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Potential welfare benefits from the public-private partnerships: A case of genetically engineered eggplant in India

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Abstract

Development of genetically engineered (Bt) eggplant in India provides a partnership example, where private sector focuses on the Bt hybrid market while donating the technology to public institutions to develop open pollinated varieties (OPVs). While partnerships like these can be justified in general on public sector human capacity enhancements and good will generation basis, it remains important to estimate the potential welfare benefits of such partnerships. An understanding of the magnitude and distribution of benefits among different stakeholders will be useful for effective design of similar partnerships in developing countries. In this study, we *ex ante* estimate the magnitude and distribution of potential welfare benefits from introducing Bt eggplant in India. We conducted a farm-level survey in Maharashtra, India, to collect data on production practices by eggplant growers, and farmers' willingness to pay for Bt technology. We also collected data from field trials of Bt eggplant to assess the economic potential of the technology in terms of increasing yield and reducing pesticide expenses. Following Moschini and Lapan framework we estimated the potential welfare benefits from Bt hybrid eggplant as the sum of the change in Marshallian surplus in the commodity market and the monopoly profit of private company in the seed market. Overall, our analysis shows that producers are likely to gain from the increased yield and reduced pesticide expenses associated with the Bt technology. However, consumers gain the majority (about 60%) of the expected welfare benefits. The higher magnitude of the forgone benefits (Rs 4,247 million/US$103 million) from not commercializing Bt OPV eggplant suggest the economic significance of the public-private partnership for developing genetically engineered varieties for crops such as eggplant which are considered 'a poor man's crop' in developing countries.

Key words: Public-private partnership, genetically engineered, eggplant, India, welfare benefits.

Introduction

Research and development (R&D) in agricultural biotechnology addresses the issue of declining/plateauing agricultural productivity by introducing technologies aimed at providing resistance/tolerance to biotic and abiotic stresses. Information on agricultural biotechnology research shows the majority of the research is carried out by the private sector in developed countries and focuses on crops important in developed countries. Less attention has been given to crops meant for local and home consumption in developing countries. Although much of the science and many tools and intermediate products are transferable to solving high-priority problems in developing countries, it is generally agreed that the private sector will not invest sufficiently to make the needed adaptations. Further, products developed by the private sector raise concerns that the pricing strategy may leave few benefits for small and poor producers in developing countries [1, 2].The public sector in most developing countries lacks the capability both technical and financial to advance agricultural biotechnology, especially in genetically engineered crops. In this context, increased collaboration between the public and private sectors will be the key to address the issues faced by disadvantaged farmers in developing countries.

The development of genetically engineered (GE) eggplant in India provides a good example for the public-private partnership in the R&D of GE crops. Eggplant is a popular non-seasonal vegetable in India with hybrid and open pollinated varieties (OPVs) cultivated across India. Production is seriously affected by eggplant shoot and fruit borer (ESFB). Previous studies assessing the impact of ESFB damage reported yield loss up to 70% in Indian conditions [3]. Mahyco (an Indian seed company, partly owned by Monsanto) developed GE varieties of hybrid eggplant and donated the technology to public institutions in India to develop GE varieties of open pollinated varieties [4]. Genetically engineered eggplant is expected to provide resistance to ESFB resulting in reduction of pesticide expenditure and yield loss for eggplant farmers. While partnerships like these can be justified in general on public sector human capacity enhancements and good will generation basis, it remains important to estimate the potential welfare benefits of such partnerships. An understanding of the magnitude and distribution of benefits among different stakeholders will be useful for effective design of similar partnerships in developing countries. In this study, we *ex ante* estimate the magnitude and distribution of potential welfare benefits from introducing GE eggplant in India.

Methodology

Eggplant occupies 9.4% of the area under vegetable crops in India, with about 30% area under hybrid cultivation [5]. Hybrid and OPV eggplant producers follow quite different production practices, where higher input hybrid production system has significantly higher yield than OPV production system. Most of the OPV growers use farm-saved seeds while most hybrid growers purchase seeds annually. Public sector contributes to the R&D of OPV seeds whereas the private sector holds major share in the hybrid seed market. Hybrid farmers are not only larger and richer on average, they have better access to major markets [6]. Because of these systematic differences between hybrid and OPV growers, we hypothesize that the substitution between hybrid and OPV growers will be less elastic than what is reported in Krishna and Qaim [7]. By extension, this way of segmenting markets based on production technologies facilitates the partnership.

In the past, most agricultural plant-based innovations were developed by the public sector and introduced into perfectly competitive markets. Under such conditions, total welfare changes due to the introduction of a new technology can be estimated as the changes in consumer and producer surpluses using methods summarized in Alston *et al.* [8]. Since Mahyco donated the technology to public institutions to develop Bt OPVs we assume a competitive market situation for Bt OPV seeds (GE eggplant uses *Bacillus thuringiensis* (Bt) gene construct).

Innovations developed by the private sector are usually protected by intellectual property rights (IPRs), which provide incentives for investments in R&D. For innovations protected by IPR, the competitive pricing conditions underlying the Alston *et al.* [8] approach cannot be used to evaluate welfare benefits [2, 9, 10]. In a study on herbicide-resistant rice Hareau *et al.* [2] reported that total surplus generated under perfect competition was 127% higher than that under imperfect competition. Even though the Bt gene used in Bt eggplant is not patented in India, Mahyco is the only company licensed by Monsanto to use it, meaning Mahyco enjoys monopoly power in the Bt hybrid seed market. Following Moschini and Lapan [9] framework we *ex ante* estimate the potential welfare benefits from Bt hybrid eggplant as the sum of the change in Marshallian surplus in the commodity market and the monopoly profit of Mahyco in the seed market.

Monopoly Bt hybrid market: Since eggplant is grown mainly for domestic consumption, we assume a closed economy model in our analysis. The Marshallian surplus (MS) is the sum of the changes in producer surplus (PS) and the consumer surplus (CS), and it is calculated as follows.

$$\Delta CS = P_0 Q_0 (1 + 0.5 Z_i \eta)\text{, i=1 if Bt hybrid, i=2 if Bt OPV} \quad (1)$$

$$\Delta PS = P_0 Q_0 (K_i - Z_i)(1 + 0.5 Z_i \eta), \quad (2)$$

$$MS = P_0 Q_0 K_i (1 + 0.5 Z_i \eta) \quad (3)$$

where P_0 and Q_0 are initial equilibrium price and quantities of eggplant, Z_i is the relative reduction in eggplant price due to new technology(i), K_i is the vertical shift in the supply function expressed as a proportion of initial price, and η is the absolute value of price elasticity of demand.

The relative reduction in price due to new technology can be calculated as

$$Z_i = K_i \varepsilon / (\varepsilon + \eta), \quad (4)$$

where ε is the price elasticity of supply. Since Bt eggplant is not yet commercialized, an *ex ante* estimate of vertical shift in supply function, K_i, can be calculated as

$$K_i = \left[\frac{E(Y_i)}{\varepsilon} - \frac{E(C_i)}{1 + E(Y_i)} \right] p A_{it} (1 - d_{it}) \quad (5)$$

where $E(Y_i)$ is the expected proportionate yield change per hectare after the adoption of the new technology i, $E(C_i)$ is the expected proportionate change in input costs per hectare due to i, p is the probability of research success (that the research will achieve the projected yield change), A_{it} is the adoption rate at time't' of technology i, and d_{it} is the depreciation factor of the new technology at time t.

The monopoly profit, π, from introducing Bt hybrid was calculated as follows.

$$\pi = Q_{Bt}(P_{Bt} - c) \quad (6)$$

where Q_{Bt} and P_{Bt} are the expected quantity (demand) and price of Bt hybrid seeds, and c is the marginal cost of producing Bt hybrid seeds. Hence, the change in total surplus generated due to the introduction of Bt hybrid is:

$$\Delta \text{ in Total Surplus due to Bt hybrid} = P_0 Q_0 K_1 (1 + 0.5 Z_1 \eta) + \pi \quad (7)$$

Competitive Bt OPV market: As mentioned previously, most OPV growers of eggplant use farm-saved seeds. The public-private partnership enables the public sector to back cross the Bt gene into its popular open pollinated varieties. In this context, we assume a perfectly competitive market for Bt OPV seeds, and the conventional economic surplus model is used in estimating the welfare effects. The change in total surplus generated is calculated as the sum of changes in consumer and producer surpluses.

$$\Delta \text{ in Total Surplus due to Bt OPV}(MS) = P_0 Q_0 K_2 (1 + 0.5 Z_2 \eta) \quad (8)$$

Due to the *ex ante* nature of our analysis, many of the parameters in our model are uncertain. Previous studies use deterministic values for uncertain parameters and conduct a sensitivity analysis or employ stochastic simulation methods to replace sensitivity analysis [2, 10]. In this study, we combine data from the farm-level survey, field trials of Bt hybrid eggplant and the published literature to specify the parameters used in the model.

Data collection: A farm-level survey was conducted during 2004-2005 in Maharashtra, India, one of the major eggplant growing states in India. According to the data from the Maharashtra State Seed Corporation, 10,907 hectares were planted under OPVs and 16,816 hectares under hybrid varieties (60% of eggplant area in the state) in 2002-2003.

The districts included in the survey were: Jalgaon, Nagpur, Ahmad Nagar and Nanded, which represent the four major geographical zones of the state. The survey covered 20 *talukas*

(a revenue division smaller than a district) and 38 villages. These sample sites chosen were known to include farmers producing substantial amounts of eggplant. Farmers were selected randomly from the lists of eggplant farmers or from the lists of all farmers provided by village administrative authorities. The research team (comprised of two enumerators and a researcher) also interviewed 41 non-eggplant vegetable growers to sample prior eggplant producers and noted the reasons for discontinuing eggplant cultivation. In addition, general information on the sample villages was collected from village administrative authorities. The classification of farmers participating in the survey is presented in Table 1. Because of the sampling procedure followed, the sample can be considered as approximately representative of the state. The representativeness of our sample was confirmed during our discussions with Mahyco marketing experts.

Table 1. Classification of surveyed farmers.

Category	Number
Hybrid eggplant growers	156
OPV/traditional eggplant growers	93
Non-eggplant vegetable growers	41
Total	290

(Source: survey data).

The first part of the questionnaire had questions on general cropping patterns, years of growing eggplant, details of adoption of hybrid seeds and detailed cultivation practices of eggplant. Questions about farmers' knowledge of and perceptions towards Bt technology and questions exploring their willingness to adopt Bt hybrid and Bt OPV eggplant were included in the second part. The research team explained the potential benefits and costs of Bt technology to the farmers based on the information gathered from scientists working on Bt eggplant. The surveyed farmers were told that adoption of Bt hybrid might cause a reduction in insecticide use against ESFB by about 70-75% and a yield increase of about 30% over conventional hybrids. Most of the farmers in the survey knew about Bt cotton, hence the questions were not unduly abstract to them. According to scientists, the Bt gene is likely to function similarly in both Bt hybrid and Bt OPV eggplants. Hence, even though the field trials included Bt hybrids only, the same benefits generated by the Bt hybrid were attributed to Bt OPV eggplant. Farmers were reminded that once purchased, Bt OPV seeds can be saved and reused for the succeeding crops. Income, land ownership and demographic details were included in the last part of the questionnaire.

Field trials of Bt eggplant: Five Mahyco hybrids were included in the first set of field trials for Bt hybrid eggplant conducted in 11 locations during 2004-2005 in India. Three additional hybrids were tested in six locations during 2005-2006. In each trial location, a Bt hybrid was grown next to non-Bt counterparts, and other conventional checks (popular OPV and competitor's hybrid). Each trial location consisted of 20 plots with five replications of each of the four types (Bt hybrid, non-Bt counterpart, competitor's hybrid and popular OPV). The data from field trials were extrapolated on per hectare basis for further analysis.

The trials were managed by the company entomologists and agronomists. Pesticide sprays on trial plots were done based on the economic threshold level (ETL) system. Although the limited number of field trials may not be sufficient for broad generalizations about the technology, they do indicate the economic potential of the technology. Data from the first set of field trials showed a 52% decrease in the use of pesticides and a 39% decrease in the number of sprayings in Bt plots compared to non-Bt plots. The yield from Bt plots was 117% higher compared to non-Bt counterparts.

Specification of parameters used in the model

Change in variable costs: The expected change in variable costs due to the adoption of Bt technology has two major components: expected change in the seed price and the expected change in pesticide expenses. Since the introduction of Bt technology is expected to abate yield loss, it is likely that increased yields will raise the demand for harvesting labor. However, it is not clear whether the reduction in the number of pesticide sprayings due to Bt technology will overcome the increased labor demand for harvesting. Hence we assume fixed labor cost in our analysis.

The price increase of the Bt seed, which is related to the premium paid to the gene's patent owner (Monsanto) and the developer of the new variety (Mahyco), is difficult to estimate. In the United States, markups on transgenic varieties follow two strategies: a premium paid above the price of seeds of the variety, and a technology fee paid by the planted acre [2]. We estimated farmers' willingness to pay (WTP) for Bt eggplant using data from the farm-level survey [11]. A modified version of double-bounded dichotomous choice approach was used to elicit farmers' willingness to pay for Bt hybrid technology [12]. The details of the WTP estimation are given below.

The econometric procedure used to reflect the nature of the dependent variable (WTP) was constructed from the relevant survey question. The observed variable Y, has an ordered response (willingness to adopt Bt hybrid or not, at two bids). The procedure we used in this analysis explicitly takes into account the values of known thresholds governing the intervals [13]. Specifically, we are interested in estimating the WTP for Bt hybrid seed, i.e. E(Y*/X), where Y* is the WTP for Bt hybrid seeds and X is the vector of explanatory variables associated with farmers, WTP. Hence, the potential adopters of the Bt hybrid technology in the sample are divided into the following three categories based on their responses to WTP question,

1. Prob $(Y^* \geq Rs400) = P(Y^* \geq 400/X)$
$= I^Y = [1-\Phi(400 - X\beta)/\sigma]$ where Φ () denotes the standard normal distribution, (9)

Similarly

2. Prob $(Pbid \leq Y^* < Rs400) = I^{NY} = \Phi(\frac{400 - X\beta}{\sigma}) - \Phi(\frac{Pbid - X\beta}{\sigma})$ (10)

3. Prob $(Y^* < Pbid) = I^{NN} = \Phi(\frac{Pbid - X\beta}{\sigma})$ (11)

where *Pbid* is the bid price offered to farmers in the sample, and I^Y (yes), I^{NY} (No, Yes), I^{NN} (No, No) are binary indicator choice variables for each farmer based on the above three categories [14]. In addition to the interval-coded data, some responses are point data (either zero or some positive values). In order to make use of all this information, interval regression model is used for estimating the mean WTP. The likelihood for the interval regression including

both interval-coded and point data is

$$L = -0.5\sum\left\{((Y_j - X\beta)/\sigma^2) + \log 2\pi\sigma^2\right\} + \sum_{j\in R}\log\left\{1 - \Phi((Y_{Rj} - X\beta)/\sigma)\right\} + \sum_{j\in I}\log\left\{((Y_{400\,j} - X\beta)/\sigma) - \Phi((Y_{bidj} - X\beta)/\sigma)\right\} + \sum_{j\in L}\log\Phi((Y_{Lj} - X\beta)/\sigma) \quad (12)$$

where observations j ∈ *C* are point data; observations j ∈ *R* are right-censored; observations j ∈ *I* are interval-coded data; and observations j ∈ *L* are left censored. Y_{bidj} is the one step-down hypothetical bid price, Y_{Rj} is the right censored WTP, Y_{Lj} is the left censored WTP, and Y_j is the point data. The mean WTP can be obtained using the estimated parameters from equation (12) at the mean level of the explanatory variables. Following Wooldridge [13], the formula for mean WTP is $E(Y^*/X) = \overline{X}\beta$

The average estimated willingness to pay for Bt hybrid eggplant was Rs 298/10 g packet, and we use this as a proxy for seed price of Bt hybrid in the baseline scenario. The estimated WTP for early adopters (who expressed their willingness to adopt Bt hybrid in the first years of its introduction) of Bt hybrid (Rs 515/10 g packet) was set as the maximum level, and Rs 105/10 g packet (which is 40% higher than the conventional hybrid seed price) as the lowest level for seed price [15].

In the case of Bt OPV, due to the public-private partnership involved in the process, it is more likely that Bt OPV seeds would be priced on a no-profit basis. We also recognize that, in contrast to hybrids, OPV growers do not need to replace their seeds annually, and hence the revenue from seed sales is very limited. Since most OPV growers use farm-saved seeds, it was difficult to use the double bounded CV approach to elicit farmers' WTP for Bt OPV. Hence, we used an open ended framework where farmers were asked to state their WTP for Bt OPV eggplant under the scenario presented to them to estimate their WTP for Bt OPV. The average estimated WTP for Bt OPV was Rs 62/50 g packet.

According to the farm-level survey, hybrid growers on average used 70 litres/ha of pesticides, while OPV growers used 26.7 litres/ha. Most of these sprayings were targeted against eggplant shoot and fruit borer; other pests targeted were mites, white flies and thrips. The average expenses on pesticides by hybrid and OPV growers were Rs 32,692/ha and Rs 12,913/ha respectively [16]. On average, the first set of field trials reported a 39% reduction in the number of sprayings, and a 52% reduction in the use of pesticides from Bt plots. Combining data from the field trials and the farm-level survey, the savings in pesticide expenditure due to the adoption of Bt hybrid eggplant was set conservatively at 40% in our baseline scenario. In order to test the robustness of the results, a sensitivity analysis was conducted using 15% as the lowest level and 70% as the upper level [17]. The estimated change in variable costs due to adoption of Bt hybrid varieties under different scenarios are presented in Table 2.

The current field trials were conducted for the evaluation of Bt hybrid eggplant only. The performance of Bt OPV may be different from that of Bt hybrid, due to the germplasm effect. However, experts opine that the behavior of Bt gene will be similar in both Bt hybrid and Bt OPV implying that the same level of pest control can be achieved in Bt hybrid and Bt OPV. Hence, the savings in pesticide costs due to Bt OPV were set the same as that due to Bt hybrid (i.e., 40% in the baseline scenario). Since OPV growers may choose not to replace their seeds annually, only the change in the pesticide expenses due to the adoption of Bt OPV was included in the calculation of expected changes in variable costs.

Table 2. Estimated changes in variable costs (VC) due to expected adoption of Bt hybrid technology.

Seed price (Rs/10 g)	Savings in pesticide expense (%)	Change in VC (%)
298	40	-15
298	70	-45
298	15	+9
105	40	-32
515	40	+4

(1 US $ is equivalent to 40.9 Indian Rupees, August 2007).

Yield increase: Subarmaniam *et al.* [18] analyzed the yield gap of major vegetables in India, and reported 51.3 metric tons/ha as the potentially achievable yield (PAY) for eggplant [19]. The average yields obtained from our farm-level survey were 17.2, 11.8 and 14.5 metric tons/ha for hybrid eggplant, OPV eggplant and the pooled sample respectively. These values indicate the extent of yield gap in eggplant cultivation.

As Bt technology is expected to provide early and efficient control of eggplant shoot and fruit borer it could reduce yield loss. Experts opine that early control of ESFB increases the reproductive growth of the crop compared to non-Bt eggplant where early shoot damage may cause increased vegetative growth instead. The yield advantage due to Bt technology may vary from farm to farm depending on the production practices and climatic conditions and pest pressure. According to the field trial data, the yield of Bt hybrid eggplant exceeded that of non-Bt counterpart, popular hybrid check, and popular OPV by 117, 108 and 192% respectively. Since the field trials were managed by company personnel, it is likely that average gains will be lower in commercial use.

We set 117% as the maximum yield advantage that can be achieved due to adoption of Bt hybrid technology. Previous studies examining the performance of Bt cotton in India reported yield advantages of 33, 45 and 63% [20, 21] . Hence, to capture the possible disparity between field level performance and field trial data, we combine information available from farm survey, field trials and Bt cotton performance in India and set 30% as the lowest level and 48% as the intermediate level of yield advantage.

According to the data from the farm-level survey, the yield of OPV is 68% that of hybrid eggplant. However, the potential yield performance of Bt OPVs needs to be assessed relative to the current yield levels of OPV eggplant and we use the same values for Bt OPVs in the analysis.

Adoption rates: Adoption rates are crucial in the economic surplus analysis as it is one of the main determinants of the change in total economic surplus generated due to the adoption of the new technology. Previous studies using an *ex ante* approach to estimate the potential welfare effects of technology adoption used logistic curves or probability distributions for adoption paths [2, 22]. As in the case of production parameters, the expected adoption rates are also unknown and difficult to estimate. We take this fact into account and estimate the expected adoption rates using farmers' responses in the CV. Building on the framework of Hubbell

et al. [12] we estimated the expected adoption rates of Bt hybrid and Bt OPV eggplants at different estimated seed prices (estimated WTP). Results from the state level analysis were extrapolated to the national level to calculate the expected proportion of Indian eggplant area under Bt technology.

Bt hybrid adoption rate at national level= [{(estimated proportion of hybrid growers willing to adopt Bt hybrid estimated average proportion of area under Bt hybrid eggplant by adopters)*Total area under hybrid eggplant in India} + {(estimated proportion of OPV growers willing to adopt Bt hybrid * estimated average proportion of area under Bt hybrid eggplant by adopters)*Total area under OPV eggplant in India}]/ Total area under eggplant in India.*

As reported earlier, area under hybrid eggplant is lower (about 30%) at the national level compared to 60% in Maharashtra. Further, technical experts in the seed industry reported that eggplant farmers in the North and North East prefer OPV eggplant compared to farmers in the Central and South India. Thus there is lot of heterogeneity among producers across the country. However, since Bt (hybrid) technology targets farmers from hybrid growing states such as Maharashtra, extrapolation of state level data to the national level is justified. The estimated proportion of area under Bt hybrid eggplant in its first year of introduction at a seed price of Rs 298/10 g packet is 10%. Given that only about 30% of the area under eggplant in India is occupied by hybrid eggplant, the estimated adoption rate of 10% is not low for the baseline scenario. The other values used in the sensitivity analysis are 14% (estimated proportion of area under Bt hybrid eggplant at a seed price of Rs 105/10 g packet) and 6% (estimated proportion of area under Bt hybrid eggplant at a seed price of Rs 515/10g packet). In a study analyzing the factors influencing adoption of Bt eggplant in India, Kolady and Lesser [6] showed that, even though introduction of low-priced Bt OPVs may cause a switch from Bt hybrid to Bt OPVs, most of the early adopters of Bt hybrid eggplant are more likely to continue with Bt hybrid cultivation even in the presence of low-priced Bt OPVs. Hence, introduction of Bt OPVs at a later date may not affect the expected adoption rate of Bt hybrid eggplant significantly.

The estimated adoption rate for Bt OPV eggplant at the national level was 9% and we use this in the baseline scenario. Since we assume a competitive market for Bt OPVs we did not estimate adoption rates at different price levels [23].

Demand elasticity: We selected demand elasticity parameters based on the published literature specific to India. Results from some previous studies on price elasticity of demand for vegetables in India are presented in Table 3. Based on the results from earlier studies, we select -0.56 as the demand elasticity for eggplant in our baseline scenario, and -0.20 and -0.75 for the sensitivity analysis [26].

Table 3. Estimates from previous studies on price elasticity of demand.

Author	Area	Estimates	Focus
Srinivasan [24]	Whole India	-0.21	Major vegetables ,rural consumers
Srinivasan [24]	Whole India	-0.40	Major vegetables, urban consumers
Nagarajan [25]	Tamil Nadu	-0.57	Vegetables
Subramaniam [18]	Whole India	-0.56	Major vegetables

Supply elasticity: The literature review did not provide any precise estimates for the price elasticity of supply of vegetables in India. Since there are no precise estimates of supply elasticity available for eggplant in India, following Alston *et al.* [8] the price elasticity of supply was set to 1. Sensitivity analysis was conducted using 0.75 and 1.25 as alternative estimates.

Price: Using the data from National Horticulture Board, India, Mishra [22] calculated the average wholesale price of eggplant for the year 1999 as Rs 5,396 per metric ton. In this study we use the average wholesale price of eggplant as Rs 5,839 per metric ton for the period 2002-2005. This price was calculated using the data available from Directorate of Marketing and Inspection (DMI), Government of India. Even though in the local market OPV eggplant fetches a slightly better price compared to hybrid eggplant, the national level data do not reflect these differences.

Quantity: A marginal increase in the area under eggplant in India is observed over the period 2002-2005. The average area for the period was 0.51 million hectares with an average yield of 14.6 metric tons/ha. The average production of eggplant in India for the period 2002-2005 was calculated to be 8,145,000 Mt (FAO STAT Database, http://faostat.fao.org/site/408/default.aspx) and the quantity (Q_0) is set at this level in this study.

Monopoly profits: The monopoly profit for the company was calculated as $Q_{Bt}(P_{Bt}-c)$, where Q_{Bt} and P_{Bt} are the expected quantity (demand) and price of Bt hybrid seeds, and c is the marginal cost of producing seed. Once a commercial transgenic variety has been developed, the seed production process is identical for Bt hybrid and non-Bt hybrid seed production. Since we assumed that the current market for hybrid seeds is competitive, we further assume that the current seed market price represents the marginal seed production cost c. The expected demand, Q_{Bt}, is calculated based on the estimated adoption rates in the study. The estimated WTP values were used as proxies for the expected seed prices.

Other variables: Based on the results from the two sets of field trials of Bt hybrid eggplant in India, the probability of research success of Bt eggplant p (i.e., the probability that the research will achieve the expected yield change), is set as 1 in the economic surplus analysis. Since our study focuses on the initial years of introduction of Bt eggplant in India, the depreciation rate for the period is set at 0%.

Results

The annual welfare effects estimated from economic surplus model are presented in Table 4. The figures in the first row of Table 4 correspond to the monopoly seed market scenario of Bt hybrid eggplant. The results indicate that with modest estimates of expected yield benefits (48%), adoption rate (10%) and expected savings in variable costs (15%), the magnitude of the change in total surplus generated is in the order of Rs 3,328 million (US$81 million) annually. The distribution of benefits among producers, consumers and the firm indicates that consumers gain the majority (60%) of the total benefits generated. Relatively low share of firm benefits (8%) may be because of the low adoption rate of hybrids at the

Table 4. Results from the economic surplus analysis of adoption of Bt eggplant in India- Baseline scenario.

Category	Producer surplus (million Rs)		Consumer surplus (million Rs)		Company profit (million Rs)
	Bt hybrid	Bt OPV	Bt hybrid	Bt OPV	
Monopoly	1,104(33%)		1,972(59%)		252(8%)
Perfect competition	5,284(36%)	1,524 (36%)	9,436(64%)	2,722 (64%)	

Note: values in parentheses are percentage to the total surplus (1 US $ is equivalent to 40.9 Indian Rupees, August 2007).

national level (small market size for hybrid technology). Since no comparable studies analyzing the distributional effects of a transgenic technology with limited market potential in developing countries have been published, it is not clear whether the rent distribution observed in our analysis is typical for protected innovations. The values reported in the second row of the table are the estimates obtained setting the seed mark-up to zero to simulate a perfectly competitive market for Bt hybrid seeds. As mentioned earlier, adoption rates are sensitive to seed prices. When seed mark-up for Bt hybrid is zero, it is likely that the expected adoption rate will increase. Since, only 30% of Indian eggplant area is under hybrid varieties, for simplicity we used 30% as the expected adoption rate of Bt hybrid under perfect competition scenario. As mentioned in the previous studies [2, 9, 10] the higher magnitude of change in total surplus under perfect condition - Rs 14,720 million (US$ 359million)- show that competitive pricing conditions underlying the conventional economic surplus approach cannot be used to evaluate the welfare benefits Bt hybrid eggplant with monopoly seed market conditions [27].

Since public institutions are involved in the development and release of Bt OPV we analyzed the welfare benefits from the adoption of Bt OPV eggplant using the conventional framework illustrated in Alston *et al.* [8]. The total change in economic surplus generated due to the adoption of Bt OPV under the baseline scenario Rs 4,246 million (US$103 million) is higher than that from the baseline scenario of Bt hybrid adoption (US $81 million). As in the case of Bt hybrid, consumers' gain the majority (64%) of the total surplus generated. The results indicate the expected potential benefits due to the introduction of GE eggplant in India to be large, Rs 7,574 million (US$184million) – the sum of expected annual potential benefits due to Bt hybrid under monopoly and Bt OPV. Contrary to the premium to be charged for the Bt hybrid seeds by the company, Bt OPV seeds are expected to be priced on a no-profit basis by the public sector and this results in the higher magnitude of change in total surplus from Bt OPV adoption.

Sensitivity analysis: We conducted sensitivity analysis to test the robustness of the results, and our results suggest that the magnitude of the change in total benefits generated is highly sensitive to the specification of model parameters.

Table 5 presents the results from the sensitivity analysis with changes in seed price and adoption rates of Bt hybrid (in order to save space other results from sensitivity analysis are not presented here). Our results show that a seed price of Rs 105/10g packet would result in the largest change in total surplus generated, however, the company's profit would be negligible (<1%) under such a scenario. We also find that the company's profit increases with increase in seed price up to Rs 540/10g (US$13) packet and decreases thereafter due to the steep reduction in the expected adoption rates. Our analysis showed that a 390% increase in seed price results in a 300% increase in the profit for the company up to Rs 540/10g packet. This shows that company profits and seed price are not linearly related and adoption rates are sensitive to seed price according to our survey data. Our results suggest that charging a very high price for Bt hybrid seeds reduces the adoption rate significantly. Results from the sensitivity analysis suggest that seed price influences both the magnitude and distribution of the total surplus generated. Given that Bt technology is already licensed to Mahyco by Monsanto, it is unclear at this point whether Mahyco has to pay a percentage royalty to Monsanto for marketing Bt hybrid eggplant using Monsanto's Bt construct, which might influence Mahyco's pricing decision.

Results from the sensitivity analysis of price elasticity of supply suggest that producers share increases with a relatively inelastic price elasticity of supply [28]. As reported in Mishra [22], our analysis showed that total surplus generated and its distribution are sensitive to changes in the price elasticity of supply. We also find that total surplus generated is less sensitive to the price elasticity of demand, while the distribution of benefits is more sensitive to changes in the values of demand elasticity. Further, the study shows that the magnitude and distribution of potential welfare benefits from adopting Bt technology are sensitive to changes in yield benefits and savings in pesticide expenses. Since results from the sensitivity analysis for Bt OPVs showed a similar pattern as that of Bt hybrid eggplant, the results are not presented here.

Conclusions and Policy Implications

Results from our study show that the welfare benefits from introducing Bt eggplant in its varied forms, Bt hybrid and Bt OPV, are large. However, the magnitude of these benefits and their distribution among producers, consumers and the company are sensitive to the parameter values in the model. Overall, our analysis shows that producers are likely to gain from the increased yield and reduced pesticide expenses associated with the Bt technology. However, consumers gain the majority (about 60%) of the expected welfare benefits. The higher magnitude of the

Table 5. Results from the sensitivity analysis with changes in adoption rate and seed price for Bt hybrid eggplant.

Seed price(Rs/10g)	Adoption-rate (%)	PS(million Rs)	CS(million Rs)	Profit(million Rs)
105	14	2,123(35.6%)	3,792(63.6%)	46(.8%)
298	10	1,104(33%)	1,971(59%)	252(8%)
515	6	394(29%)	704(51%)	282(20%)

Note: values in parentheses are percentage to the total surplus (1 US $ is equivalent to 40.9 Indian Rupees, August 2007).

forgone benefits (Rs 4,247 million/ US$103 million) from not commercializing Bt OPV eggplant suggest the economic significance of the public-private partnership for developing genetically engineered varieties for crops such as eggplant which are considered 'a poor man's crop' in developing countries. Given that most of the farmers grow traditional/open pollinated varieties of such multi-seasonal vegetable crops and over-use pesticides, providing access to genetically engineered technology for marginal and small farmers will have larger implications for health and environment as well. However, such an analysis requires more detailed and specific information on pesticide residues on farmers' blood stream and food products, and health expenses for farmers from illness due to pesticide spraying [29].

Results from the study suggest that the use of a conventional economic surplus approach in estimating the welfare benefits of protected technologies such as Bt hybrid results in an overestimation of the benefits. The monopoly assumption in the Bt hybrid seed market may change over the years if many players enter the Bt hybrid seed market, as has happened in the case of Bt cotton [30]. Further, as the area under Bt eggplant increases, the magnitude and distribution of the welfare benefits may change. However, our study provides initial empirical estimates of the potential welfare benefits of introducing GE crops in the context of public-private partnership in developing countries. The 'Indian model' studied here will be useful for policy makers to understand the magnitude and distribution of the potential benefits in the context of the partnership. A better understanding of the magnitude of the potential welfare benefits and the conditions that facilitate such a partnership will help them to replicate a similar agreement for other crops in other countries.

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[4]The public-private partnership (P-P) involves Mahyco (developer of Bt hybrid eggplant) and public institutions such as Tamil Nadu Agricultural University. This P-P arrangement was facilitated by Agricultural Biotechnology Project II (http://www.absp2.cornell.edu/)

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[11]In our survey, for the WTP question for Bt hybrid, the first bid offered was Rs 400/10 g packet. If the response was "no" from the farmer, a lower bid was offered . The lower bids offered were: Rs 350, Rs 300, Rs 250, Rs 200, and Rs 150 each for a 10 g packet. The bid ranges were chosen to cover what we perceived to be a likely range of retail prices, and WTP for Bt hybrid seeds. During the pre-testing of the survey, we identified farmers' difficulties in responding to a double-bounded CV framework for Bt OPV. This may be due to the fact that OPV seeds are marketed at a cheaper price and that farmers do not replace seeds of open pollinated varieties annually. Hence, an open-ended CV format where farmers were requested to state their WTP for Bt OPV eggplant was used. During the survey the market price for OPV seeds was Rs 16/50g packet. Note that 1 US $ is equivalent to Rs 40.9 (August, 2007). Because of the small amount values are expressed in Rs.

[12]Hubbell, B.J., Marra, M.C. and Carlson, G.A. 2000. Estimating the demand for a new technology: Bt cotton and insecticide policies. Am. J. Agri. Econ. **82**:118-132.

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[14]The first category of farmers have WTP higher than or equal to Rs 400/ 10 g packet, second group has WTP higher than second lower bid, but less than Rs 400, and the third group has WTP less than second lower bid. Please see footnote 1 for further details.

[15]Since we set 40% as the savings in pesticide expenses due to Bt hybrid in our baseline scenario we set 40% over conventional hybrid seed price as the lowest value of expected Bt hybrid seed price.

[16]Kolady, D. and Lesser, W. 2007. Is genetically engineered technology a good alternative to pesticide use? The case of GE eggplant in India (In press, Int. J. of Biotechnology).

[17]Based on the results from the field trials, we conservatively selected 40% for the baseline scenario. This is much smaller than what was reported in the questionnaire (70-75%). Since most of the farmers in the sample were familiar with the performance of Bt cotton we do not think that there is any bias in farmers responses, and set 70% as the upper level.

[18]Subramaniam, S. R., Vardarajan, S. R. and Asokan, M. 2000. India. In Ali, M. (ed.). Dynamics of Vegetable Production, Distribution, and Consumption in Asia. The World Vegetable Center, AVRDC, Thailand, pp. 99-138.

[19]PAY is estimated as the 90% of the best available yield in the research stations and in adaptive trials. The study also reported a yield gap of 36.6 metric tons for eggplant in India.

[20]Qaim, M., Subramanian, A., Naik, G. and Zilberman, D. 2006. Adoption of Bt cotton and impact variability: Insights from India. Rev. Agri. Econ. **28**:48-58.

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[22]Mishra, S. 2003. An Ex-Ante Economic Impact Assessment of Bt Eggplant in Bangladesh, the Philippines and India. Unpublished Master's thesis, Virginia Tech University, USA.

[23]The large number of OPV varieties grown by farmers creates the demand for developing multiple Bt OPVs meeting diversified requirements. However, the financial constraints of the public sector may limit the number of Bt OPV varieties developed and thus the adoption rate of

Bt OPVs. Hence, our estimate of 10% may not be very low in the Indian context.

[23]Since two of the previous studies focused on rural/urban consumers only, we selected -0.56 for the baseline scenario.

[24]Srinivasan, R. 1987. A Study on Nutritional Status of Rural Households in Madurai District. Department of Agricultural Economics, Tamil Nadu Agricultural University, Madurai, India.

[25]Nagarajan, 1994. Changing Structure of Demand for Agricultural Products in Tami Nadu (Research Report). Tata Economic Consultancy Services, Chennai, India.

[26]Since two of the previous studies focused on rural/urban consumers only, we selected -0.56 for the baseline scenario.

[27]Change in total economic surplus under perfect market scenario is 343% higher than that under monopoly market scenario. This higher percentage may be because of the assumption we used - all area under hybrid eggplant will be converted to Bt hybrid when seed mark-up is zero- in the analysis. However, our results are comparable to those from Hareau *et al.* [2].

[28]To reduce the number of tables, results from the sensitivity analysis of some parameters such as price elasticity of demand, price elasticity of supply, yield change, savings in pesticide expenses are not reported here.

[29]Most of the small farmers in India grow more than one crop. Hence collecting information specific to eggplant is difficult in the Indian context.

[30]Bt cotton is not patented in India, however each Bt hybrid has to be approved by Genetic Engineering Approval Committee (GEAC) in India. Mahyco used the Bt construct licensed from Monsanto in its Bt cotton varieties, and later sub-licensed the technology to selected seed companies in India. Thus Mahyco enjoyed monopoly power in the Bt seed market (charges price four times the conventional hybrid seed price). However, state government such as Andhra Pradesh in India intervened to reduce the price of Bt cotton seeds. Further, indigenously developed Bt technologies by JK seeds and Nath seeds are now available for Bt cotton seeds.