrary, sprays on Bt plots were further reduced, but sprays on conventional plots were reduced as well. This might be due to self-selection of farmers: by 2006-07, farmers who used to apply a lot of insecticides in conventional cotton had adopted Bt technology, so that the sample of non-adopters now mostly consists of farmers who spray little anyway, either because of lower pest problems or because of lack of awareness. Moreover, due to the wide dissemination of Bt cotton over the past 2-3 years, there seems to be an overall decline in the populations of Bt target pests, especially the American bollworm (Khadi et al., 2007). This can be interpreted as a positive externality of Bt technology for non-adopting farmers. (It could potentially even lead to a free-rider problem, including technology disadoption among some, although the relatively low Bt seed prices observed today might prevent this from happening.)

Apart from insecticide reductions, a major effect of Bt cotton in India is a significant yield advantage due to lower crop losses, as previously predicted by Qaim and Zilberman (2003). Over the years, average yields were 30-40% higher for Bt than for conventional plots, which is due to more effective pest control and thus a reduction in crop damage. Again, differences over the years are largely due to variability in pest pressure. Higher yields and crop revenues are also the main reason for the significant gains in cotton profits. Profit differences between Bt and conventional cotton even increased over time, from Rs 2161 (US $49.23) per acre in 2002-03 to

Rs 2940 (US $66.97) in 2006-07. These are large benefits for cotton-producing households in India, many of whom live at or below the poverty line.

What is the role of the government's seed-price interventions in this respect? Tables 3 and 4 demonstrate that Bt seed costs were indeed much lower after the interventions in 2006. In the initial years of adoption, official Bt seeds were more than three times as expensive as conventional seeds, while by 2006-07 the average price markup had declined to 68%. Therefore, the state price controls unquestionably contributed to increasing advantages for farmers, but it should be stressed that significant benefits also occurred prior to these interventions. In summary, Bt cotton adoption is associated with remarkable agronomic and economic advantages for farmers in India, and the observed benefits have been sustainable over the first five years of widespread technology use.

### Net Productivity Effects

In the previous sub-section, we compared crop performance between Bt and conventional cotton plots. However, a mere comparison of mean yield levels might lead to a bias, because there are other factors that could vary between the plots for which we did not control. This requires an econometric approach. We specify a Cobb-Douglas production function, where cotton yield per acre (expressed in logarithmic terms) is used as dependent variable, and inputs such as fertilizers, pesticides, labor, and irrigation as independent variables. Moreover, state dummies capture regional effects. A Bt dummy is included as the treatment variable of particular interest here; this takes a value of "1" if the plot was grown with Bt cotton hybrids and "0" if conventional hybrids were used. The production function was estimated separately for the three seasons. The estimated coefficients for the Bt dummy as well as the derived net yield effects are shown in Table 5 (Model 1). The results are similar to yield differences shown in Table 4, but they are not identical, which underlines that controlling for differences in input use is important when analyzing the productivity effects of new technologies.

Selectivity bias presents another potential problem in impact analysis; since technology adoption is not a random process, there might be farmer or household unobservables that could lead to correlation between the Bt variable and error term. A common way to deal with this problem is to use an instrumental variable approach or similar two-step estimation procedure. For instance, Fernandez-Cornejo, Klotz-Ingram, and Jans (2002) esti-

**Table 5. Net yield effects of Bt cotton with different econometric specifications.**

| | Model 1 Cobb-Douglas specification (whole sample) | | Model 2 Cobb-Douglas specification (only Bt adopters) | | Model 3 Damage control specification | |
|---|---|---|---|---|---|---|
| | Bt coefficient[a] | Net yield gain[b] | Bt coefficient[a] | Net yield gain[b] | Bt coefficient[a] | Net yield gain[b] |
| **2002-03** | 0.245*** (0.074) | 27.7% | 0.211** (0.082) | 23.5% | 0.451** (0.178) | 22.2% |
| **2004-05** | 0.380*** (0.059) | 46.2% | 0.457*** (0.074) | 57.9% | 0.975*** (0.214) | 45.2% |
| **2006-07** | 0.281*** (0.070) | 32.4% | 0.290*** (0.097) | 33.6% | 0.651*** (0.202) | 31.4% |

[a] *Point estimates (β) are shown for the different specifications with standard errors in parentheses. In the Cobb-Douglas specifications, Bt is included as a normal dummy variable; in the damage control specifications, the Bt dummy is included in the logistic damage control function.*

[*], [**], [***] *Estimated coefficients are significant at the 10%, 5%, and 1% level, respectively.*

[b] *In the Cobb-Douglas specifications, the percentage net yield gain is calculated as [exp(β)-1]\*100. In the damage control specifications, the net yield gain is derived by evaluating the estimated logistic damage control function with and without Bt, holding everything else constant.*

mated a two-step treatment effect model in their analysis of the farm-level effects of herbicide-tolerant soybeans in the United States. Unfortunately, in our context we could not identify a suitable instrument, which is correlated with Bt adoption but uncorrelated with cotton yield. However, the advantage of our data is that observations for both Bt and conventional cotton plots are partly available on the same farms. Adopting farmers in our sample often grew a plot of Bt cotton next to a plot of conventional cotton in order to gain more experience with the technology during the early adoption phases. We used this fact to re-estimate our Cobb-Douglas production functions, excluding the non-adopters. Thus, the sample only consists of the Bt and conventional plots of adopting farmers, so that the treatment effect cannot be disturbed through differences in unobservables between adopters and non-adopters. The results of these additional estimates are also shown in Table 5 (Model 2). For 2002-03, the net yield effect of Bt cotton is somewhat lower than the one derived with Model 1, and it is higher in 2004-05. The magnitude of the effects is similar to that in Model 1, however, suggesting that a selectivity bias is small and without a clear direction over the years.

Authors also have estimated productivity effects of Bt cotton using a damage-control specification (e.g., Huang, Hu, Rozelle, Qiao, & Pray, 2002; Kuosmanen, Pemsl, & Wesseler, 2006; Qaim & de Janvry, 2005), as Bt actually leads to a reduction in crop damage rather than an increase in yield potential. In order to test how sensitive our results are to different model specifications, we also employed a damage-control framework. As in Qaim & Zilberman (2003), we incorporated the Bt

dummy in a logarithmic damage-control function. The results of these non-linear estimates are also shown in Table 5 (Model 3). The net yield gains are fairly similar to the ones derived with the Cobb-Douglas production functions. Hence, we conclude that the finding of positive and sustainable net yield effects is robust to different model specifications.

## Willingness to Pay for Bt Cotton Seeds

A farmer's decision to adopt a new technology reveals that his or her expected utility derived from the innovation is bigger than or equal to its price. For Bt cotton in India, widespread adoption demonstrates that this is the case for the majority of farmers. However, the positive adoption decision does not reveal the concrete magnitude of the expected utility for an individual farmer. This might be near the market price or also well above. In order to better understand Indian farmers' valuation of Bt cotton, we estimate the WTP for the technology based on stated preference data.

### Methodology

We analyze farmers' WTP for official Bt cotton seeds using a contingent valuation (CV) dichotomous choice approach. During all three survey rounds, farmers—both adopters and non-adopters—were asked whether they would use the technology in the next cotton season at a certain initial price bid, $P$. If the response was "yes," no follow-up question was asked, but if the response was "no," the same question was asked at a certain lower price bid, $P_L$. Hence, farmers can be categorized into three possible response groups, namely "yes," "no-

yes," and "no-no." This is called a one-and-one-half-bound dichotomous choice format; Cooper, Hanemann, and Signorello (2002) showed that this is more efficient than the double-bounded CV method—other than reducing a potential response bias—as it eliminates the element of surprise of a higher second price bid. Qaim & de Janvry (2003) used a similar approach to estimate WTP for Bt cotton seeds in Argentina. In terms of price bids, in the first two survey rounds, we set the initial price bid, *P*, at the prevailing market price for official Bt seeds of Rs 1600 per packet. Follow-up price bids, $P_L$, were randomly varied between questionnaires in Rs 100 intervals between Rs 200-1500. Due to price interventions in 2006, in the 2006-07 round, *P* was randomly varied between Rs 1200-1600, and $P_L$ between Rs 600-1100.

We estimate WTP separately for the three seasons using the following log-likelihood function (Qaim & de Janvry, 2003).

$$\ln L = \sum_{i=1}^{n} d^Y \ln\left[1 - \Phi\left(\frac{P - \beta'X}{\sigma}\right)\right]$$
$$+ d^{NY} \ln\left[\Phi\left(\frac{P - \beta'X}{\sigma}\right) - \Phi\left(\frac{P_L - \beta'X}{\sigma}\right)\right]$$
$$+ d^{NN} \ln\left[\Phi\left(\frac{P_L - \beta'X}{\sigma}\right)\right] \quad (1)$$

where $d^Y$, $d^{NY}$, and $d^{NN}$ are dummy variables for the three response groups, *X* is a vector of farm, household, and contextual variables expected to influence WTP, and $\sigma$ is the standard error of the regression. The estimation coefficients, $\beta$, can directly be interpreted as the marginal effects of the *X* variables on WTP. Mean WTP is derived by evaluating the estimated coefficients at variable mean values.

### Estimation Results

Table 6 shows the results of estimating WTP models for the three survey rounds. Farm size, expressed in terms of land area owned, has a positive influence on WTP for Bt cotton seeds, but the effect is very small and only statistically significant in 2006-07; for every additional acre of land owned by the farmer, his/her WTP increases by roughly Rs 15 per packet. In contrast, availability of irrigation facilities has no significant influence on WTP, nor does soil quality show a clear pattern. Black soils are considered to provide the best growing conditions for cotton, so farmers possessing such soils might be

expected to derive higher utility from Bt technology. Indeed, their WTP was Rs 455 higher in 2002-03, but this effect turned insignificant in subsequent years. Apparently, farmers have realized that Bt technology is advantageous also under less favorable agroecological conditions.

Input dealers are a very important source of information about new technologies for farmers in India. This also holds true for Bt cotton. However, since input dealers make a large share of their profits through pesticide sales (which are reduced through Bt), they were not too happy with the technology initially (Kambhampati, Morse, Bennett, & Ismael, 2005). Input dealers even contributed to the spread of misinformation about Bt cotton during the early stages. With the rapid rise of Bt adoption, input dealers now make good profits through seed sales. Therefore, it is not surprising that those farmers—for whom the input dealer is the major source of information—had a significantly higher WTP in 2004-05, but not in 2002-03. In 2006-07 the technology had already spread so widely that the source of information was not relevant anymore.

In India, cotton is grown in the form of both hybrids and OPVs, although so far Bt has been only commercialized in hybrids. Some previous OPV growers switched to hybrids through Bt adoption. Nonetheless, the results in Table 6 show that farmers, who had already used hybrids previously, have a significantly higher WTP for Bt cotton. Strikingly, the farmer's education level does not significantly influence WTP, whereas experience with cotton cultivation has a positive impact. It is not unlikely that farmers with longer cotton experience have already tried different approaches of pest control, so Bt is a particularly welcome alternative. Except for 2002-03, household expenditure (which we use as a proxy for standard of living) had a positive effect on WTP, and this effect was significant in 2004-05. Furthermore, previous use of Bt cotton influences WTP in a positive way, especially in 2004-05, indicating that—after an initial learning process—most farmers are now satisfied with their own technological experience.

District dummy variables in Table 6 were included to account for possible regional effects. Many of them are significant, although they display varying signs over the years. This is actually not surprising. To some extent, the district dummies capture pest pressure, which can fluctuate spatially and seasonally. For instance, if bollworm pressure is high in a particular district and season, farmers' WTP for Bt seeds also will be high in the next season and vice versa. In addition, ger-

**Table 6. Estimation results of the WTP models for Bt cotton seeds.**

| | 2002-03[a] (n=434) | 2004-05[a] (n=465) | 2006-07[a] (n=373) |
|---|---|---|---|
| **Constant** | 864.93 (562.52) | 2469.18[***] (798.22) | 896.56[**] (374.42) |
| **Farm size (acres)** | 2.47 (6.44) | 11.09 (6.84) | 14.83[***] (5.02) |
| **Irrigation (dummy)** | -231.74 (193.58) | 7.60 (227.68) | -4.64 (115.64) |
| **Black soil (dummy)** | 454.51[**] (220.39) | -347.47 (276.00) | -42.75 (131.06) |
| **Input dealer is major information source (dummy)** | -130.66 (173.37) | 380.23[*] (199.85) | -14.22 (23.04) |
| **Previous use of cotton hybrid seeds (dummy)** | 1183.56[**] (470.85) | 346.12 (591.42) | 396.91[**] (199.94) |
| **Education (years)** | 16.19 (18.34) | 21.19 (22.53) | -3.54 (11.04) |
| **Cotton experience (years)** | 18.02[*] (10.35) | 29.47[**] (13.77) | 4.11 (5.44) |
| **Annual per-capita household expenditure (thousand Rs)** | -31.50 (25.15) | 32.94[**] (14.55) | 20.59 (32.51) |
| **Household expenditure squared** | 0.82[*] (0.45) | -0.29[***] (0.10) | -0.45 (1.06) |
| **Previous use of Bt (dummy)** | 176.61 (186.74) | 921.44[***] (260.69) | 279.33 (183.05) |
| **District dummies[b]** | | | |
|     **Aurangabad** | 108.23 (380.41) | -1398.89[*] (606.04) | -14.63 (194.56) |
|     **Parbhani** | -1272.03[***] (376.99) | -2117.45[***] (598.37) | -477.90[**] (201.90) |
|     **Haveri** | -255.03 (390.08) | -1100.40[*] (623.25) | 92.85 (209.21) |
|     **Belgaum** | -735.33[*] (388.65) | -3594.23[***] (722.61) | -393.42 (244.41) |
|     **Raichur** | 99.63 (389.51) | -2449.55[***] (594.29) | 302.33 (277.32) |
|     **Guntur** | -1773.39[***] (442.57) | -1300.91[**] (600.55) | -425.27[*] (238.28) |
|     **Kareemnagar** | -2352.52[***] (451.47) | -726.11 (595.00) | 171.72 (210.82) |
|     **Warangal** | -1333.95[***] (387.82) | 252.28 (654.33) | 398.76[*] (236.70) |
|     **Coimbatore** | 1134.07[**] (470.65) | -2429.69[***] (683.87) | -503.86[**] (244.74) |
| **Log-likelihood** | -351.57 | -273.75 | -281.03 |
| **Wald χ² value** | 56.02[***] | 45.03[***] | 47.43[***] |
| **Mean WTP[c] (Rs/packet)** | 1632.78 (960.75) | 2594.47 (1319.43) | 1808.51 (369.15) |

*Notes. Estimation coefficients are shown with robust standard errors in parentheses. The coefficients can directly be interpreted as marginal effects on the WTP.*

*[*], [**], [***] Estimates are significant at the 10%, 5%, and 1% level, respectively.*

*[a] Data collection was carried out at the end of the respective cotton-growing seasons, but the WTP questions in each round actually referred to the next season—that is, 2003-04, 2005-06, and 2007-08.*

*[b] The reference variable for the district dummies is Beed.*

*[c] These are weighted means, taking sample weights of Bt adopters and non-adopters into account.*

mplasm effects might play a role (Qaim et al., 2006). As mentioned above, in the first years of adoption, only a few Bt hybrids were available; these hybrids were not very well adapted to all agroecological conditions in India, so their performance was different across districts. For instance, in 2002-03, negative germplasm effects of Bt hybrids occurred particularly in the state of Andhra Pradesh. This is reflected in the low WTP for Bt seeds after that season in Guntur, Kareemnagar, and Warangal districts, all three located in Andhra Pradesh. Especially since 2005, the number of Bt hybrids commercialized in India has increased considerably; the

problems of negative germplasm effects became much less severe. Accordingly, regional differences in farmers' WTP for Bt seeds have declined in our last survey round, both in terms of coefficient sizes and significance levels.

### Mean WTP

Based on the estimation results, we also derived farmers' mean WTP for Bt cotton seeds. As Bt adopters were over-sampled in the beginning of our panel, we used sampling weights for adopters and non-adopters in all three survey rounds in order to obtain results representa-

tive of the situation in central and southern India. The results are shown in the last row of Table 6. After the 2002-03 growing season, mean WTP was Rs 1633 per packet of Bt seeds, which was very near the official market price, indicating that many farmers had a general openness to try the new technology in spite of the fact that Bt seed prices were relatively high. This is consistent with the increasing adoption rates in subsequent years. After the 2004-05 season, mean WTP even increased to Rs 2595. This coincides with the technology's take-off phase in India.

In 2006, the government interventions began, fixing Bt seed prices at Rs 750 per packet. Even though price caps should not influence farmers' technology valuation in theory, it appears that they did lower mean WTP—at least in terms of stated preferences. The explanation is simple: if farmers know that the price is officially fixed at a certain level, why should they reveal their true valuation of the technology in a CV survey? Remarkably, however, the mean WTP estimated for 2006-07 is still much higher than the maximum retail price of Rs 750. This underlines the fact that the benefits perceived by most farmers considerably outweigh the official price; discounting for a potential response bias in our survey context, the true WTP might still be higher. Our analysis also shows that at the previous price of Rs 1600 per packet, Bt adoption rates would only be slightly lower than they actually are today, still exceeding 50%. This is not to say that Bt demand is unresponsive to seed price changes, but the price responsiveness decreases at lower price levels. Strikingly, the low maximum retail price led to a situation where Bt seed demand was much higher than supply in 2006, and there were incidents of farmers mobbing Bt cotton sales points, worrying that they might not get a sufficient quantity of seeds ("Farmers Rush," 2007). Indeed, some farmers in our 2006-07 survey round reported that they had to pay more than the maximum retail price to obtain Bt seeds, and they were more than willing to do so.

## Conclusion

In this article, we have analyzed the field performance of Bt cotton in India over the first five years of technology adoption. We have used three rounds of a panel data set, which is representative of the country's central and southern cotton-growing areas. Bt cotton technology has proved to be a success story in India, with farmers benefiting from pesticide reductions, higher effective yields, and significantly higher profits. So far, these advantages have been sustainable, with no indications of Bt resis-

tance development or the sudden spread of secondary pests. Even though the diffusion of Bt was a learning process for farmers in the beginning, aggregate adoption has increased steadily and reached 65% of the country's cotton area in 2007-08. This widespread technology adoption has helped to achieve a record cotton harvest in India, at a time when other cotton-producing countries face a slowdown in production. Both small- and large-scale cotton farmers in India are now satisfied with the innovation, as is reflected in their high WTP for Bt seeds. This situation bodes well for other Bt technologies likely to be introduced in India in the near future, such as Bt vegetables (e.g., Krishna & Qaim, 2007). Indian authorities are also at the verge of approving the first public-sector Bt cotton OPVs.

Beyond the farm-level effects, we have also analyzed the issue of government price interventions in the cotton seed market. In 2006, Indian state governments had set maximum retail prices for Bt seeds at Rs 750 per packet, which is less than half the price previously charged by seed companies. This policy seems to be the outcome of a strong political lobbying process rather than the result of objective analyses of what constitutes a "reasonable" price level. The price caps have further increased the profits to farmers, and they probably also contributed to the declining role 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.

What are potential longer-term implications of the price controls in India? When there is a minimum protection of intellectual property rights, technology developers always have some kind of monopoly, which allows them to charge a price higher than the competitive market price. As this price markup is meant to cover the research investments plus some profits for the innovator, it acts as an incentive for private companies to develop new technologies. Yet, in the case of GM seeds, the monopoly is a restricted one because there are always conventional seed alternatives that farmers prefer when GM seed prices become too high (Basu & Qaim, 2007). Therefore, a company interested in widespread adoption of its GM seeds can only charge a price that leaves sufficient benefits for farmers. If the government fixes the seed price and trait value at a much lower arbitrary level—as happened to Bt cotton in India—farmers' benefits might further increase in the short run, but company revenues shrink and so does the incentive

to invest in the development of new technologies (Lence, Hayes, McCunn, Smith, & Niebur, 2005). Therefore, longer-term innovation rates and agricultural productivity growth could suffer, especially in a country like India where the private sector contribution to crop improvement research has been very important in the recent past. Even the short run benefits for farmers are reduced by the fact that price caps led to a shortage of seed supply, thus increasing effective seed prices—and opportunity costs for those whose demand remained unsatisfied.

Government price controls also tend to create a mentality among farmers that they have a right to cheap technologies, regardless of the benefits, as is reflected by the drop in Indian farmers' WTP for Bt cotton seeds after 2006. This is not to say that government interventions in seed pricing are always bad. In some cases, such policies might be important to improve disadvantaged farmers' access to beneficial new technologies. However, if necessary, interventions should be implemented in a more targeted way, based on careful situation analyses, in order to avoid negative long-term consequences for agricultural innovation.

## References

AP government moves MRTPC against Monsanto on Bt cotton royalty. (2006a, January 3). *The Hindu Business Line*. Available on the World Wide Web: http://www.thehindubusinessline.com/2006/01/03/stories/2006010301881200.htm.

Basu, A.K., & Qaim, M. (2007). On the adoption of genetically modified seeds in developing countries and the optimal types of government intervention. *American Journal of Agricultural Economics*, *89*(3), 784-804.

Bennett, R., Ismael, Y., & Morse, S. (2005). Explaining contradictory evidence regarding impacts of genetically modified crops in developing countries: Varietal performance of transgenic cotton in India. *Journal of Agricultural Science*, *143*, 35-41.

Bennett, R., Kambhampati, U., Morse, S., & Ismael, Y. (2006). Farm-level economic performance of genetically modified cotton in Maharashtra, India. *Review of Agricultural Economics*, *28*(1), 59-71.

Bt cotton royalty issue: AP seeks PM's support. (2006, January 24). *The Hindu Business Line*. Available on the World Wide Web: http://www.thehindubusinessline.com/2006/01/24/stories/2006012401701900.htm.

Cotton Association of India (CAI). (2008, January 15). *Cotton statistics and news* (Issue No. 42). Mumbai, Maharashtra, India: Author.

Chandrashekhar, G. (2006, June 3). Are tech fees for Bt cottonseed really high? *The Hindu Business Line*. Available on the World Wide Web: http://www.thehindubusinessline.com/2006/06/04/stories/2006060402670400.htm.

Cooper, J.C., Hanemann, M., & Signorello, G. (2002). One-and-one-half-bound dichotomous choice contingent valuation. *The Review of Economics and Statistics*, *84*(4), 742-750.

Crost, B., Shankar, B., Bennett, R., & Morse, S. (2007). Bias from farmer self-selection in genetically modified crop productivity estimates: Evidence from Indian data. *Journal of Agricultural Economics*, *58*(1), 24-36.

Farmers rush for Bt cottonseeds in Andhra Pradesh. (2007, May 29). *The Hindu Business Line*. Available on the World Wide Web: http://www.thehindubusinessline.com/2007/05/29/stories/2007052900791200.htm.

Fernandez-Cornejo, J., Klotz-Ingram, C., & Jans, S. (2002). Farm-level effects of adopting herbicide-tolerant soybeans in the U.S.A. *Journal of Agricultural and Applied Economics*, *34*, 149-163.

Fukuda-Parr, S. (2007). Emergence and global spread of GM crops: explaining the role of institutional change. In S. Fukuda-Parr (Ed.), *The gene revolution: GM crops and unequal development* (pp. 15-35). London, Sterling, VA: Earthscan.

Gandhi, V.P., & Namboodiri, N.V. (2006). *The adoption and economics of Bt cotton in India: Preliminary results from a study* (Working paper number 2006-09-04). Ahmedabad, India: Indian Institute of Management.

Huang, J., Hu, R., Rozelle, S., Qiao, F., & Pray, C.E. (2002). Transgenic varieties and productivity of smallholder cotton farmers in China. *Australian Journal of Agricultural and Resource Economics*, *46*, 367-387.

Hubbell, B.J., Marra, M.C., & Carlson, G.A. (2000). Estimating the demand for a new technology: Bt cotton and insecticide policies. *American Journal of Agricultural Economics*, *82*, 118-132.

James, C. (2007). *Global status of commercialized biotech/GM crops: 2007* (ISAAA Brief No. 37). Ithaca, NY: International Service for the Acquisition of Agri-Biotech Applications.

Kambhampati, U., Morse, S., Bennett, R., & Ismael, Y. (2005). Perceptions of the impacts of genetically modified cotton varieties: A case study of the cotton industry in Gujarat, India. *AgBioForum*, *8*(2&3), 161-171.

Khadi, B.M., Rao, M.R.K., & Singh, M. (2007). The Hindu survey of Indian agriculture 2007: Potential to improve lives of ryots. *The Hindu*.

Kuosmanen, T., Pemsl, D., & Wesseler, J. (2006). Specification and estimation of production functions involving damage control inputs: A two-stage, semiparametric approach. *American Journal of Agricultural Economics*, *88*, 499-511.

Krishna, V.V., & Qaim, M. (2007). Estimating the adoption of Bt eggplant in India: Who benefits from public-private partnership? *Food Policy*, *32*, 523-543.

Lalitha, N. (2004). Diffusion of agricultural biotechnology and intellectual property rights: Emerging issues in India. *Ecological Economics*, *49*, 187-198.

Lence, S.H., Hayes, D.J., McCunn, A., Smith, S., & Niebur, W.S. (2005). Welfare impacts of intellectual property protection in the seed industry. *American Journal of Agricultural Economics*, *87*(4), 951-968.

Murugkar, M., Ramaswami, B., & Shelar, M. (2007). Competition and monopoly in the Indian cotton seed market. *Economic and Political Weekly*, *42*(37), 3781-3789.

Pray, C.E., Bengali, P., & Ramaswami, B. (2005). The cost of biosafety regulations: The Indian experience. *Quarterly Journal of International Agriculture*, *44*, 267-289.

Pray, C.E., Huang, J., Hu, R., & Rozelle, S. (2002). Five years of Bt cotton in China—The benefits continue. *The Plant Journal*, *31*(4), 423-430.

Qaim, M., & de Janvry, A. (2003). Genetically modified crops, corporate pricing strategies and famers' adoption: The case of Bt cotton in Argentina. *American Journal of Agricultural Economics*, *85*(4), 814-828.

Qaim, M., & de Janvry, A. (2005). Bt cotton and pesticide use in Argentina: Economic and environmental effects. *Environment and Development Economics*, *10*, 179-200.

Qaim, M., Pray, C.E., & Zilberman, D. (2008). Economic and social considerations in the adoption of Bt crops. In J. Romeis, A. Shelton, & G. Kennedy (Eds.), *Integration of insect-resistant genetically modified crops within IPM programs* (pp. 329-356). New York: Springer.

Qaim, M., Subramanian, A., Naik, G., & Zilberman, D. (2006). Adoption of Bt cotton and impact variability: Insights from India. *Review of Agricultural Economics*, *28*(1), 48-58.

Qaim, M., & Zilberman, D. (2003). Yield effects of genetically modified crops in developing countries. *Science*, *299*, 900-902.

Subramanian, A., & Qaim, M. (2009). Village-wide effects of agricultural biotechnology: The case of Bt cotton in India. *World Development*, *37*, 256-267.

Wang, S., Just, D., & Pinstrup-Andersen, P. (2006, July). *Tarnishing silver bullets: Bt technology adoption, bounded rationality and the outbreak of secondary pest infestations in China*. Paper presented at the American Agricultural Economics Association Annual Meetings, Long Beach, CA.

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