Estimating the Adoption of Bt Eggplant in India: Who Benefits from Public-Private Partnership?

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Abstract

The study analyzes ex ante the adoption of insect-resistant Bt eggplant technology in India. Farmers' willingness to pay (WTP) is estimated using the contingent valuation method. Given the economic importance of insect pests in eggplant cultivation, the average WTP for Bt hybrids is more than four times the current price of conventional hybrid seeds. Since the private innovating firm has also shared its technology with the public sector, proprietary hybrids will likely get competition through public open-pollinated Bt varieties after a small time lag. This will reduce farmers' WTP for Bt hybrids by about 35%, thus decreasing the scope for corporate pricing policies. Nonetheless, ample private profit potential remains. Analysis of factors influencing farmers' adoption decisions demonstrates that public Bt varieties will particularly improve technology access for resource-poor eggplant producers. The results suggest that public-private partnership can be beneficial for all parties involved.

Key words: Biotechnology; Public-private partnership; Bt eggplant; Adoption; Willingness to pay; India

1. Introduction

Over the last decade, transgenic crops have been adopted rapidly both in industrialized and developing countries (James, 2004). Yet, the range of transgenic technologies commercialized so far is still rather limited, with herbicide-tolerant soybeans and insect-resistant Bt cotton and maize accounting for the lion's share of the total transgenic area. This narrow portfolio is largely due to the fact that the private sector, which concentrates on large lucrative markets, dominates the development and commercialization of transgenic crops. Under such conditions, there is the risk that certain technologies, which are of particular relevance for poor farmers, are not being developed (Morris et al., 1998; FAO, 2004; Naylor et al., 2004). The situation is being aggravated by biotechnology acceptance problems and widespread public distrust against multinational corporations – factors which have increased the cost and time required to channel transgenic technologies through biosafety processes (Pray et al., 2005; Qaim and Matuschke, 2005). More public research, focusing on the problems of the poor, and public-private partnerships are needed to ensure an equitable biotechnology evolution in developing country agriculture (Rausser et al., 2000; Zilberman and Graff, 2005). Although there are numerous examples of public-private research cooperation, none of these joint projects has yet led to a commercialized transgenic crop. Accordingly, there is still uncertainty as to who will actually benefit from public-private partnership and how institutional arrangements influence the outcome. The present paper analyzes such aspects for Bt eggplant in India, a technology which is being developed under a unique collaborative agreement.

In India, eggplant is often described as "the poor man's vegetable", because it is popular amongst small-scale farmers and low-income consumers. Bt eggplant technology, which makes the plant resistant to the shoot and fruit borer, has been developed by the Maharashtra Hybrid Seed Company (MAHYCO) – the biggest private company in the Indian market for eggplant hybrid seeds. The first Bt hybrids are likely to be commercialized in the near future. In addition, MAHYCO has shared its technology and know-how with public research institutes. With financial assistance of the Agricultural Biotechnology Support Project (ABSP) these institutes are now developing Bt open-pollinated varieties (OPVs) especially targeted at resource-poor farmers. This public-private partnership agreement might have a positive public relations effect for MAHYCO. However, although proprietary Bt hybrids will probably have a head start of two or three years, the company's market share might shrink once Bt OPVs are going to be released. If many customers would substitute low-cost Bt OPVs for more expensive Bt hybrids, the agreement would be associated with a high opportunity cost. Based on farm survey data collected in 2005, the present study projects the adoption profile of Bt eggplant hybrids and estimates farmers' willingness to pay (WTP) in the presence and absence of Bt OPVs. The analysis can help better understand the implications of public-private partnership and the underlying incentives for the parties involved.

The next section provides some background of the Indian eggplant sector and examines the importance of transgenic insect resistance. It also includes details of primary data collection and results of the first field trials with Bt eggplant. Subsequently, farmers' WTP for Bt hybrids in the absence of Bt OPVs is analyzed, before socioeconomic characteristics determining farmers' preferences for Bt hybrids versus OPVs are examined. The last section concludes and discusses policy implications.

Eggplant production in India and relevance of Bt technology

Eggplant (*Solanum melongena* L) is one of the most important vegetable crops in India, and the country is the second largest eggplant producer after China. Though the crop is popular amongst small and marginal farmers, cultivation is often input intensive, especially with respect to insecticides (George et al., 2002). Eggplant is infested by a dozen of insect pest species, among which the most serious and destructive one is the eggplant shoot and fruit borer (ESFB), *Leucinodes orbonalis* Guen. (Nair, 1986; Ghosh et al., 2003). ESFB larvae feed inside the shoots and fruits, retarding the vegetative growth and making the fruit unmarketable and unfit for human consumption. Due to its infestation, considerable economic loss is occurring during every crop season, adversely affecting both quality and quantity of crop output. Fruit damage as high as 92.5% and reduction in yield up to 60% have been reported (Mall et al., 1992).

Many wild species of *Solanum* were found resistant to ESFB infestation, but attempts to cross eggplant with its wild relatives to impart resistance had only limited success so far (Collonnier et al., 2001). While integrated pest management strategies are able to reduce borer infestation up to 30%, due to their complexity and high labor requirements, they are not popular among farmers. As a result, farmers lean heavily on chemical methods for ESFB control, and the pest has been subjected to heavy selective pressures by different groups of chemical insecticides. Due to resistance development, many insecticides – including synthetic pyrethroids – were found to become less effective against ESFB over time (Ali, 1994). Apart from the financial cost associated with high and increasing insecticide applications, there are negative externalities, including environmental pollution, effects on non-target organisms, secondary pest outbreaks, resurgence of target pests, and danger to human health (Wilson and Tisdell, 2001). Food consumers also experience real income losses, because pest damage and high production costs entail an increase in market prices (Talekar, 2002).

In this connection, Bt eggplant technology developed by MAHYCO promises to increase farmer and consumer welfare to a substantial degree. The first Bt hybrids could be commercially released in 2006. Transgenic OPVs, which are being developed by different institutes under the Indian Council of Agricultural Research (ICAR) in collaboration with MAHYCO, could follow in 2008 or 2009. Based on the experience with Bt cotton in India (Qaim et al., 2006, in press), the technology – if effective – is likely to be adopted rapidly by farmers.

Farm survey and economics of production

For the present study, an interview-based farm survey was implemented between February and May 2005. During the survey, 360 eggplant farmers were visited and interviewed in three major eggplant-producing states of India – Andhra Pradesh, Karnataka, and West Bengal. Together these three states account for 36% of the total eggplant area in India and contribute 42% to total production (NHB, 2003). States, districts, and taluks (revenue subdivisions within each district) were selected in close interaction with local agronomists. Within the identified taluks, villages and farmers were selected randomly from complete lists of eggplant growers. Based on expert assessments, the sample can be considered as representative for the major eggplant-growing regions of India. The survey concentrated on input-output relationships in eggplant production and information needed to forecast productivity and future technology adoption. Questions on farmers' WTP for Bt hybrids and OPVs and on household characteristics were also included.

As indicated in earlier studies (George et al., 2002; Rashid et al., 2003), eggplant in South Asia is being cultivated with excessive quantities of plant protection chemicals. In our survey, farmers were spending Rs. 3,570/acre (1 US$ = Rs. 44) on insecticides, 64% of which was intended to control ESFB. On average, for a crop of 180 days 2.34kg/acre of active ingredient were applied in 30 sprays. Farmers were well-aware of associated healthhazards and negative externalities: 25% had experienced one or more forms of health impairments associated with agro-chemical use during the previous year. Despite the excessive input use, eggplant remains an economically viable enterprise for farmers with an average benefit-cost ratio of 2.08, and a gross margin of Rs. 21,119 per acre across the three states (Table 1). This probably explains the increasing popularity of eggplants in the vegetable tracts of India. Total average production expenditure was calculated at Rs. 19,630 per acre, and the average marketable yield obtained was 94 quintals per acre (Q/acre). The yield level was highest in Karnataka followed by Andhra Pradesh. But, due to the high output price level prevailing in Andhra Pradesh, the gross returns for farmers there were significantly higher than for their counterparts in Karnataka. Despite the heavy dosage and frequent application of insecticides, crop losses are high. According to own statements, farmers suffered revenue losses of Rs.11,250 per acre, because a certain part of their harvest was unmarketable due to ESFB infestation. Actual losses might still be higher, because pest larvae also damage the plants' shoots. Against this background, the positive impact of Bt technology in India could be sizeable, so that farmers' WTP for Bt hybrids is hypothesized to be significantly higher than the current price of hybrid seeds.

Field trials with Bt eggplant

The first set of multi-location field trials with five Bt eggplant hybrids was carried out by MAHYCO during 2004-05. In these trials, Bt hybrids were grown next to non-Bt counterparts (i.e., isogenic hybrids without the Bt gene) and other conventional checks. In total, five MAHYCO Bt hybrids, suitable for different agro-climatic regions of India, were evaluated. These were MHB-80, MHB-4, MHB-10, MHB-9, and MHB-99. Out of a total of 11 trial locations, 9 locations had complete data on yield levels and insecticide use, so that they were included in our analysis. Although the limited number of trials is insufficient to make broad generalizations about the impact of Bt eggplant technology, they provide a first impression of the agronomic effects and the economic potential.

The results suggest a considerable reduction in insecticides. The average quantity of insecticides used on the Bt plots was 2.82 kg/acre, 45% less than on non-Bt plots. Both Bt and non-Bt plots were sprayed equally to control sucking pests, so that the reduction was entirely due to insecticides applied against ESFB. On average, the quantity applied against ESFB was 0.38 kg/acre on Bt plots, whereas it was 2.67 kg on non-Bt plots. This is equivalent to a reduction of 86% (Figure 1). The trial results, however, suggest that the major impact of Bt technology is a yield advantage. While the mean yield of Bt eggplant was 221 Q/acre, it was only 102 Q/acre for the non-Bt counterparts (Figure 2). This sizeable yield effect is due to the high ESFB pressure in India. Obviously, chemical control measures alone are not able to avoid significant crop damage. Similar results were obtained for Bt cotton field trials in India (Qaim and Zilberman, 2003).

Farmers' WTP for Bt hybrids

Before analyzing ex ante the adoption of Bt hybrids, it is instructive to look at current adoption patterns of conventional hybrids in eggplant cultivation. Adoption of hybrid seeds shows wide regional disparities, for which a large number of factors – ranging from soil characteristics and pest pressure to state government policies – are responsible. Secondary data show the extent of hybrid adoption in the overall Indian eggplant area to be 20% (Kataria, 2003), which is considerably higher than in many other vegetables of the country. Since Indian seed laws were liberated in the 1980s, private investment in vegetable seed research has risen sharply. Hybrid eggplant seeds are so widely adopted in Karnataka that OPVs are rarely encountered: 90% of the sampled farmers in Karnataka were using hybrid seeds (Table 1), with MAHYCO, Ankur, and Safal private seed companies providing the most popular hybrids. In Andhra Pradesh, hybrids were adopted by 38% of the farmers, while in West Bengal, the state accounting for more than 25% of the total eggplant area, adoption was less than 1%. The low hybrid adoption in West Bengal is due to the high incidence of bacterial wilt, against which local OPVs are more resistant, and a less developed seed marketing network.

Contingent valuation approach

To elicit eggplant farmers' WTP for Bt hybrid seeds, the contingent valuation (CV) method was employed. A dichotomous choice (DC) approach was used, which is generally superior to an open-ended format, as it confronts respondents with a more market-like situation (Bateman et al., 2002). Bt eggplant technology was explained in detail to all farmers, before they were asked whether they would be willing to use Bt hybrids at a certain price level. Price bids were varied randomly across questionnaires in Rs. 500 intervals, ranging from Rs. 1000/acre, the average price of conventional hybrids, to Rs. 8000/acre, which was determined as a maximum in a smaller pilot survey. Depending on the answer, a second bid was given: for "yes" respondents the second bid was higher, and for "no" respondents it was lower than the first bid. The exact magnitude of the second bid was also randomly assigned. Such a double bounded dichotomous choice (DBDC) model was shown to be statistically more efficient than a single bounded approach (Hanemann et al., 1991).

To get realistic WTP estimates in CV studies, the reference (*status quo*) and target levels (state of the world with the proposed change) of each attribute of interest should be clearly described to the respondent (Bateman et al., 2002). In the present study, farmers were clearly detailed about the probable benefits of Bt eggplant through reduction in both pesticide use as well as reducing the uncontrolled yield loss due to ESFB infestation. Insights from the first MAHYCO field trials were used for formulating the description on potential benefits, whereby the trial results were adjusted to reflect the situation in farmers' fields more realistically: farmers were told that Bt hybrids would allow a reduction in insecticide use against borers by around 75% and yield increases by around 40% over conventional hybrids. They were also informed that own reproduction of Bt hybrids is not possible, so that seeds have to be bought every year.

For the purpose of analysis, respondents were categorized in four response groups according to their answers to the two sequential bids. The probabilities for observing each group can be specified as:

$$(1) \qquad \begin{aligned} Prob\,(yes/yes) &= Prob(WTP \geq P^H) \\ Prob\,(yes/no) &= Prob(WTP \geq P^H) - Prob(WTP \geq P^*) \\ Prob\,(no/yes) &= Prob(WTP \leq P^*) - Prob(WTP \leq P^L) \\ Prob\,(no/no) &= Prob(WTP \leq P^L) \end{aligned}$$

where P^*, P^L and P^H denote initial price bid, lower price bid and higher price bid, respectively. Assuming a normal distribution, the log-likelihood function for this WTP model is

$$(2) \qquad ln\, L = \sum_{i=1}^{n} I^{YY} ln[1 - \Phi(\frac{P^H - \beta' x}{\sigma})] \quad + I^{YN} ln[\Phi(\frac{P^H - \beta' x}{\sigma}) - \Phi(\frac{P^* - \beta' x}{\sigma})]$$

$$+ I^{NY} ln[\Phi(\frac{P^* - \beta' x}{\sigma}) - \Phi(\frac{P^L - \beta' x}{\sigma})] \quad + I^{YY} ln[\Phi(\frac{P^L - \beta' x}{\sigma})]$$

where, the *I* symbols denote binary indicator variables for the four response groups, and x is a vector of farm, household and contextual variables expected to influence the adoption decision. The division by σ in the coding of our likelihood model allows one to estimate β directly, so that the coefficients can be interpreted as the marginal effects on WTP in rupee terms.

Explanatory variables and estimation results

Current farming practices are expected to influence farmers' WTP for new technology. For example, the higher the cost saved in chemical control due to Bt technology, the greater would be the WTP for it. Hence, a positive relationship between current insecticide use against ESFB and WTP can be anticipated. The influence of current adoption of hybrid seeds could be in both directions. For farmers who currently use OPVs and mostly rely on farm-saved seeds, the adoption of Bt hybrids would imply a more drastic change. On the other hand, the potential increase in yield could be higher for current OPV growers, because the Bt yield effect would come in addition to the heterosis effect of the hybrid.

Along with these farming variables, a number of socioeconomic factors, such as farm size, land tenure status, credit availability, income, education, and age, are expected to have a bearing on the WTP. Since Bt technology has already been commercialized in Indian cotton production, knowledge about this existing technology, according to the perceived economic benefit, could positively or negatively influence the farmer's decision to adopt Bt eggplant. These and other variables included in our DBDC model are described in Table 2, along with the maximum-likelihood estimation results.

While hybrid adoption does not significantly influence the WTP for Bt hybrids, insecticide expenditures have a significantly positive effect. For each Rs. 1000 that a farmer spends on insecticides against ESFB his WTP for Bt hybrids increases by Rs. 135. Similar observations on impact of insecticide use on WTP for Bt technology were made by Payne et al. (2003) and Qaim and de Janvry (2003) in different contexts. There has been an active debate whether the land tenure system constrains technology adoption. In their seminal review paper, Feder et al. (1985) showed that in many cases tenant farmers were initially reluctant to adopt new varieties of seed, due to risk considerations. Also in our study, farmers cultivating eggplant on leased-in land were willing to pay Rs. 1,096 less than those cultivating on owned land. Farm size, on the other hand, does not seem to have a significant effect, since Bt technology is neutral in scale. Yet, the income situation matters: on average, an additional Rs. 1,000 in per capita income increases the WTP for Bt hybrids by Rs. 71/acre (at mean income levels).

The household size has a positive effect, indicating that farmers having larger households can associate higher utility to Bt eggplant hybrids than those having smaller households. To some extent, household size proxies family labor availability, shortage of which usually explains non-adoption of labor-intensive technologies (Feder et al., 1985). The farm survey reveals that the average labor cost, including the imputed value of family labor, was Rs. 1,522/acre for borer management (insecticide application and removal of infested fruits and twigs), whereas it was Rs. 5,350/acre for harvesting and marketing. Thus, the projected Bt eggplant effects would result in increased labor requirements worth around Rs. 1000/acre, so that households with more family labor available would be at an advantage. Higher labor requirements of Bt technology were also observed by Qaim et al. (2006, in press) in the Indian cotton sector, where the yield gain similarly dominates the insecticide-reducing effect.

Our results also show that the major source of information for eggplant farming matters: farmers depending mostly on private dealers for advice are willing to pay Rs. 998 more for Bt hybrids than others. The important role of information in the adoption of new technologies has also been highlighted in other contexts (e.g., Marra et al., 2001). Knowledge on the existence of Bt cotton was found to have a relatively big positive effect on WTP for Bt eggplant hybrids, indicating that most farmers consider the impact of Bt cotton to be positive. Regional disparity was also found to be important: farmers in West Bengal are willing to pay Rs. 2,651 more for Bt eggplant hybrids than their counterparts in Karnataka, and also the coefficient for Andhra Pradesh is positive, albeit not significant. ESFB pressure is particularly high in West Bengal and Andhra Pradesh, and eggplant in these states often plays a somewhat greater relative role in the farming systems as compared to Karnataka.

Mean WTP

Based on these estimates, we calculated the mean WTP for Bt hybrids, inserting average values of the explanatory variables, at Rs. 4,642/acre (US$ 106). This is more than four times the price of conventional hybrids, and more than 10 times the current average seed cost of Rs. 440/acre over all seed sources. Nonetheless, the value is not unrealistically high.

The estimated cost of ESFB infestation, calculated as the sum of insecticide expenditure, labor for spraying, and losses due to fruit damage, amounts to around Rs. 15,000/acre. Although Bt technology will not eliminate this entire cost, the big economic damage caused by ESFB puts the WTP for Bt hybrids into perspective. The estimated share of farmers adopting Bt hybrids at different price levels is depicted in Figure 3. Strikingly, the demand curve of current hybrid growers is very similar to that of current OPV growers. This suggests that MAHYCO will be able to increase its market share, as a significant number of OPV growers is likely to convert to hybrid seeds, once Bt technology is introduced.[1] MAHYCO has not yet determined its sales price of Bt eggplant seeds. Since the market for conventional eggplant hybrids is competitive, the current price of around Rs. 1,000/acre should more or less reflect the marginal cost of seed production. Hence, there is a relatively wide range of prices where MAHYCO can achieve a sizeable innovation rent for its Bt technology and still leave farmers with ample benefits of adoption.

Adoption of Bt hybrids in the presence of Bt OPVs

Once Bt OPVs enter the Indian seed market after a small time lag, the adoption process will probably become more complex. Farmers will have three options: (i) adopting Bt hybrids, (ii) adopting Bt OPVs, and (iii) non-adoption of the technology. Bt hybrids are expected to have achieved some popularity in the market before Bt OPVs are introduced two or three years later. As field trials with Bt OPVs have not been carried out so far, it is difficult to determine their exact performance. It is likely that their yield levels will be lower than those of Bt hybrids, but the insecticide reduction effect is expected to be of equal magnitude. To elicit farmers' preferences in this changed scenario, a simple choice experiment was

[1] In our sample, 28% of all farmers reported to use MAHYCO hybrid seeds in eggplant cultivation.

implemented. The first bid of the earlier DBDC question was used as the price bid for Bt hybrids. Then, a new price bid for Bt OPVs was added as another alternative, together with explanations of the advantages and disadvantages of this new option. Random price bids of Bt OPVs were ranging from Rs. 60/acre, the average cost of conventional OPVs, to Rs. 350. Farmers' choices for one of the three options were analyzed by using a multinomial logit model, which allows us to study the socioeconomic determinants. Similar models have also been used by different authors in the context of ex-post adoption studies (e.g., Barham et al., 2004).

Technological preferences and socioeconomic determinants

Our estimation results are presented in Table 3. Apart from the individual price bids for Bt hybrid and OPVs, which enter the model, variable definitions are the same as those in Table 2. Unsurprisingly, higher prices of Bt hybrids reduce the probability of their adoption, while the price of Bt OPVs does not have a significant impact on Bt hybrid adoption. However, the Bt OPV price is critically important in differentiating Bt OPV adopters from non-adopters. Although Bt OPVs can be reproduced by farmers, initial procurement costs seem to influence their popularity. As in the DBDC model, the level of insecticide use against ESFB increases the probability of Bt adoption, and farmers who currently spend a lot on insecticides obviously prefer Bt hybrids over lower-cost Bt OPVs. Interestingly, current use of hybrids does not increase the probability of Bt hybrid adoption, but it makes complete non-adoption unlikely. Tenant farmers seem to prefer Bt OPVs over hybrids, while farm size has the opposite effect: larger farmers are more likely to adopt Bt hybrids than Bt OPVs. The same holds true for richer farmers and for households with a higher share of off-farm income. These results clearly underline the social relevance of developing Bt OPVs as *pro-poor* seeds for smallholders. If Bt technology were to be introduced only in hybrids, it is likely that a considerable share of resource-poor farmers would have problems in accessing the technology.

As in the DBDC model, larger households show a higher probability of adopting Bt technology, and they prefer Bt hybrids over OPVs. As Bt hybrids will be higher yielding than Bt OPVs, they are also more labor intensive, so that the availability of family labor is again an advantage. Unlike the DBDC model, education has a significant impact on Bt hybrid adoption. Farmers depending on the public extension service for information are showing a higher propensity to adopt Bt OPVs over hybrids, which is not surprising, because Bt OPVs will be supplied through the public agricultural network. Knowledge on Bt cotton increases the farmers' preference for Bt eggplant hybrids, at the same time making Bt OPV adoption more unlikely. The latter result is somewhat surprising, but it should be mentioned that Bt cotton technology in India is only available in hybrids.

Changes in mean WTP for Bt hybrids

The question whether farmers' WTP for Bt hybrids would change significantly after the introduction of Bt OPVs is of particular importance from the point of view of the private sector. If the market for Bt hybrids would fade, the incentive for companies to engage in future public-private partnerships would certainly shrink. To estimate the mean WTP for Bt hybrids in the presence of Bt OPVs, the non-parametric Turnbull estimator was employed. The Turnbull estimator has emerged as a popular distribution-free alternative to standard parametric approaches (Bohara et al., 2001; Haab and McConnell, 2002; Crooker and Herriges, 2004). The analytical procedure of the Turnbull model as well as details of the estimates are given in the Appendix. A comparison is made between farmers' elicited responses to the first bid in the DBDC question, i.e. without Bt OPVs (*Situation 0*), and their responses in the multiple option format with Bt OPVs (*Situation I*).

The resulting mean WTP estimates are presented in Table 4. In the absence of Bt OPVs, the mean WTP is similar to the previous and more efficient results of the DBDC model, which strengthens the general validity of the estimation approach. With Bt OPVs the WTP for Bt hybrids decreases to Rs. 2,831/acre, with the difference of Rs. 1,500 being statistically significant. This implies that MAHYCO will have to adjust the price for Bt hybrid seeds downward, in order not to lose a large share of its market. Yet the mean WTP for Bt hybrids will still be much higher than the current price of conventional hybrids, so that the potential to attain a sizeable innovation rent remains. Furthermore, Bt hybrids will have a time advantage over Bt OPVs, and the more efficient private seed delivery system is likely to foster a speedier adoption of Bt hybrids.

Figure 4 reports estimated technology adoption rates with and without the existence of Bt OPVs. The share of farmers adopting was calculated at mean bid levels from the interviews. When no Bt OPVs are available, 51% of the farmers would adopt Bt hybrids at the mean bid of Rs. 4,523/acre. This proportion would be reduced to 31% when Bt OPVs are sold at Rs. 197/acre. Although this reduction is significant, MAHYCO's market share would still be somewhat bigger than the company's current share of 28% in our sample. Of the 49% initial non-adopters of Bt hybrids, the majority would adopt low-priced Bt OPVs. In total, only 14% of all eggplant growers would not adopt Bt at all when the technology is available in both hybrids and OPVs. Of course, these numbers should not be over-interpreted, since the exact technology performance and pricing policies are still unknown.

6. Conclusions

Bt eggplant technology is expected to bring about significant productivity growth in the Indian eggplant sector. Bt hybrids are currently being tested in the field and will be commercialized by the private company MAHYCO in the near future. The farmers' mean WTP for Bt hybrids was found to be more than four times the current price of conventional hybrids, which leaves ample scope for both MAHYCO and the farmers to benefit from the technology. Apart from proprietary Bt eggplant hybrids, Bt OPVs will be commercialized after some delay, as MAHYCO has also shared its technology with the public sector to target resource-poor farmers. We have analyzed the implications of this collaborative agreement for technology adoption.

Larger and richer farmers will generally prefer adopting Bt hybrids, whereas resource-poor farmers would opt for Bt OPVs, once these become available. Hence, the development of Bt OPVs under the public-private partnership is indeed an important means to promote equitable technology development in the Indian eggplant sector. However, because a clear segmentation between hybrid and OPV markets is not possible, this will also affect MAHYCO's potential to market its technology. Our results show that farmers' mean WTP for proprietary Bt hybrids would decrease by about 35%, once cheaper Bt OPVs become available. Accordingly, the company might have to lower its price in order not to lose too much of its market. Nonetheless, the mean WTP for Bt hybrids will remain almost three times higher than the current price of conventional hybrid seeds, so that there is still sufficient potential to attain a sizeable innovation rent. Also, it should not be underestimated that public-private partnership might facilitate technology approval processes for proprietary technologies. In India, in particular, biosafety procedures are often highly politicized, with technology critics trying to block technologies developed by the private sector. This can lead to serious delays and costly additional testing requirements. Involvement of the public sector with a special emphasis on resource-poor farmers might somewhat rationalize the process and reduce widespread reservations against private biotechnology and seed companies.

In conclusion, innovative models of public-private partnership, like the one analyzed here, can be beneficial for all parties involved: the private sector, which improves its image and can reduce the cost and hurdles of technology approval processes; the public sector, which gets access to proprietary technologies and know-how; and farmers, who receive productivity-enhancing transgenic seeds at affordable prices, including varieties that are suitable for the poor. More political effort and financial support are needed to make such types of collaborative agreements successful on a larger scale.

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Table 1. Economics of eggplant production in India[#]

	Mean (Std. deviation)			
	Andhra Pradesh (N = 120)	**Karnataka (N = 120)**	**West Bengal (N = 120)**	**Overall (N = 360)**
Farm size owned by household in acres	3.51	6.42	2.46	4.13
	(3.76)	(6.02)	(2.42)	(4.63)
Plot size under eggplant in acres	0.91	0.71	0.33	0.65
	(0.77)	(0.41)	(0.21)	(0.57)
Extent (%) of hybrid seed adoption	38.33	90.00	0.83	43.05
Number of insecticide sprays per crop	14.42	8.78	65.88	29.69
	(9.25)	(6.49)	(93.83)	(60.19)
Quantity of insecticides (active ingredient) applied in kg/acre	1.98	0.74	4.31	2.34
	(1.74)	(0.64)	(8.59)	(5.27)
Expenditure incurred on insecticides in '000 Rs/acre	2.66	1.29	6.78	3.57
	(2.44)	(1.23)	(14.48)	(8.80)
Cost of cultivation in '000 Rs/acre	20.85	14.94	23.09	19.63
	(10.86)	(6.80)	(18.65)	(13.47)
Marketable yield in Q/acre	100.06	111.92	70.52	94.16
	(66.89)	(76.64)	(57.24)	(69.42)
Average market price in Rs/Q	484.29	365.29	466.65	432.74
	(167.49)	(153.72)	(174.92)	(171.32)
Gross revenue in '000 Rs/acre	48.46	40.88	32.91	40.75
	(34.94)	(30.87)	(29.37)	(32.36)
Net return in '000 Rs/acre	27.61	25.94	9.81	21.12
	(35.05)	(29.89)	(25.30)	(31.31)

[#] 1 US$ = Rs.44.

Table 2.
Variable definitions and results of the WTP model for Bt eggplant hybrids (N = 360)

Variables	**Description**	**Mean (Std. deviation)**	**Coefficient (Std. error)**
Hybrid	1 if farmer cultivated hybrid eggplant during the previous season, 0 otherwise	0.43	0.673 (0.711)
Insecticides	Expenditure on chemical insecticides against ESFB infestation during the previous season in ‘000 Rs/acre.	3.11 (7.99)	0.135*** (0.047)
Health hazard	1 if farmer or his family members suffer from health hazard due to insecticide application; 0 otherwise	0.25	0.495 (0.537)
Leased-in	1 if eggplant was cultivated in the leased-in land, 0 otherwise	0.23	-1.096** (0.572)
Farm size	Size of farm owned by the household in acres	4.13 (4.63)	0.091 (0.059)
PCAI	Per capita annual income of household in ‘000 Rs.	17.18 (22.98)	0.105*** (0.028)
Square of PCAI			-0.001*** (0.000)
Off-farm income	Share of household income from off-farm sources ranging from 0-1.	0.14 (0.23)	-0.094 (0.911)
Credit	1 if farmer depended on external credit for eggplant cultivation, 0 otherwise	0.21	0.322 (0.577)
Age	Chronological age of the farmer years	40.03 (12.59)	-0.011 (0.018)
Household size	Number of members in the household	5.97 (3.12)	0.204*** (0.079)
Education	Formal education attained by the farmer in years of schooling	6.40 (5.12)	0.055 (0.045)
Extension	1 if farmer acknowledged formal extension network as a major source of information, 0 otherwise	0.26	-0.206 (0.501)
Dealer	1 if farmer acknowledged input dealer(s) as a major source of information, 0 otherwise	0.76	0.998** (0.516)
Media	1 if farmer acknowledged public media as a major source of information, 0 otherwise	0.21	0.702 (0.538)
Bt cotton	1 if the farmer knew about Bt cotton, 0 otherwise	0.06	1.847** (0.969)
Andhra Pradesh	1 if farmer was from Andhra Pradesh, 0 otherwise	0.33	1.094 (0.784)
West Bengal	1 if farmer was from West Bengal, 0 otherwise	0.33	2.651*** (0.878)
Intercept			-0.993 (1.268)
Log-likelihood			-447.66
χ^2 value			93.71***
Estimated mean WTP (Rs/acre)#			4641.51 (2239.65)

Dependent variables are in ‘000 rupees and coefficients can directly be interpreted as marginal effects.
*, **, *** Statistically significant at 0.10, 0.05 and 0.01 levels, respectively.
1 US$ = Rs. 44.

Table 3.
Multinomial logit analysis of factors influencing Bt eggplant adoption

Variables	**Coefficient (std. error)**		
	Bt hybrids over Bt OPVs	**Bt hybrids over non-adoption**	**Bt OPVs over non-adoption**
Bt hybrid seed price#	-0.199***	-0.158*	0.041
	(0.070)	(0.095)	(0.088)
Bt OPV seed price##	2.317	-2.584	-4.901**
	(1.726)	(2.447)	(2.293)
Hybrid	-0.324	0.953	1.277**
	(0.496)	(0.615)	(0.565)
Insecticides	0.073***	0.309**	0.236*
	(0.022)	(0.128)	(0 .127)
Health hazard	-0.375	0.496	0.871
	(0.364)	(0.616)	(0.588)
Leased-in	-0.838*	-0.771	0.067
	(0.465)	(0.594)	(0.525)
Farm size	0.074*	0.068	-0.006
	(0.039)	(0.072)	(0.069)
PCAI	0.042**	0.088***	0.046
	(0.021)	(0.031)	(0.029)
Square of PCAI	-3.02E-04*	-5.50E-04***	-2.47E-04*
	(1.69E-04)	(2.00E-04)	(1.48E-04)
Off-farm income	1.248*	-0.721	-1.968**
	(0.641)	(0.851)	(0.822)
Credit	0.407	0.170	-0.237
	(0.401)	(0.510)	(0.492)
Age	0.004	-0.003	-0.007
	(0.013)	(0.017)	(0.016)
Household size	0.092*	0.259***	0.168*
	(0.049)	(0.100)	(0.098)
Education	0.076**	0.084*	0.007
	(0.036)	(0.049)	(0.046)
Extension	-0.706*	0.034	0.740
	(0.367)	(0.504)	(0.473)
Dealer	0.704*	0.192	-0.512
	(0.395)	(0.485)	(0.448)
Media	0.336	0.326	-0.010
	(0.365)	(0.571)	(0.536)
Bt cotton	2.431***	0.114	-2.316**
	(0.844)	(0.794)	(1.024)
Andhra Pradesh	1.741***	0.569	-1.172*
	(0.556)	(0.724)	(0.664)
West Bengal	-0.069	1.725**	1.794**
	(0.619)	(0.884)	(0.787)
Intercept	-3.415***	-2.849**	0.567
	(1.030)	(1.452)	(1.329)

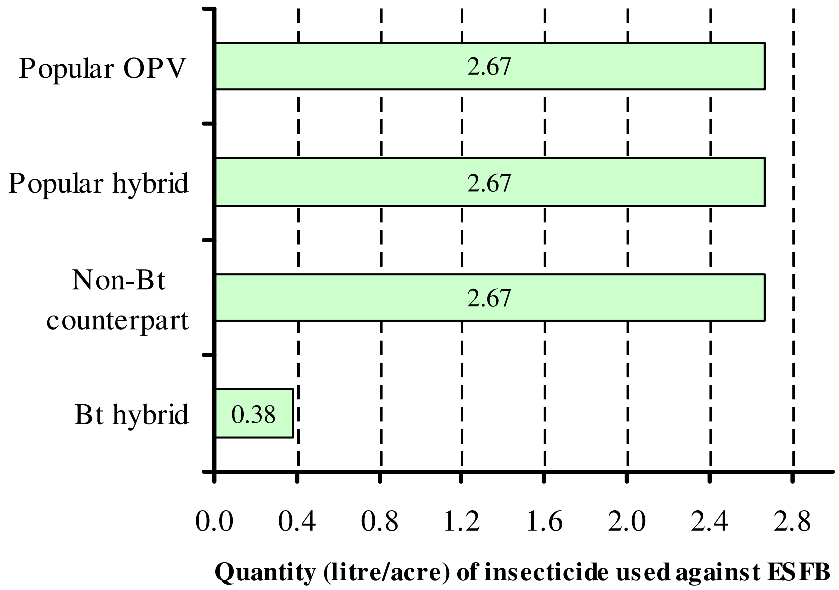
Notes: Log-likelihood = -260.22, $\chi^2_{(40)}$ = 176.78 (significant at 0.01 level).
*, **, *** Statistically significant at 0.10, 0.05 and 0.01 levels, respectively.
Price bid against which farmers were asked to elicit their willingness to adopt Bt hybrid in the presence of Bt OPVs in '000 Rs. (Mean: 4.523 ±2.139).
Price bid against which farmers were asked to elicit their willingness to adopt Bt OPVs in the presence of Bt hybrids in '000 Rs. (Mean: 0.197 ±0.084).

Table 4.
WTP for Bt hybrids in the presence and absence of Bt OPVs (Turnbull estimates)

	Estimated WTP (Rs./acre)[#]		Difference in mean WTP
	Situation 0	Situation I	
Mean	4331.90	2831.41	1500.49***
Standard error	156.80	139.18	

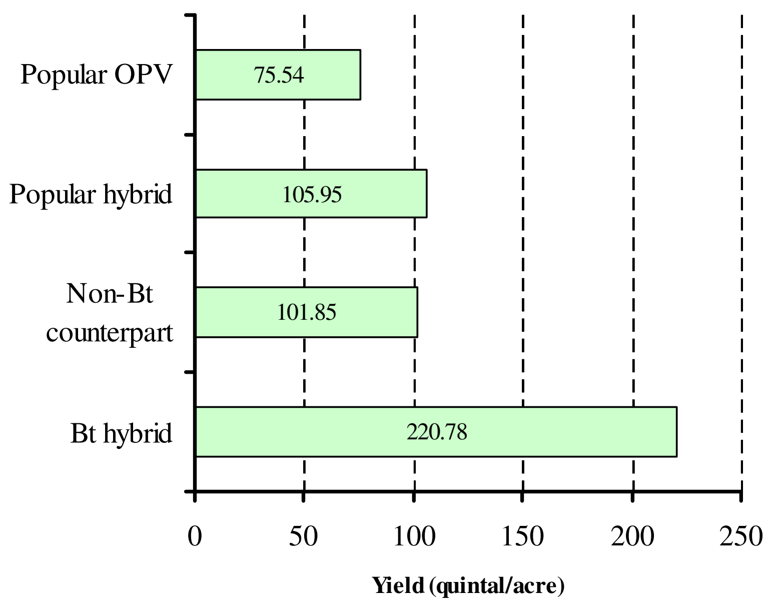
Note: See the Appendix for estimation details.
*** Statistically significant at 0.01 level.
[#] 1 US$ ≈ Rs. 44.

Figure 1.
Impact of Bt hybrids on insecticide use and yield (N = 9)



Source: Data from MAHYCO field trials in 2004-05.

Figure 2.
Impact of Bt hybrids on yield (N = 9)



Source: Data from MAHYCO field trials in 2004-05.

Figure 3.
Estimated percentage of farmers adopting Bt eggplant at different price levels

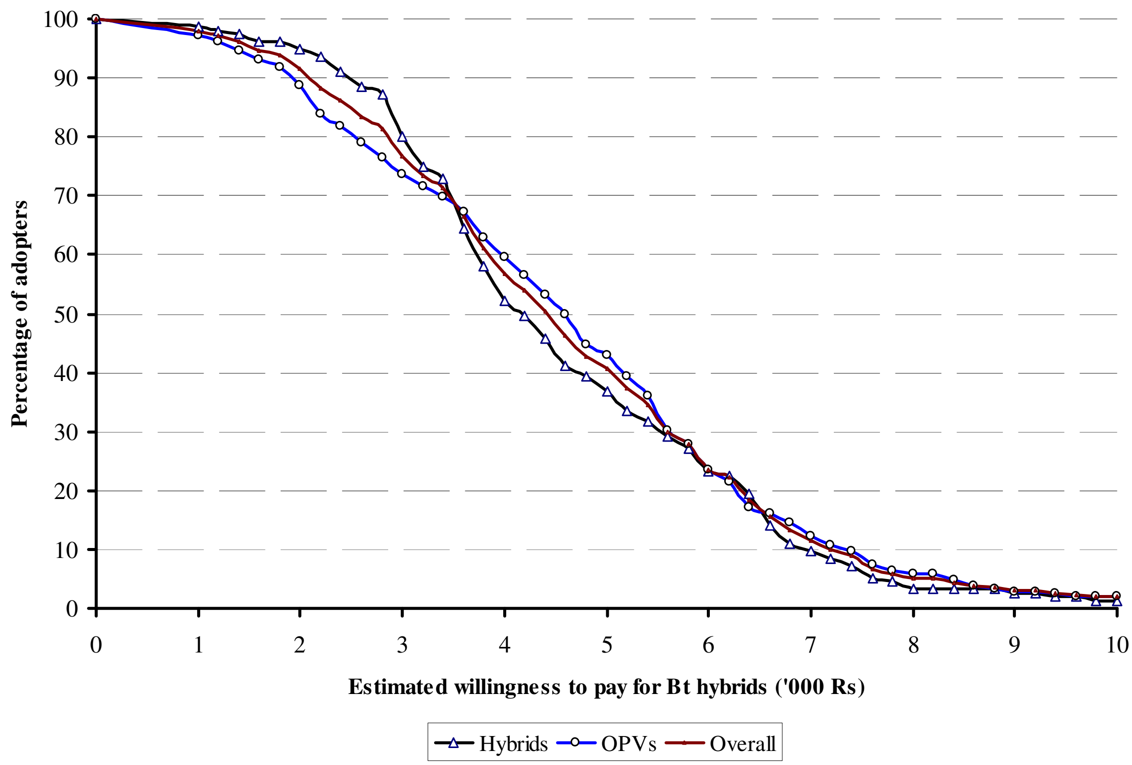
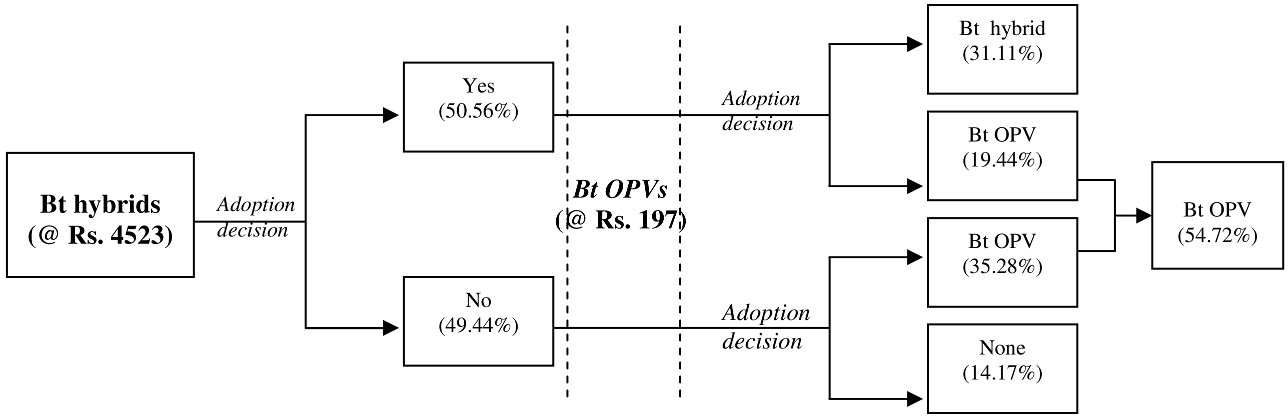


Figure 4.
Estimated adoption rates at mean price bids for Bt hybrids and OPVs (N = 360)



Appendix

Turnbull estimation of WTP - Methodology

The Turnbull estimator is based on the fact that a dichotomous choice CV response provides a single observation on the outcome of a Bernoulli trial where the probability of success ("YES") for a bid value of B_k is given by,

(A.1) $$Prob(WTP > B_k) = 1 - F_w(B_k) = 1 - F_k$$

where, $F_w(.)$ denotes the cumulative density function of WTP and $F_k \equiv F_w(B_k)$. If T_k denotes the number of individuals that face the same bid level B_k, and N_k denotes the number who respond "NO", then Haab and McConnell (2002) showed that the maximum likelihood estimate of F_k is given by,

(A.2) $$F_k = N_k/T_k \, .$$

The Turnbull estimator takes this simple analysis one step further by imposing the monotonicity assumption that $F_k \le F_{k+1}$ if $B_k \le B_{k+1}$. This is accomplished by pooling adjacent cells that violate the monotonicity assumption. That is, for all adjacent cells such that $F_k > F_{k+1} > \ldots > F_{k+s}$, the maximum likelihood estimates in *(A.2)* are replaced by,

(A.3) $$F_{k,s}^{*} = \frac{\sum_{l=k}^{k+s} N_l}{\sum_{j=k}^{k+s} T_j} \text{, otherwise, } F_k^{*} = F_k.$$

Given this information, one can construct a lower bound on the mean WTP ($\overline{WTP}_{LB}$) using

(A.4) $$\overline{WTP}_{LB} = \sum_{k=1}^{K} B_k (F_{k+1}^{*} - F_k^{*}) \, .$$

Similarly, the variance $V(\overline{WTP}_{LB})$ can be found out as

(A.5) $$V(\overline{WTP}_{LB}) = \sum_{k=1}^{K} \frac{F_k^{*}(1 - F_k^{*})}{T_k^{*}} . (B_k - B_{k-1})^2 \, .$$

The comparison of mean WTP for Bt hybrids in the presence (Situation 1) and absence (Situation 0) of Bt OPVs is examined under the null hypothesis that the difference between the means is zero. The statistic for finding the statistical significance of the comparison is,

(A1.6) $$\frac{\overline{WTP}_{LB}^{0} - \overline{WTP}_{LB}^{1}}{\sqrt{V^0 + V^1}}$$

which is normally distributed with mean zero and variance 1. The superscripts 0 and 1 stand for Situation 0 (with out Bt OPVs) and Situation 1 (with Bt OPVs). The Turnbull estimates of farmers' WTP for Bt hybrids is presented in Table A1.

Table A1.
Turnbull estimates of willingness to adopt Bt hybrids

Upper bound for bid intervals (Rs.)	Number of farmers asked to elicit their response (T_j)	Situation 0: only Bt hybrids		Situation I : Bt hybrids and OPVs	
		Number of 'NO' responses (N_j)	N_j/T_j	Number of 'NO' responses (N_j)	N_j/T_j
1000	21	6	0.286	10	0.476
1500	21	7	0.333	11	0.524
2000	27	14	0.519	17	0.630
2500	24	10	0.417	17	0.708
3000	27	11	0.407	21	0.778
3500	23	11	0.478	15	0.652
4000	24	13	0.542	16	0.667
4500	25	11	0.440	18	0.720
5000	23	14	0.609	16	0.696
5500	26	12	0.462	16	0.615
6000	24	13	0.542	18	0.750
6500	24	13	0.542	18	0.750
7000	23	13	0.565	18	0.783
7500	22	15	0.682	19	0.864
8000	26	15	0.577	18	0.692
8000+	--	--	1.000	--	1.000