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Who Adopts What Kind of Technologies? The Case of Bt Eggplant in India

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The public-private partnership involved in the development of Bt eggplant in India is unique in the context of developing countries, where poor farmers' access to technology is limited. The key questions arising in this context are: Who adopts what kind of technology? What are the factors influencing their decisions? We answer these questions using data from a farm-level survey conducted in Maharashtra, India. Our results indicate that factors influencing hybrid adoption exert similar effects on the expected adoption of Bt hybrid eggplant and opposite effects on the decision to adopt Bt open-pollinated varieties (OPV). Even though some farmers who decided to grow Bt hybrid eggplant might switch to Bt OPVs when available, most of the early adopters of Bt hybrid would continue to grow Bt hybrid eggplant. Thus, our study gives initial empirical evidence on the economic feasibility of the public-private partnership in the research and development of Bt eggplant in India.

Key words: bivariate probit model, Bt eggplant, eggplant shoot and fruit borer, GM crops, India, technology adoption.

Introduction

Agriculture has been the engine of economic growth in developing countries, and will continue to be so in Africa and South Asia in the next decades. More than two thirds of the population live in rural areas and derive their livelihoods from agriculture. To meet the increasing food demands with declining per-capita arable land, increased agricultural productivity and product diversifications are required to ensure broad-based economic growth capable of improving the livelihoods of the poor. Research and development (R&D) in agricultural biotechnology—especially in genetically modified (GM) crops—is addressing the issue of declining or plateauing agricultural productivity. The effectiveness of this technology at different locations depends on prevailing socioeconomic, environmental, and political conditions, and thus it is difficult to generalize the costs and benefits of the adoption of GM crops. Furthermore, in countries where GM crops are accepted, adoption rates vary by crops. Microlevel studies focusing on the adoption of GM technologies targeted at developing countries are very limited.

Bt hybrid eggplant, developed by Mahyco (a private seed company in India), is the first GM vegetable crop to be commercialized in India. In addition, the private company donated the Bt gene royalty-free to public institutes to develop Bt open-pollinated varieties (OPVs).[1] Thus, the development of Bt eggplant in India is the first of its kind, where public and private institutes collaborate in the R&D of GM crops that are economically important for farmers in developing countries. In this context of two different forms of the technology—Bt hybrid and Bt OPV—it is important to analyze farmers' adoption decisions, as that could provide insights on the implications for the success of the public-private partnership.

Background

Eggplant has been regarded as a popular nonseasonal vegetable in South and Southeast Asia and Africa. Eggplant growers in India specialize in either OPVs or hybrid varieties of eggplant. About 30% of the area under eggplant in India is occupied by hybrid varieties. The private sector contributes 64% of the market share of vegetable hybrids in India; only 3% is from the public sector (Kataria, 2005).[2]

Eggplant production is seriously affected by damage caused by eggplant shoot and fruit borer (ESFB). Found throughout the tropics in Asia and Africa, ESFB (*Leucinodes orbonalis*) feeds almost exclusively on eggplant (AVRDC, 2001). Previous studies assessing the impact of ESFB damage report yield losses of up to 70% in Indian conditions (Dhandapani, Shelkar, & Murugan, 2003). According to our survey, eggplant growers sprayed an average of 27 times over a period of about

1. *Unlike in hybrids, farmers could save and use the seeds of OPVs.*
2. *The remainder is accounted for by imported seeds.*

eight months. Most of these sprays were targeted against ESFB; other pests included aphids, white flies, and so forth. Control of these pests by frequent application of toxic insecticides threatens the health of farmers and consumers, pollutes the environment, and increases prices.

Bt hybrid eggplant, developed by Mahyco, contains a gene (*Cry1Ac*) obtained from the bacterium *Bacillus thuringiensis* that produces a protein toxic to ESFB. Mahyco donated the technology royalty free to public institutes (Tamil Nadu Agricultural University, University of Agricultural Sciences-Dharwad, and Indian Institute of Vegetable Research) to develop Bt OPVs. Results from the first round of field trials of Bt hybrid eggplant indicated a 39% reduction in the number of pesticide applications and a substantial increase (117%) in the yield compared to non-Bt counterparts (unpublished data available from Mahyco). Although the data from the field trials are not conclusive, given the magnitude, the yield advantage of Bt eggplant in India would be sizable, and if it were made available to farmers at an affordable price, it would help reduce the existing gap between the potentially achievable yield and the modest yield realized by farmers to a great extent. Bt hybrid eggplant is expected to be commercialized by the end of 2006–07 upon completion of regulatory procedures. Bt OPVs are expected to be commercialized after 2–3 years of introduction of Bt hybrid in India.

Given that most Indian farmers grow OPV eggplant, the commercialization of Bt hybrid eggplant by a private company, while donating the Bt technology to the public sector for development of Bt OPVs, is very unique in the context of developing countries, where poor farmers' access to technology remains a significant issue. This public-private partnership also addresses the issue of less attention being paid by the private sector to crops important to poor and small farmers in developing economies. The key questions arising in this context include: Who adopts what kind of technology? What are the factors influencing their decisions? Do hybrid and OPV growers of eggplant behave differently towards Bt eggplant? Do hybrid (OPV) growers behave differently when it comes to Bt hybrid (OPV) eggplants? Does introduction of royalty-free Bt OPVs by public institutes affect the market potential of Bt hybrid eggplant?

We answer these questions using data from a farm-level survey conducted in Maharashtra, India. As farmers' adoption decisions have implications for the economic feasibility of the public-private partnership, the findings of this study would provide initial empirical evidence on the success of the partnership.

Literature Review

There is an increasing subset of technology adoption literature that focuses on the adoption of GM crops (Alexander & Van Mellor, 2005; Fernandez-Cornejo, Daberkow, & McBride, 2001; Marra, Hubbell, & Carlson, 2001; Qaim & de Janvry, 2003). Marra et al. (2001) studied relative importance of quality of information and its sources on the farmers' adoption decision of Bt cotton in the Southeast. Fernandez-Cornejo et al. (2001) used a Tobit model to study the factors influencing adoption of GM crops in the United States. The study showed that farm size, price of chemical insecticides, education, and operator's experience positively influence the adoption decision. Alexander and Van Mellor (2005) used a probit model to identify the determinants of rootworm-resistant corn adoption in Indiana. According to the study, market access variables, price variables, and insect-resistant management plans are significant in the adoption decision.

Among the studies focusing on Bt technology in developing countries, Qaim and de Janvry (2003) estimated farmers' willingness to pay (WTP) for Bt cotton in Argentina. According to the study, Bt technology significantly reduced insecticide applications and increased yields; however, the advantages were constrained by the high price of GM seeds. The study also found that expenditure on insecticides was positively related to the adoption of Bt cotton in Argentina. In a study on Bt cotton in China, Pray, Huang, Hu, and Rozelle (2002) reported that yield increase and reduction in pesticide costs are the major benefits from adopting Bt cotton. Bennett, Kambhampati, Morse, and Ismael (2006) conducted a production function analysis to compare the performance of Bt cotton and non-Bt cotton farmers' plots in Maharashtra, India. The study reported significant and positive impact of Bt technology on the average yield and on the economic performance of cotton growers. Using data from on-farm field trials of Bt cotton in India, Qaim and Zilberman (2003) showed that Bt technology substantially reduced pest damage and increased yield.

Mishra (2003) estimated the potential economic benefits from the adoption of Bt eggplant in India, the Philippines, and Bangladesh using an ex ante partial equilibrium economic surplus analysis. Because Bt eggplant was in the initial stages of development, the study relied on previous works on GM crops in other countries and also on information from scientists. The study also assumed that Bt eggplant is being developed by the public sector. According to the study, the welfare benefits from adopting Bt eggplant in India would be US$422 million, and consumers gain a major part of the welfare benefits generated (57%).

Most of the previous studies analyzed the adoption of commercial/field crops in an ex post framework, whereas studies on crops such as eggplant—which are economically important for farmers in developing countries—are limited. Previous studies on adoption of GM crops focused on technologies developed by private sector mainly for farmers in developed countries, while our study is unique in its context and distinct in its analysis.

Methods

The analysis of technology choice typically employs dichotomous choice methods to compare adopters and nonadopters and to discern what characteristics explain adoption. In the case of eggplant farmers in India, they already made a decision on whether to adopt hybrid eggplant, and with the expected introduction of Bt eggplant, they need to decide whether to adopt Bt eggplant. The framework thus includes two dichotomous decisions, where the disturbance terms of the two equations are likely to be correlated; that is, some unobservable characteristics captured in the error term of the hybrid adoption equation are likely to influence the error term in the expected adoption of Bt eggplant equation. Hence, we employ a bivariate probit model to include the two dichotomous decisions and the potential correlation between them. Use of the bivariate probit model helps us to analyze whether hybrid (OPV) growers behave differently when it comes to Bt hybrid (OPV) eggplants. The details of the model are given below.

The farmer's decision process is modeled using the random utility framework. From the utility theoretic standpoint, a farmer is willing to adopt a new technology if the farmer's utility with the new technology, minus its cost, is at least as great as the old technology—that is, if

$$U(1, Y_1 - C; \mathbf{X}) \geq U(0, Y_0; \mathbf{X}), \tag{1}$$

where 1 indicates the new technology and 0 the conventional alternative. Y_1 and Y_0 are expected profits from new and old technologies, respectively; C is the price to be paid for the new technology by the farmer; and $\mathbf{X}$ is a vector of farm, demographic, and contextual characteristics.

The farmer's utility function $U(i, Y; \mathbf{X})$ is unknown to the researcher, and the deterministic part of the utility function is $V(i, Y; \mathbf{X})$, so the inequality can be written as

$$V(1, Y_1 - C; \mathbf{X}) + \upsilon_1 \geq V(0, Y_0; \mathbf{X}) + \upsilon_0, \tag{2}$$

where υ_1 and υ_0 are independently and identically distributed random disturbances with zero means and unit variances.

With the introduction of Bt eggplant seeds, farmers have to make a decision on whether to adopt Bt seeds. Thus, the framework to model probability of adoption of Bt seeds includes two dichotomous decisions, where the second decision (hypothetical adoption of Bt over conventional varieties) might be correlated with the first decision (adoption of hybrid over OPV). The decision model to predict the probability of adoption of Bt technology is discussed below. Let

$$Y^*_1 = \beta_1'\mathbf{X}_1 + \upsilon_1, \tag{3}$$

where $\beta_1'\mathbf{X}_1 = V(1, Y_1 - C; \mathbf{X}) - V(0, Y_0; \mathbf{X}) = V^1 - V^0$, $Y_1 = 1$ if $Y^*_1 > 0$ (adopted hybrid), and $Y_1 = 0$ otherwise (not adopted hybrid). V^1 stands for deterministic part of utility from adopting hybrid seeds, V^0 stands for that from OPV seeds, and υ_1 is the disturbance term in Equation 3. Y_1 is the dummy for adoption of hybrid, and Y^*_1 is the underlying latent variable capturing the change in utility from adopting hybrid seeds. Let

$$Y^*_2 = \beta_2'\mathbf{X}_2 + \upsilon_2, \tag{4}$$

where $\beta_2'\mathbf{X}_2 = V(\text{Bt}, Y_{\text{Bt}} - C; \mathbf{X}) - V(\text{nBt}, Y_{\text{nBt}}; \mathbf{X}) = V^{\text{Bt}} - V^{\text{nBt}}$, $Y_2 = 1$ if $Y^*_2 > 0$ (willing to adopt Bt eggplant), and $Y_2 = 0$ otherwise (not willing to adopt Bt eggplant). V^{Bt} stands for deterministic part of utility from Bt seeds, V^{nBt} stands for that from non-Bt seeds , and υ_2 is the disturbance term in Equation 4. Y_2 is the dummy for the expected adoption of Bt eggplant, and Y^*_2 is the latent variable capturing the change in marginal utility by adopting Bt technology.

It is assumed that $(\upsilon_1, \upsilon_2) \sim N(0, 0, 1, 1, \rho)$, where ρ is the correlation between disturbance terms in Equations 3 and 4. Nested logit models are generally used to model interrelated choice scenarios. Although this approach allows for dependence among the levels of decisions, it does not provide for meaningful interpretations among them (Neill & Lee, 2001). Hence, assuming a bivariate normal relationship for υ_1 and υ_2, a bivariate probit model is employed to estimate the probability of adoption of Bt technology. Following Tuanli (1986), the log likelihood function for the bivariate probit model is

$$\ln L(\beta_1, \beta_2, \rho) = \sum_{y_1=1,y_2=1} \ln \Phi_2(\beta_1'\mathbf{X}_1, \beta_2'\mathbf{X}_2, \rho) + \sum_{y_1=1,y_2=0} \ln \Phi_2(\beta_1'\mathbf{X}_1, -\beta_2'\mathbf{X}_2, -\rho) + \sum_{y_1=0,y_2=1} \ln \Phi_2(-\beta_1'\mathbf{X}_1, \beta_2'\mathbf{X}_2, -\rho) + \sum_{y_1=0,y_2=0} \ln \Phi_2(-\beta_1'\mathbf{X}_1, -\beta_2'\mathbf{X}_2, \rho), \quad (5)$$

where Φ_2 represents the bivariate normal Cumulative Distribution Function (CDF) and ρ is the correlation coefficient between the two equations. The model considers the effects of **X** on four outcomes: (a) the probability that a farmer adopts the hybrid and is willing to adopt the Bt, (b) the probability that a farmer adopts the hybrid and is not willing to adopt the Bt, (c) the probability that the farmer does not adopt the hybrid but is willing to adopt the Bt, and (d) the probability that a farmer does not adopt the hybrid and is not willing to adopt Bt technology. Because the likelihood function in Equation 5 contains more information than would a univariate probit likelihood function, maximization of Equation 5 offers efficiency gains over univariate probit (Cooper & Keim, 1996). Furthermore, the bivariate probit model accounts for potential correlation between Equations 3 and 4, which may reveal how those unobservable factors associated with hybrid adoption are related to expected adoption of Bt technology.

Data Collection and Description of the Variables

We conducted a farm-level survey during 2004 and 2005 in Maharashtra, one of the major eggplant-growing states in India. Prior to the survey, discussions were held with marketing professionals and scientists from public and private institutes to understand the structure of the eggplant seed market in the state. According to the data available from Maharashtra State Seed Corporation, 10,907 hectares were planted with OPVs and 16,816 hectares with hybrids of eggplant (60% of eggplant area in the state). The districts included in the study were Jalgaon, Nagpur, Ahmad Nagar, and Nanded. These districts were chosen to represent the four major geographical zones (Marathwada, Vidarbha, Khandesh, and Western Maharashtra) of the state and to collect information on different market segments of eggplant. The survey covered 20 *talukas* (a revenue division smaller than district) and 38 villages from the four selected districts; these sampling sites were chosen because they were known to include farmers producing substantial amounts of eggplant. Farmers were selected randomly from the list of eggplant farmers or from the list of all farmers provided by the village administrative authorities. Two enumerators surveyed 290 households, including 41 vegetable growers not growing eggplant during the season (to identify the reasons for not growing eggplant), from the selected districts using a structured questionnaire. In addition, general information on the sample villages was collected from the village administrative authorities. A pilot survey was conducted prior to the survey to train the enumerators on data collection and to check farmers' level of understanding of the questions. Based on the feedback received, necessary corrections were made to the questionnaire. The classification of farmers who participated in the survey is presented in Table 1. As our survey covered the four agro-climatic zones in the state, and due to the sampling procedure we followed, our sample is considered as representative of the state.

Table 1. Classification of farmers included in the survey (2004–05).

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

The research team used separate questionnaires to interview eggplant growers, non-eggplant growers, and village administrative authorities. The questionnaire for the eggplant growers consisted of three parts. The first part included questions on general cropping pattern, area under cultivation, years of growing eggplant, adoption details of hybrid seeds, detailed cultivation practices, and eggplant marketing details. Questions about farmers' knowledge of and perceptions towards Bt technology, their willingness to adopt Bt hybrid seeds, their preference towards Bt OPV seeds, and their willingness to pay for Bt technology, were included in the second part.[3] All of the surveyed farmers cultivating hybrid eggplant purchased new seed packets each year as they were aware of the yield reduction associated with the F2 generation seeds. A modified version of double-bounded dichotomous choice contingent valuation (CV) approach was followed to elicit the information on adoption and WTP for Bt hybrid technology. The research team explained the potential benefits and costs of Bt technology to the farmers based on the informa-

Table 2. Description of the variables used in the analysis.

Variables	Description	Hybrid growers	OPV growers
District 1 (D)	1 if Jalgaon	.08(.29)	.54 (.50)**
District 2 (D)	1 if Nagpur	.28 (.44)	.28(.45)
District 3 (D)	1 if Ahmad Nagar	.39(.49)	0**
District 4 (D)	1 if Nanded	.24(.42)	.18(.29)
Total land	Land owned by the household (acres)	10.6 (10.26)	8.9(6.5)*
Family size	Number of people in the household	7.25 (4.9)	6.6(3.4)
Age	Age of the head of the family	44.4(11.6)	48.5(12.8)**
Access to banks	1 if has good access to banks	.87(.34)	.76(.43)
Distance	Distance to the eggplant market (km)	76.3(91.7)	49.7(87.5)**
Credit (D)	1 if credit is availed for eggplant cultivation	.08(.27)	.18(.39)**
Crop intensity	Types of crops(#)/total land	.55(.43)	.66(.52)*
Literate (D)	1 if operator is literate	.87(.34)	.82(.39)
Season (D)	1 if kharif is the growing season	.36(.48)	.77(.42)**
Expenses	Pesticide expenses (Rs/acre)	13,236(10,051)	5,228(7,041.6)**
Knowledge of Bt (D)	1 if knew about Bt technology	.57(.49)	.7(.5)**
Off-farm income (D)	1 if off-farm income available	.17(.38)	.18(.38)
Varietal preference (D)	If major preference is for yield	.33(.47)	.14(.35)**
Bid	Hypothetical bid offered for Bt hybrid seeds (Rs/10 g)	248.4(72.4)	251.1(68.4)
Yield	Output (quintal/acre)	75.1(39.7)	51.1(27.9)
N	Number of observations	156	93

Note. D = Dummy variable. Values in parentheses are standard deviations.
***Mean values are statistically different at 5% level from hybrid growers. *Mean values are statistically different at 10% level.*

tion gathered from the scientists working in the field. The surveyed farmers were told that adoption of Bt hybrid might cause a reduction in insecticide use against ESFB by 70–75% and an yield increase of about 30% over conventional hybrids. In the case of Bt OPV, an open-ended CV approach was followed based on the feedback from pilot survey. According to the scientists, the behavior of Bt gene is likely to be same in both Bt hybrid and Bt OPV eggplants. Hence, the same benefits as the Bt hybrid were attributed to the Bt OPV eggplant, while farmers were reminded that once they purchased the Bt OPV seeds, they could save and use the seeds from the previous crop. Income, land ownership, and demographic details were included in the last part of the questionnaire.

Description of the variables used in the analysis is presented in Table 2. Results in Table 2 show that farm, demographic, and contextual characteristics of farmers cultivating OPV eggplant are significantly different from that of hybrid-growing farmers. The variables included in the analysis were chosen based on the economic theory on adoption. Contextual characteristics, such as district dummies and distance, are included in the analysis, as they might capture the agro-climatic differences, infrastructure variations, and the regional preferences in the state, which might influence the farmers' adoption decision. Farm and farmer attributes, such as total land holding, major season of growing eggplant, per-acre expenses on pesticides, off-farm income, crop intensity, age, education, and varietal preferences (farmers' preferred seed traits), are expected to influence the farm-level adoption of Bt technology and hence included in the analysis.

3. *For the WTP question, the first bid offered was Rs 400/10 g packet of hybrid eggplant, and if the response was "no," a lower bid was offered .The lower bids offered were Rs 350, Rs 300, Rs 250, Rs 200, and Rs 150 per 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. Hybrid seeds were sold at an average price of Rs 75/10 g packet. In addition, farmers were asked to state their preference towards Bt OPV and their WTP for the technology (open ended) once it was introduced. This approach was followed to correspond to the current market scenario of OPV seeds, where OPV seeds are marketed at a cheaper price (Rs 16/50 g packet).*

Results

According to the survey, some farmers were willing to adopt Bt hybrid eggplant in the first year of its introduction, while some others were willing to adopt in later years. Hence, we conducted our analysis separately for different groups of farmers (early adopters and late adopters) to examine whether these two groups of farmers are different socioeconomically. Estimated coefficients from the bivariate probit model on Bt hybrid adoption for expected early adopters (Model 1) are presented in Table 3. In Model 1, Y_1 takes the value of one if the farmers adopted hybrid eggplant and zero otherwise, and Y_2 takes the value of one if the farmer was willing to adopt Bt hybrid eggplant in its first years of introduction and zero otherwise.

As reported in the previous studies, farm size (Fernandez-Cornejo et al., 2001) has a positive influence on the expected adoption of Bt hybrid (Y_2), but its effect is not significant on the adoption of hybrid eggplant. The nonsignificance of farm size on the hybrid adoption might be because we do not differentiate between early and late adopters of hybrid eggplant but rather pool them together in our analysis. The effect of access to banks is clearly positive on both hybrid and Bt hybrid adoption decisions. Farmers from district 1 (Jalgaon) and district 2 (Nagpur) are less likely to adopt hybrid and Bt hybrid eggplant. Even though not very significant, farmers from district 3 (Ahmad Nagar) are more likely to adopt Bt hybrid eggplant.[4] These results imply that most of the farmers in Jalgaon and Nagpur have revealed preference towards OPV eggplant, whereas those from Ahamad Nagar have revealed preference towards hybrids. Ahmad Nagar is located in Western Maharashtra, which includes Mumbai (the financial capital of India); Jalgaon is located in the Khandesh region bordering Madhya Pradesh state in central India. Thus, apart from agro-climatic conditions, the district dummies might be capturing the neighborhood effects and the varietal preferences exhibited by different regions. Farmers' preference for higher crop yields as a seed trait to other attributes (such as taste or appearance of the fruit) has a positive impact on hybrid adoption, while its influence is negative (not highly significant) on the likelihood of adopting Bt hybrid. As shown in previous studies (Fernandez-Cornejo et al., 2001) the effect of education on hybrid adoption and on the likelihood of Bt hybrid adoption is positive and significant. From the above-mentioned estimated coefficients, it can be concluded that the factors influencing the hybrid adoption decision might exert a similar influence on the likelihood of Bt hybrid adoption.

Table 3. Estimated coefficients from the bivariate probit model for the expected adopters of Bt hybrid in the first years of its introduction.

Variables	Hybrid adoption	Bt hybrid (early adopters)
Total land	.004(.01)	.03(.01)**
District 1	-2.0(.26)**	-1.2(.32)**
Family size	.03(.03)	-.02(.03)
Age	-.008(.008)	.01(.01)
Access to banks	.72(.27)**	1.3(.31)**
District 2	-.83(.22)**	-.57(.3)*
District3		.25(.46)
Distance		.005(.001)**
Credit		-.2(.3)
Crop intensity		.46(.3)**
Literate	.23(.31)	.15(.29)
Kharif		.19(.25)
Pesticide expenses		.00002(.00001)
Prior knowledge of Bt		.87(.38)**
Off-farm income		-.25(.22)
Varietal preference	.82(.23)**	-.008(.22)
Bid (Rs/10 gm)		-.002(.001)*
Constant	.3(.5)	-2.6(.76)
ρ	.69(.10)**	
Adoption rate (%)	69	41

Note. Values in parentheses are standard errors.
***Statistically significant at 5 % level. *Statistically significant at 10% level.*

Although not very significant, the current expenditure on chemical pesticides has a positive effect on the likelihood of adopting Bt hybrid eggplant. This might be because most farmers consider Bt technology to be a substitute for chemical pesticides; those who spend more on pesticides are more likely to adopt Bt hybrid technology. The estimated coefficient on hypothetical bid for the WTP of Bt hybrid eggplant indicates that an increase in seed price certainly can discourage the adoption of expensive Bt hybrid seeds. As expected, prior knowledge of Bt technology has a positive and significant effect on the adoption of Bt hybrid eggplant. Given that the area under Bt cotton in India is increasing rap-

4. *All the surveyed farmers from district 3 (Ahmad Nagar) adopted hybrid eggplant. Hence, the dummy for hybrid adoption (Y_1) and that for the explanatory variable district 3 are highly correlated for the observations from district 3. Therefore, district 3 was not included in the hybrid adoption equation.*

Table 4. Estimated coefficients from the bivariate probit model for the expected adopters of Bt hybrid in the later years of its introduction.

Variables	Hybrid adoption	Bt hybrid (late adoption)
Total land	.005(.01)	-.0004(.01)
District 1	-1.97(.26)**	-.29(.45)
Family size	.02(.03)	.02(.03)
Age	-.008(.008)	-.02(.01)*
Access to banks	.75(.27)**	-.45(.32)
District 2	-.79(.23)**	.17(.33)
District3		.24(.47)
Distance		-.005(.002)**
Credit		.04(.35)
Crop intensity		.04(.25)
Literate	.25(.31)	1.3(.43)**
Kharif		-.33(.31)
Pesticide expenses		.000003(.000009)
Prior knowledge of Bt		-.48(.3)*
Off-farm income		-.03(.35)
Varietal preference	.82(.23)**	.35(.25)
Bid (Rs/10 gm)		-.002(.001)
Constant	.28(.53)	-.45(.86)
ρ	.47(.18)**	
Adoption rate(%)	69	5

Note. Values in parentheses are standard errors.
***Statistically significant at 5 % level. *Statistically significant at 10% level.*

idly, and 60% of surveyed farmers knew about Bt technology and its performance, the positive and significant effect of prior knowledge of Bt technology on early adopters of Bt hybrid eggplant is as expected. The estimated coefficient on crop intensity, which captures on-farm enterprise diversification, has a positive effect on the likelihood of adopting Bt hybrid technology. Enterprise diversification is usually associated with operator's risk aversion attitude (Harwood, 1999); our finding suggests that risk-averse farmers have higher likelihood of adopting Bt hybrid eggplant in its initial years of introduction. As reported in Table 2, hybrid growers market their produce (eggplant fruits) at markets distant relative to OPV growers in order to fetch good prices. Hence, the positive and significant effect of distance on Bt hybrid adoption is as expected.

Our results show a positive and significant correlation between the two adoption decisions—hybrid eggplant and Bt hybrid eggplant—which justifies the use of bivariate probit model in the analysis. This positive correlation indicates that the unobservable characteristics in Equations 3 and 4—adoption of hybrid eggplant and the expected adoption of Bt hybrid eggplant—are very similar. The estimated adoption rates of hybrid eggplant and expected adoption of Bt hybrid eggplant in the state are 68% and 43%, respectively.

Table 4 reports the estimated coefficients from the bivariate probit model on the late adopters of Bt hybrid eggplant (Model 2). In this model, Y_1 takes the value of one if the farmers adopted hybrid eggplant and zero otherwise, and Y_2 takes the value of one if the farmer was willing to adopt Bt hybrid eggplant in the later years (after two years) of introduction and zero otherwise. Our results show that age, distance, and prior knowledge of Bt technology have a negative influence on late adopters of Bt hybrid eggplant, whereas education has a positive effect. We also find a positive and significant correlation (although of less degree compared to that in Table 3) between the two dichotomous decisions—the decision to adopt hybrid eggplant and the decision to adopt Bt hybrid eggplant in the later years. Most of the significant variables in Table 3 differ from those in Table 4 in their sign and effect on the Bt hybrid adoption decision, which suggests that early and late adopters of the Bt hybrid differ significantly in their socioeconomic characteristics.

As mentioned earlier, after collecting information on farmer's willingness to adopt Bt hybrid eggplant, farmers were asked to state their willingness to adopt Bt OPV eggplant. The results from the bivariate probit model on adoption of Bt OPV are presented in Table 5. In this model (Model 3), Y_1 takes the value of one if the farmer adopted hybrid eggplant, and Y_2 takes the value of one if the farmer is willing to adopt Bt OPV. Farmers with large farm size, more distance to market, and good access to banks are less likely to adopt Bt OPV. These results imply that resource-limited (OPV) farmers are more likely to adopt Bt OPV eggplant. The estimated coefficients on district dummies suggest the significance of regional preference/location to the adoption decision. As expected, farmers from Jalgaon (district 1) are more likely to adopt Bt OPV, while farmers from Ahmad Nagar (district 3) are less likely to adopt Bt OPV. Vegetable farmers in India grow a large number of varieties of eggplant, and farmer's varietal preferences vary from village to village. Our study indicates that researchers and marketing professionals need to pay attention to these regional preferences to enhance the diffusion of Bt eggplant.

Expenditure on pesticides has a negative and significant effect on Bt OPV adoption. The negative effect of expenditure on chemicals on the decision to adopt Bt

Table 5. Estimated coefficients from the bivariate probit model for the expected adopters of Bt OPV eggplant.

Variables	Hybrid adoption	Bt OPV adoption
Total land	.003(.01)	-.03(.02)*
District 1	-1.9(.25)**	1.2(.35)**
Family size	.03(.03)	.01(.03)
Age	-.009(.008)	-.001(.009)
Access to banks	.77(.28)**	-.67(.27)**
District 2	-.82(.23)**	-.13(.34)
District3		-5.7(.8)**
Distance		-.004(.002)**
Credit		.14(.31)
Crop intensity		-.43(.25)*
Literate	.23(.32)	-.24(.31)
Kharif		-.11(.25)
Pesticide expenses		-.00003(.00001)*
Prior knowledge of Bt		-.46(.29)
Off-farm income		-.32(.29)
Varietal preference	.86(.24)**	-.09(.24)
Bid (Rs/10 gm)		-.001(.001)
Constant	.30(.53)	1.5(.77)
ρ	-.72(.09)**	
Adoption rate(%)	69	18

Note. Values in parentheses are standard errors.
***Statistically significant at 5 % level. *Statistically significant at 10% level.*

OPV might be because on average, OPV growers spend less on pesticides relative to hybrid growers. Although not highly significant, crop intensity has a negative effect on the likelihood of adopting Bt OPV. Of particular interest here is the negative and significant correlation between the hybrid adoption and the expected adoption of Bt OPV (-0.71). Given that most of the statistically significant variables in the Bt OPV adoption equation have opposite sign to those in the hybrid adoption equation, it could be concluded that these two adoption decisions are negatively correlated. All of the significant variables in Table 5 have opposite sign to those in Table 3, suggesting that expected adopters of Bt hybrid and Bt OPV differ in their farm, farmer, and contextual characteristics. Overall, our data and analysis suggest that hybrid growers of eggplant are more likely to adopt Bt hybrid, and OPV growers are more likely to adopt Bt OPV. The estimated (expected) adoption rate of Bt OPV eggplant in the state is 18%.

After presenting the case of Bt OPV, farmers were allowed to reconsider their decision on Bt hybrid adoption and express their preference for Bt eggplant in one of the following ways: They would adopt (a) Bt hybrid only, (b) Bt OPV only, (c) both Bt hybrid and Bt OPV, or (d) neither Bt hybrid nor Bt OPV. Because we want to examine the effect of introduction of royalty-free Bt OPVs by public institutes on farmers' decision to adopt Bt hybrids, we reexamined farmers' adoption decisions on Bt hybrid eggplant (Table 6). In this model (Model 4), Y_1 takes the value of one if the farmer adopted hybrid eggplant and zero otherwise; Y_2 takes the value of one if the farmer is willing to adopt Bt hybrid when Bt OPV is available and zero otherwise. Most of the estimated coefficients and the estimated adoption rate of Bt hybrid eggplant (39%) in Table 6 are similar to the values of early adopters of Bt hybrid eggplant reported in Table 3. Unlike in Table 3, however, farmers who prefer higher yield (as a seed trait) have higher probability to adopt Bt hybrid eggplant when Bt OPVs are available. These results indicate that most of the farmers willing to adopt Bt hybrid in its first years of introduction might continue with Bt hybrid cultivation even if Bt OPVs were available at a lower price. Our results indicate a reduc-

Table 6. Estimated coefficients from the bivariate probit model for the expected adopters of Bt hybrid eggplant when Bt OPVs are available.

Variables	Hybrid adoption	Bt hybrid (final adopters)
Total land	.008(.01)	.02(.01)*
District 1	-1.9(.25)**	-1.4(.37)**
Family size	.02(.03)	-.0006(.02)
Age	-.007(.008)	.006(.008)
Access to banks	.75(.27)**	.63(.27)**
District 2	-.79(.24)**	-.1(.3)
District3		.84(.49)*
Distance		.003(.001)**
Credit		-.2(.3)
Crop intensity		.4(.2)*
Literate	.21(.31)	.43(.28)
Kharif		-.13(.23)
Pesticide expenses		.00002(.00001)
Prior knowledge of Bt		.23(.34)
Off-farm income		-.45(.24)*
Varietal preference	.83(.23)**	.4(.2)*
Bid (Rs/10 gm)		-.0009(.001)
Constant	.23(.54)	-1.9(.8)
ρ	.69(.11)**	
Adoption rate(%)	69	39

Note. Values in parentheses are standard errors.
***Statistically significant at 5 % level. *Statistically significant at 10% level.*

tion in expected adoption rate of Bt hybrid upon introduction of Bt OPV (from 46% to 39%), suggesting that some of the farmers who decided to adopt Bt hybrid might switch to Bt OPV once they become available, even though the magnitude of the switch is not very significant.[5] Our study suggests that Bt hybrid and Bt OPV eggplants are not good substitutes for most of the farmers, and the two technologies are targeted at different groups of farmers.

Summary and Policy Implications

Our study suggests that hybrid growers of eggplant have higher probability to adopt Bt hybrid eggplant, while farmers growing open pollinated varieties (OPVs) are more likely to adopt Bt OPV eggplant. Our results indicate that factors influencing hybrid adoption exert similar effects on the expected adoption of Bt hybrid eggplant and opposite effects on the decision to adopt Bt OPV. Even though there will be a reduction in the adoption rates of Bt hybrid eggplant due to the introduction of Bt OPVs, most of the farmers willing to grow Bt hybrid in the first years of its introduction would continue to grow Bt hybrid even in the presence of Bt OPVs.

As Bt hybrid and Bt OPV eggplants are targeted at different groups of farmers, our findings have positive implications for the success of the public-private partnership. Private companies developing Bt hybrid eggplant could target farmers/regions growing hybrid eggplant, while public institutes developing Bt OPV could target farmers/regions growing OPV eggplants. Farmers who value or prefer higher yield (mainly hybrid growers) would adopt Bt hybrid even if Bt OPVs were available at a lower price. Thus, the private companies and public institutes are not competing to capture the same market, and Bt hybrid and Bt OPV are not good substitutes for most of the eggplant growers. Because the results from the field trials of Bt hybrid eggplant are very promising (39% reduction in pesticide applications and 117% increase in yield), producers and consumers are expected to gain significantly from the adoption of Bt eggplant. Results from our analysis provide initial empirical evidence for policy makers and researchers analyzing the economic feasibility of the public-private partnership in the R&D of GM crops in India.

5. *The 46% was calculated as the sum of early adoption rate (41%) and late adoption rate (5%).*

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