Adoption of Genetically Modified Eggplant in India:-An *Ex Ante* Analysis

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Abstract

This paper uses a bivariate probit model to estimate the probability of adoption of Genetically Modified eggplant (Bt eggplant) in India. According to the study farm and contextual characteristics influence the expected adoption of Bt technology. Models that predict acreage under Bt technology, given the decision to adopt are also estimated.

Key Words: Genetically Modified Crops, Bt Eggplant, Adoption, India

JEL Classifications: O13, O14, O33

I. 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, as more than two-third of the population lives in rural areas and derive their livelihoods from agriculture. To meet the increasing food demands with declining per capita arable land, agricultural productivity increase and product diversifications are required to ensure broad-based economic growth capable of improving the livelihoods of the poor. Technologies associated with Green Revolution especially, conventional plant breeding techniques are becoming less promising after serving well the cause of increased agricultural productivity and enhanced food production. Research and development in agricultural biotechnology is addressing the issue of declining or plateauing agricultural productivity. Technological advances in agricultural biotechnology especially, in Genetically Modified (GM) crops, have been the topic of global debate. Effectiveness of this technology at different locations depends on prevailing socio-economic, environmental, and political conditions, and thus it is difficult to generalize the costs and benefits of GM crops' adoption. Further, in countries where GM technology is accepted, adoption rate varies by crops. Most of the research and development on GM crops has targeted farmers of developed countries and successful technologies are being transferred to developing countries through mechanisms like Genetically Modified Organisms (GMOs) for rent (Evenson, 2004). Among the developing countries, China, India, and Brazil are rapidly developing the capacity to be major GM technology suppliers, addressing the problems and requirements of their respective countries or regions.

Micro level studies focusing on the adoption of GM technologies targeted at developing countries are very limited and this study fills the gap by analyzing the adoption of GM eggplant (Bt eggplant) in India in an *ex ante* framework. India is considered as one of the centers of origin of eggplant (known as *brinjal* in India) – a popular vegetable in the country. Marginal and poor farmers grow eggplant as it provides cash flow for a minimum of six months. Open Pollinated Varieties (OPVs-where seeds can be saved and used again) and hybrids of *brinjal* are under cultivation across India. According to the latest statistics available, 30 % of *brinjal* area in India is under hybrid cultivation. Eggplant Shoot and Fruit Borer (ESFB) - *Leucinodes orbonalis, is* the most serious pest of *brinjal* in India. Various studies have reported yield loss up to 70 %, due to this pest. In many cases, farmers are applying multiple toxic pesticides, and are not waiting for the required time interval between spraying and harvesting. Needless to say, this spraying places both farmers and consumers at greater health risks .Compounding this problem is that ESFB is becoming resistant to chemicals. Frustrated farmers have reacted by mixing pesticides together in "cocktails” which is both illegal and extremely hazardous to human health and the environment.

Bt eggplant in India was developed by a private company, Mahyco, in Maharashtra, and the first phase of multi-location field trials for assessing agronomic performance was completed recently. It was developed by inserting *Cry1Ac* gene *of Bacillus thuringiensis* (Bt) into eggplant, to confer resistance to ESFB, through the production of a specific toxin, that kills the larva which feeds on eggplant. Use of Bt seeds for controlling the insect's attack is considered to be cost effective compared to chemical alternatives.

Research and development of Bt hybrid eggplant by private companies, is at an advanced stage, while research on Bt OPV by various public institutions is in the initial stages. Since Bt seeds are not yet available in market, an empirical comparison of costs and profits under alterative practices is not possible. Hence, use of direct revelation technique is the best tool available for analyzing farmers' adoption of the anticipated technology (Cooper et al., 1996).

A farm level survey covering four major eggplant growing districts of Maharashtra, in India was conducted during December 2004-February 2005. We estimate the probability that farmers will adopt Bt eggplant as a function of household, farm, and contextual characteristics. In addition, we estimate how many acres the farmers will allocate to Bt technology, given the decision to adopt. Based on prior studies of production practices for brinjal in India, the intensity of production for hybrids is notably more intensive than for OPV. In particular, hybrid producers use more fertilizer and pesticide sprays, up to 35 per season, compared to OPV producers who typically use few inputs. For this analysis we hypothesize that there will be a difference in adoption rates for Bt crops between hybrid and OPV producers, and maintaining that distinction in the analysis will enhance the efficiency of the estimates.

II. Literature Review

Beginning with the seminal work of Griliches (1957) which identified the importance of economic factors in the adoption decision, many studies have been conducted to analyze the factors influencing technology adoption in agriculture. Most of these studies in the past looked at adoption in an *ex-post* framework. Feder et al. (1985) review many of these studies focusing on agricultural technologies in developing countries.

Econometric models like binary logit (Hintze et al.,2003; Deberkow et al.,1998),, multinomial logit (Hintze et al.,2003), tobit (Adesina and Zinnah,1993; Shiyani et al., 2002), and double hurdle models(Nichola, 1996) have been used to identify and analyze the factors influencing technology adoption in agriculture(Hintze et al.,2003; Shiyani et al.,2002).

Caswell et al., (1994) identified four methodological approaches to *ex ante* projections of adoption: producer survey, producer survey with diffusion, expected profits and historical trends. Among these, historical trends are not applicable for technologies like GM crops as they are new to farmers. Batz et al., (2003) proposed an improved approach for predicting the speed and ceiling of adoption, which is crucial information for research priority setting. According to the authors, expert based *ex ante* estimates of technology adoption might lead to biased research assessments and distorted results in priority setting exercises.

Lesser et al., (1986) used a survey approach (of dairy farmers of New York state) for predicting the adoption rate of biotechnology products with special focus on Bovine Somatotropin .A multinomial logit model was employed to predict adoption of Bovine

Somatotropin(BST), by California milk producers. The study also analyzed the potential structural changes in the California Dairy industry due to the release of rBST technology (Zepeda, 1990). In a study by Hareau (2002) partial budgeting was used to conduct an *ex ante* analysis of the benefits from the adoption of Corn Root Worm (CRW) resistant transgenic technology**.**

A few empirical studies analyzing the factors influencing adoption of GM crops in developing countries have reported thus far (Huang et al., 2002; Qaim et al., 2003). Mishra (2003) estimated the total economic effects from the introduction of Bt eggplant in India, Bangladesh and the Philippines. Since Bt eggplant was in the initial stages of development, predictions regarding its adoption were made by interviewing scientists and by comparing the adoption rate of other Bt technologies such as Bt cotton in other countries. According to the study, the welfare benefits from the adoption of Bt eggplant were estimated at US $ 422 million in India and the simulation results showed that consumers will gain 57 % of total welfare benefits and producers will gain 43 %.

III. Method

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

$$U(1, \mathrm{Y}_1 - C; \mathrm{X}) \geq U(0, \mathrm{Y}_0; \mathrm{X}) \qquad \textbf{(1)}$$

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. X is a vector of farm, economic, farmer, and contextual characteristics.

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

$$V(1, \mathrm{Y}_1 - C; \mathrm{X}) + \upsilon_1 \geq V(0, \mathrm{Y}_0; \mathrm{X}) + \upsilon_0 \qquad \textbf{(2)}$$

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

As hybrid seeds of *brinjal* were introduced in mid 1980s in India, *brinjal* farmers are having a revealed preference towards hybrid technology- either they adopted hybrids or did not adopt hybrids. With the introduction of Bt seeds, farmers have to take a decision on whether to adopt Bt seeds or not. 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. We drop the subscript *i*, which refers to the *i*th observation in the following discussion.

Let

$\mathrm{Y}_1^* = \beta_1{}' \mathrm{X}_1 + \upsilon_1$ Where $\beta_1{}' \mathrm{X}_1 = V(1, \mathrm{Y}_1 - C; \mathrm{X}) - V(0, \mathrm{Y}_0; \mathrm{X}) = V^1 - V^0$

$\mathrm{Y}_1 = 1$ if $\mathrm{Y}_1^* > 0$

$=0$ otherwise **(3)**

where V^1 stands for hybrid seeds and V^0 stands for 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. X_1 stands for the vector of explanatory variables (farm, farmer and location characteristics) in the model.

Let

$$Y_2^* = \beta_2^{'} X_2 + \upsilon_2 \text{ Where } \beta_2^{'} X_2 = V(1, Y_1 - C; X) - V(0, Y_0; X) = V^1 - V^0$$

$$Y_2 = 1 \text{ if } Y_2^* > 0$$

$$=0 \text{ otherwise} \quad \textbf{(4)}$$

where V^1 stands for Bt seeds and V^0 stands for currently using /conventional seeds , and υ_2 is the disturbance term in equation (4).Y_2 is the dummy for the expected adoption of Bt *brinjal,* and Y_2^* is the latent variable capturing the change in marginal utility by adopting Bt technology. It is assumed that (υ_1, υ_2) ~N(0,0,1,1, ρ) where ρ is the correlation between disturbance terms in equations (3) and (4). Ignoring this relationship between the adoption of hybrid and the expected adoption of the Bt technology might lead to biased estimates in the continuous adoption stage (Fishe et al., 1981). Nested logit models are generally used to model interrelated choice scenarios. While this approach allows for dependence among the levels of decisions, it does not provide for meaningful interpretations among them (Neill and Lee, 2001).

Hence, assuming a bivariate normal relationship for υ_1 and υ_2, bivariate probit model is employed to estimate the probability of adoption of Bt technology. The log likelihood function for the bivariate probit model is

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

(5)

where Φ_2 represents the bivariate normal Cumulative Distribution Function (CDF), and ρ is the correlation coefficient between two equations. The model considers the effect of X on four outcomes: 1) the probability that a farmer adopts the hybrid and is willing to adopt the Bt, 2) the probability that a farmer adopts the hybrid and is not willing to adopt the Bt, 3) the probability that the farmer does not adopt the hybrid but is willing to adopt the Bt, and 4) the probability that a farmer never adopts a new 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. Furthermore, 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 Bt adoption. This analysis is done separately for the adoption decisions of Bt hybrid and Bt OPV seeds, which will help us to compare and contrast the two decision making processes.

In addition to developing the adoption decision model, we would also like to know what proportion of area under *brinjal* a farmer will allot to the Bt technology, and the factors influencing the intensity of adoption given the decision to adopt Bt. The expected allocation of area under the Bt technology is given by

Y_3= PRAREA= $\gamma^{'}Z + \upsilon_3$ **(6)**

where PRAREA is the expected proportion of acres under Bt (stated preference), Z is a vector of explanatory variables, and υ_3 is a random disturbance. Ordinary Least Square (OLS) estimates of equation (6) on farmers who are willing to adopt Bt have the potential for bias as these hypothetical acreages are only observed for the farmers who answered 'yes' to willingness to adopt Bt technology question. Selectivity bias arises because the underlying decision process is ignored when estimating the expected proportion of area under Bt *brinjal*. Here, we are encountered with multiple selectivity criteria, where two interrelated decisions form the basis of outcome equation, and ignoring this interrelation may lead to biased estimates (Fishe et al., 1981; Cooper et al., 1996). In the case where the decision equation is modeled using the probit assumptions and where the outcome equation is normal, Heckman (1976) and Lee (1976) have proposed a simple two stage estimation technique. An extension of Heckman two-stage estimation procedure to three equations is employed here to capture the multiple selectivity criteria present in the study. To explain this, let the total sample of eggplant farmers S be divided into four cells based on adoption of Y_1 and Y_2

Hypothetical adoption $\mathbf{Y_{2(Bt)-}}$ **=**		**Not Adopt** **0**	**Adopt** **1**
Past adoption $\mathbf{Y_{1(Hybrid)}}$**=**	**Not Adopt** **0**	S1	S2
	Adopt **1**	S3	S4

Hence, the sub-samples (S_2 and S_4) for equation (6) are not drawn randomly from the survey. Following Tunali (1986), the regression function for the sub-sample S_4 can be written as

$$E(Y_3 / Y_1 = 1, Y_2 = 1; Z) = E(Y_3 / \upsilon_2 > -\beta_2' X_2, \upsilon_1 > -\beta_1' X_1; Z) \quad \textbf{(7)}$$

hence,

$$E(Y_3 / Y_1 = 1, Y_2 = 1, Z) = \gamma' Z + E(\upsilon_3 / \upsilon_2 > -\beta_2' X_2, \upsilon_1 > -\beta_1' X_1) \quad \textbf{(8)}$$

Similarly observations in S_2 have

$$E(Y_3 / Y_1 = 0, Y_2 = 1, Z) = E(Y_3 / \upsilon_2 > -\beta_2' X_2, \upsilon_1 < -\beta_1' X_1) = \gamma' Z + E(\upsilon_3 / \upsilon_1 < -\beta_1' X_{1,} \upsilon_2 > -\beta_2' X_2) \quad \textbf{(9)}$$

Hence, if $E(\upsilon_3 / X; Y) \neq 0$, where Y is the joint outcome of the two selection rules, or the sample selection regime, linear regression of Y_3 on Z (equation 6) in the relevant sub-sample will result in inconsistent parameter estimates. Consistent estimation of γ requires knowledge of the form of the conditional distribution of the error term.

As additional terms in equation (8) and equation (9) are not accounted for in OLS estimation on sample of adopters, estimation of equation (6) generally provides biased estimates of population function due to omitted variable bias (Maddala, 1983). This can be corrected using an extension of Heckman procedure for estimating equations (8) and (9) when ρ is statistically different from zero. Since the sub cells S_2 and S_4 are comprised of the expected adopters of Bt brinjal who are observationally equivalent to the researcher, following Fishe et al., (1981), a pair wise comparison is employed between farmers in the sub-samples S_4 and S_2. This will help us to compare the outcome equations for these two sub-samples, S_2 and S_4.

Sub-sample S4, (Y_1=1, Y_2=1):Farmers adopted hybrid eggplant, willing to adopt Bt eggplant

The expectation of proportion of area under Bt eggplant for farmers in sub-cell S_4 is

$$E(Y_3 / \upsilon_1 > -\beta_1^{1} X_1, \upsilon_2 > -\beta_2^{'} X_2)$$
$$= \rho_{13} \frac{\phi(\beta^{'}{}_1 X_1)\Phi[(\beta_2^{'} X_2 - \rho\beta_1^{'} X_1)/(1-\rho^2)^{1/2}]}{P_{11}} + \rho_{23} \frac{\phi(\beta_2^{'} X_2)\Phi[(\beta_1^{'} X_1 - \rho\beta_2 \; X_2)/(1-\rho^2)^{1/2}]}{P_{11}}$$
(10)

where ρ_{13} and ρ_{23} are the correlation between Y_1 and Y_3 , and Y_2 and Y_3 respectively. P_{11} is the bivariate normal CDF $\Phi(\beta_1^{'} X_1, \beta_2^{'} X_2, \rho)$. Hence, the revised version of equation (6) is $Y_3 = \gamma^{'} Z + \gamma_1 \hat{\lambda}_{41} + \gamma_2 \hat{\lambda}_{42} + \upsilon_{43}$ **(11)**

where $\hat{\lambda}_{41}$ and $\hat{\lambda}_{42}$ are the inverse mills ratios calculated using the estimates from bivariate probit model. Variables λ_{41} and λ_{42} are defined as

$$\lambda_{41} = \frac{\phi(\beta_1^{'} X_1)\Phi[(\beta_2^{'} X_2 - \rho\beta_1^{'} X_1)/(1-\rho^2)^{1/2}]}{P_{11}} \quad \textbf{(12)}$$

$$\lambda_{42} = \frac{\phi(\beta_2^{'} X_2)\Phi[(\beta_1^{'} X_1 - \rho\beta_2^{'} X_2)/(1-\rho^2)^{1/2}]}{P_{11}} \quad \textbf{(13)}$$

Sub-Sample S2(Y_1=0,Y_2=1) :farmers not adopted hybrid , willing to adopt Bt

The expectation of proportion of area under Bt eggplant for farmers in sub-cell S_4 is

$$E(Y_3 / \upsilon_1 < -\beta_1 X_1, \upsilon_2 \geq -\beta_2^{'} X_2)$$
$$= \rho_{13} - \frac{\phi(\beta_1^{'} X_1)\Phi[(\beta_2^{'} X_2 - \rho\beta_1^{'} X_1)/(1-\rho^2)^{1/2}]}{P_{01}} + \rho_{23} \frac{\phi(\beta_2^{'} X_2)\Phi[-(\beta_1 \; X_1 - \rho\beta_2 \; X_2)/(1-\rho^2)^{1/2}]}{P_{01}}$$
(14)

where P_{01} is the bivariate normal CDF $\Phi(-\beta_1^{'}X_1, \beta_2^{'}X_2, -\rho)$. Hence, the revised version of equation (6) is

$$Y_3 = \gamma^{'}Z + \gamma_3 \hat{\lambda}_{21} + \gamma_4 \hat{\lambda}_{22} + \upsilon_{23} \quad \textbf{(15)}$$

Variables λ_{21} and λ_{22} are defined as

$$\lambda_{21} = -\frac{\phi(\beta_1^{'}X_1)\Phi[(\beta_2^{'}X_2 - \rho\beta_1^{'}X_1)/(1-\rho^2)^{1/2}]}{P_{01}} \quad \textbf{(16)}$$

$$\lambda_{22} = \frac{\phi(\beta_1^{'}X_1)\Phi[-(\beta_1^{'}X_1 - \rho\beta_2^{'}X_2)/(1-\rho^2)^{1/2}]}{P_{01}} \quad \textbf{(17)}$$

IV. Data

A farm level survey for 2004-2005 cropping year was conducted in Maharashtra, India, during December 2004-February 2005. The survey covered four major eggplant growing districts of the state: Jalgaon, Nagpur, Ahmad Nagar, and Nanded. A map of the study area is given in Fig.1. The following sampling procedure was used to select the 290 households included in the survey: 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 *brinjal*. The survey covered 20 *talukas* (a revenue division smaller than district) and 38 villages from the four selected districts, and these sampling sites were chosen because they were known to include farmers producing substantial amounts of *brinjal*. Farmers were selected randomly from the list of *brinjal* farmers or from the list of all farmers provided by the village administrative authorities. In addition, general information on the sample villages was collected from the village administrative authorities.

The questionnaire consisted of three parts. The first part included questions on general cropping pattern, years of growing *brinjal*, adoption details of hybrid seeds, and detailed cultivation practices for eggplant. Questions about farmers' knowledge of and perceptions towards Bt technology, their willingness to adopt Bt hybrid seeds, their preference towards Bt OPV seeds and questions exploring their Willingness To Pay (WTP) were included in the second part[1]. Income and demographic details were included in the last part of the questionnaire. The copy of the survey is available from authors.

According to the latest statistics available from Maharashtra State Seed Corporation, 10,907 hectares were planted to OPV and 16,816 hectares to hybrids (60% of *brinjal* area in the state). The classification of surveyed farmers in different categories (OPV, Hybrid, Both OPV and Hybrid and Non-Brinjal farmers) is given in Table 1. Since Bt cotton was commercially released in 2002 in India, it was assumed that many of the farmers might be knowing about or heard about Bt technology. According to the survey about 60% of the surveyed farmers had heard about Bt technology from different sources. Definition of explanatory variables used in the analysis along with sample statistics for adopters and non-adopters of hybrid are presented in Table 2. Data indicate significant statistical differences between hybrid and OPV farmers especially, for variables like area under *brinjal*, proportion of agricultural income from *brinjal*, expenses on ESFB control, distance to the market, number of irrigations per season, and yield. The values are not significantly different for variables like education of the head of the family, years of

[1] For the WTP question, the first bid offered was Rs 400/10 gm packet of hybrid brinjal, 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. The bid ranges were chosen to cover what we perceived to be a likely range of retail prices, and WTP for Bt hybrid seeds. In addition, farmers were asked to state their preference towards Bt OPV, and their WTP for the technology. This approach was followed to correspond to the current market scenario of OPV seeds, where seeds are marketed at a cheaper price-Rs 40/50 gm packet

growing *brinjal*, crop intensity, and market price for the product. The size-wise distribution of *brinjal* farmers from the sample is presented in Fig 2. The figure suggests that small farmers (area<=0.5 acres) constitute the highest percentage of the sample, followed by medium farmers (0.5-<=1 acres).

V. Results

Analysis of adoption of Bt eggplant was conducted separately for of Bt hybrid and Bt OPV adoption decisions, when a correlation between past adoption of hybrid and expected adoption of Bt was assumed and when it was not assumed. Table 3 reports the univariate probit estimates (when $\rho = 0$) and bivariate probit estimates (when $\rho \neq 0$) on the adoption decisions. The most conspicuous feature of these estimates is that the assumption of correlation does not change the estimated coefficients significantly. This is expected because the simple probit estimates are consistent when there is correlation between decision equations. However, as mentioned earlier, this result may not apply to the estimation of the outcome equation in the second stage of two-stage estimation employed in the study (Fishe et al., 1981).

It can be noted from Table 3 that the signs of the coefficients of most of the explanatory variables for the dummy dependent variables- hybrid and Bt hybrid, are similar except for the variables distance to the market and crop intensity. Among the regressors of hybrid adoption, dummy for the commercial cultivation of OPV in the village, area under *brinjal*, square of the area under *brinjal*, distance to the market, years of growing *brinjal*, dummy for the source of information about hybrids, number of irrigations per season, and District 3(Ahmad Nagar) are significant in the adoption decision on hybrid *brinjal*. Positive significance of area under *brinjal* and negative significance of area square confirms the farm size-technology adoption relationship reported in earlier studies on technology adoption (Marra and Carlson, 1987). Number of irrigations per season was positively and significantly associated with hybrid adoption and this might be because of the intensive production practices associated with hybrid cultivation. Negative significance of OPV and positive significance of District 3 indicate the importance of contextual factors in adoption decision. If OPVs are grown commercially in the village it implies a good local/regional market, and farmers in that village have a greater incentive to continue with OPV cultivation. As previously mentioned, among the four districts chosen, District 3 (Ahamad Nagar) is well developed with good access to large markets like Mumbai and Pune. Hence, its positive significance in the adoption decision of new technology is as expected. According to the survey, all the surveyed farmers in District 3, cultivate only hybrid brinjal and hence this variable was dropped out of the univariate probit model on hybrid adoption presented in Table 3. Distance to market is negatively associated with adoption, and as expected, internal sources of information (friends, family, neighbors) are positively associated with adoption. Contrary to earlier studies on adoption (Feder et al. 1985), years of growing eggplant is negatively and significantly associated with hybrid adoption, which suggests that even though hybrid cultivation provides higher yields, personal preferences based on taste, and culture limits adoption of hybrids.

The last column of Table 3 presents the coefficients of regressors of the second dummy dependent variable (Bt hybrid) in the bivariate probit model. As mentioned earlier these results indicate that most of the regressors have the expected a priori signs as that of hybrid adoption. Among the variables significant for the hybrid adoption, only two variables-years of growing brinjal and District 3(Ahamad Nagar) are significant in the expected adoption of Bt hybrid. Positive significance of total land and access to banks suggests that wealthy farmers can afford to buy Bt hybrid seeds and have the higher probability to adopt Bt hybrid seeds. Negative significance of credit suggests that farmers currently availing credit from private sources for pesticides and fertilizers have less probability to adopt Bt hybrid. This may be because they are unsure whether their creditors would agree to Bt adoption. Positive significance of expenditure on chemicals implies that farmers who spend more on chemicals have higher probability to adopt Bt hybrid seeds. Positive significance of the variable crop intensity (number of crops/land holding) which is included to capture the risk aversion nature of the farmer, suggests that risk averse farmers have a higher probability to adopt Bt hybrid which is promoted as cost reducing technology. This result also reflects the importance of farmer's attitude on adoption decision (Fernadez-Cornejo et al., 1994). As expected, prior knowledge of Bt technology is positively associated with adoption of Bt hybrid

Finally, the positive significance of ρ indicates a high degree of positive correlation in the disturbance terms between the two decisions and justifies the use of bivariate probit which provides efficient estimates. The pattern of current adoption behavior of hybrid *brinjal* and expected adoption behavior of Bt hybrid, for hybrid eggplant farmers is presented in Fig. 3, which suggests a positive correlation between the two. The conditional probability of adopting Bt hybrid, given that the farmer already adopted hybrid *brinjal* is very high at 85%. The marginal effects of significant variables in table 3 are presented in the first part of table 4.

The estimates from bivariate probit model reported in Table 3 were used in estimating the proportion of area under Bt hybrid eggplant, given the decision to adopt Bt hybrid seeds. Even though, the objective was to estimate equations (11) and (15) separately to have a comparative analysis of area allocation for farmers coming under sub-cells S_4 and S_2 respectively, the number of observations corresponding to the sub-cell S_2 is less than 30, and thus could not get meaningful estimates for equation (15). This result is revealing in itself as it suggests that the non-adoption of hybrid constrains the adoption of Bt hybrid substantially. Table 5 presents the OLS estimates of proportion of area under Bt hybrid brinjal for the sub-cell S_4. It can be noted from Table 5 that most of the coefficients of the exogenous variables have a priori expected signs. The major exception here is the negative sign of area under *brinjal*, which actually nets a positive effect when the impact of area through square of area, λ_{41}, and λ_{42} are included in the calculation. Among the other regressors, credit, yield, λ_{41} and district dummies are significant to at least 10 % level. Farmers getting higher yield and farmers availing credit will allocate less proportion of area under Bt technology. The joint significance of λ_{41} and λ_{42} at 22% level, justifies the use of two stage estimation procedure employed for the analysis. Negative signs of district dummies may be due to the extraneous effects associated with the allocation of area under Bt technology.

As stated previously, analysis of discrete and continuous adoption decision on Bt OPV was also done. Table 6 reports the univariate and bivariate probit estimates on decision to adopt hybrid and Bt OPV brinjal. It can be noted from the table that the variables OPV, District 1(Jalgaon), and District 3(Ahamad Nagar) influence the decision to adopt Bt OPV in the direction opposite to that of Bt hybrid adoption, which suggests a potential for segmented market for Bt seeds. This result supports the argument for the development of Bt OPV by public institutes, which provide many options for farmers to choose from. Finally, the negative significance of correlation coefficient (ρ) in Table 6 implies that the decisions to adopt hybrid and Bt OPV eggplant are negatively correlated. Taken together, the results in Table 3 and Table 6 suggest that hybrid growers of eggplant are having higher probability to adopt Bt hybrid, while OPV eggplant farmers prefer Bt OPV. The marginal effects of the significant variables in the model are reported in the second part of the Table 4.

The estimates from bivariate probit model on adoption decision of Bt OPV eggplant, reported in Table 6 were used in estimating the proportion of area under Bt OPV eggplant, given the decision to adopt Bt OPV seeds. Table 7 reports the estimates from regression on expected allocation of area under Bt OPV for sub-cells S_4 and S_2. The dummy variable District 3(Ahmad Nagar) was dropped from the analysis, as all the farmers surveyed in the district are cultivating hybrid eggplant. The joint significance of λ_{21} and λ_{22} at 11 % level, justifies the use of two stage estimation procedure employed here.

VI .Conclusion

Hybrid seeds of eggplant were introduced during the 1980s in India, and according to the latest information available, Genetically Modified seeds (Bt seeds) of eggplant are expected to enter the Indian seed market by next year. In this paper we use a direct revelation technique based on random utility model to conduct an *ex ante* analysis of adoption of Bt eggplant in India. The importance of the study is that, information from the current adoption behavior of farmers towards hybrid eggplant is incorporated in the *ex ante* assessment of probability of adoption of Bt eggplant. A bivariate probit model which allows for correlation among dichotomous decisions is used to model the expected adoption of Bt eggplant as a function of household, farm, and contextual characteristics. Estimations are done separately for adoption decisions on Bt hybrid and Bt Open Pollinated Variety (OPV) eggplant, as introduction of Bt OPV seeds might take longer time than that of Bt hybrid seeds. Models that predict the acreage allotted, given the decision to adopt Bt technology, are also estimated. Results from this study can be used to assess the socio-economic impact of the introduction of Bt Eggplant in India.

According to the study, farm and contextual characteristics of farmers cultivating hybrid and OPV eggplant are different. The study indicates a positive correlation between past adoption of hybrid and expected adoption of Bt hybrid, while a negative correlation between past adoption of hybrid and expected adoption of Bt OPV. The study suggests that farm and contextual characteristics significantly influence the likelihood of adopting Bt technology. These results presented here suggest a potential for segmented markets for Bt eggplant seeds: Bt hybrids and Bt OPVs. Development of segmented markets for Bt eggplant, meeting the requirements of OPV and hybrid eggplant farmers will address the issues associated with poor access to technology by small farmers in India. But the issues like, how many OPVs to be transformed to Genetically Modified eggplant to meet the highly diverse demand of OPV farmers' and the equity issues associated with it, and economic viability of public investments in research and development of Bt OPV are the issues to be addressed in the future studies.

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Table 1: Classification of Surveyed Farmers

Category	**Number**	**Percent of Brinjal Farmers**	**Percentage of All Farmers**
Only hybrid	142	**57.03**	48.6
Only OPV	93	**37.35**	32.06
Both hybrid and OPV	14	**5.6**	4.8
Non brinjal	41		14.14
Total	290		

Table 2: Definition of the Explanatory Variables

Variable	**Description**	**Adopters of Hybrid Mean(S.D)**	**Non Adopters Mean(S.D)**
Area eggplant	Area under Brinjal(acres)	1.19(1.24)**	.48(.54)
Area square	Square of area under brinjal(acres)	2.95(8.27)**	.52(1.07)
Total land	Total land holding by farmer (Acres)	10.61(10.27)**	8.29(6.22)
Distance	Distance to the product market (km)	76.26(91.69)**	48.78(86.76)
OPV	1-if OPV is grown commercially in the village	.19(.39)	.95(.98)**
Years	Years of growing brinjal by the household	7.78(4.41)	8.85 (9.12)
Family size	Number people in the household	7.26(4.98)*	6.40(3.41)
Age	Age of the head of the family	44.37(11.64)	48.34(13.33)**
Irrigation	Number of irrigations per season	28.71(24.97)**	16.76(11.74)
Expenses ESFB	Expenditure of chemicals for controlling ESFB(Rs)	9307.34** (9970.82)	2098.01(2154.02)
District 1	Jalgaon(1/0)	.09(.29)	.45(.49)
District2	Nagpur(1/0)	.28(.45)	.31 (.47)
District3	Ahamad Nagar(1/0)	.39(.49)	.07 (.26)
District 4	Nanded(1/0)	.24(.43)	.16(.37)
Education	Education of the head of the family 1 –if secondary or higher level	.68(.47)	.66(.48)
Prop income	Proportion of agricultural income from brinjal(%)	30.06(20.94)**	16.09(17.75)
Access banks	1- if very good access to banks	.87(.34)**	.77(.42)
Bt heard	1- if prior knowledge about Bt	.57(.49)	.65(.48)
Info source(int)	1- if first heard about hybrid from an internal source	.48(.50)	.05(.23)
Credit	1- if farmer borrowed money for brinjal cultivation	.08(.27)	.14(.35)
Crop Intensity	Number of crops/total land holding	.55(.43)	.64(.47)
Yield	Yield(quintal/acre)	75.14(39.69)**	51.13(27.90)
Price	Price of eggplant(Rs/Kg)	6.77(2.39)	7.00(2.70)

Table 3: Probit Estimates of Decision Equations (for Bt Hybrid)

Variables	**Simple Probit**		**Bivariate Probit**	
DV***	**Hybrid**	**Bt Hybrid**	**Hybrid (Y_1)**	**Bt Hybrid(Y_2)**
OPV	-2.15(.42)**	-.218(.231)	-1.859(.421)**	-.229(.241)
Area eggplant	1.66(.57)**	.294(.597)	1.957(.578)**	.502(.540)
Area square	-.250(.079)**	.022(.159)	-.271(.078)**	-.025(.129)
Total land	.036(.029)	.031(.022)	.0144(.027)	.042(.023)*
Family size	.054(.043)	.013(.032)	.056(.042)	.002(.034)
Age	-.027(.014)	-.011(.009)	-.022(.014)	-.011(.009)
Access banks	.092(.41)	.656(.283)**	.459(.405)	.61(.283)**
Distance	-.009(.003)**	.0005(.002)	-.010(.003)**	.0004(.002)
Years	-.079(.025)**	-.039(.016)**	-.078(.024)**	-.055(.018)**
Credit		-.837(.384)**		-.610(.367)*
Info source (int)	1.074(.470)**		.848(.460)*	
Education	.080(.391)	-.396(.3000)	.113(.369)	-.364(.288)
Crop intensity	-.263(.359)	.657(.271)**	-.347(.346)	.635(.278)**
Irrigation	.029(.014)**	.007(.011)	.027(.013)**	.017(.012)
District1	-.552(.439)	-.243(.333)	-.543(.441)	-.138(.343)
District 2	.140(.429)	.855(.384)**	-.120(.398)	.917(.387)
District 3	dropped	1.988(.732)**	8.444(1.084)**	2.09(.685)**
Bt heard		.676(.387)*		.674(.355)*
Expenses ESFB		.0002(.0000)**		.0001(.0000)**
Prop income		-.0007(.006)		-.003(.006)
Constant	1.562(.990)	-1.399(.78)*	1.037(.981)	-1.316(.830)
Rho(ρ)			.608(.151)**	

Note: *** Dependent Variable
** indicates significant at 5% level
*significant at 10% level
(Standard Errors are given in parenthesis)

Table 4: Marginal Effects of Significant Variables from Bivariate Probit Models on Adoption of Bt Eggplant

Variables	Bt Hybrid		Bt OPV	
	$P(Y_1=1,Y_2=1)$	**$P(Y_1=0,Y_2=1)$**	**$P(Y_1=1,Y_2=1)$**	**$P(Y_1=0,Y_2=1)$**
OPV	-.05(.05)	.008(.005)	.06(.03)	.008(.006)
Area brinjal	.10(.10)	-.008(.005)	.07(.04)	-.007(.005)
Area square	-.006(.02)	.002(.0008)	-.016(.008)	.0008(.0006)
Total land	.008(.004)	.00001(.0001)		
Family size			-.002(.002)	-.0003(.0003)
Age			-.001(.0007)	.00009(.00008)
Distance market			-.00006(.0002)	.00004(.00003)
Years	-.01(.004)	.0003(.0002)	-.0009(.0015)	.0004(.0002)
Credit	-.14(.10)	-.0009(.0007)		
Crop Intensity	.11(.06)	.003(.002)		
Irrigation	.003(.002)	-.00009(.00008)	-.0008(.0008)	-.0001(.00008)
District1	-.03(.07)	.004(.006)	.067(.046)	.004(.006)
District 2	.13(.05)	.003(.004)	-.021(.021)	.0004(.002)
District 3	.40(.07)	-.172(.057)	-.298(.075)	-.215(.063)
Heard Bt	.13(.08)	.001(.0009)		
Expenses ESFB	.00002(.00001)	2.05e-07(.0000)		

Note: Standard errors are reported in the parentheses

Table 5: OLS Regression on Proportion of Acres Enrolled for Bt Hybrid (N=139)

Variable	**Coefficients (S.E)**
Total land	.005(.003)
Area	-.034(.046)
Area square	.002(.006)
Family size	.0002(.004)
Age	-.00006(.002)
Access banks	.024(.059)
Distance	-4.28e-06(.0003)
Years	.005(.006)
Credit	-.115(.065)*
Expenses FSB	5.80e-07(1.77e-06)
Prop Income	.001(.001)
Education	-.017(.052)
Yield	-.001(.0007)*
Crop Intensity	.108(.071)
Irrigation	.0003(.0006)
District 1	-.262(.114)**
District 2	-.347(.081)**
District 3	-.441(.119)**
Heard	.064(.058)
λ_{41}	-.158(.095)*
λ_{42}	.065(.151)
Constant	.637(.167)**
R^2 =0.50	

Note: ** indicates significant at 5% level
* Significant at 10% level

Table 6.Probit Estimates of Decision Equations (for Bt OPV)

Variables	Simple Probit		Bivariate probit	
	Hybrid	**Bt OPV**	**Hybrid (Y_1)**	**Bt OPV (Y_2)**
OPV	-2.15(.42)**	.951(.262)**	-2.321(.427)**	.931(.270)**
Area eggplant	1.66(.57)**	.711(.526)	2.343(.630)**	.793(.531)
Area square	.250(.079)**	-.165(.108)	-.326(.086)**	-.195(.109)*
Total land	.036(.029)	.008(.017)	.003(.029)	.005(.017)
Family size	.054(.043)	-.041(.027)	.074(.041)*	-.032(.028)
Age	-.027(.014)**	-.012(.009)	-.034(.014)**	-.013(.009)
Access banks	.092(.41)	-.204(.287)	.081(.436)	-.224(.281)
Distance	-.009(.003)**	-.0003(.002)	-.011(.003)**	-.0003(.002)
Years	-.079(.025)**	-.008(.018)	-.082(.024)**	-.008(.019)
Credit		-.583(.334)*		-.658(.329)**
Info source (int)	1.074(.470)**		1.285(.478)**	
Education	.080(.391)	-.301(.259)	.303(.387)	-.331(.259)
Crop intensity	-.263(.359)	.278(.287)	-.412(.359)	.289(.287)
Irrigation	.029(.014)**	-.005(.010)	.030(.014)**	-.012(.011)
District1	-.552(.439)	.679(.332)**	-.537(.409)	.674(.336)**
District 2	.140(.429)	-.282(.341)	-.234(.404)	-.299(.333)
District 3	dropped	dropped	8.632(1.048)	-7.233(.486)**
Bt heard		-.090(.393)		-.041(.368)
Expenses ESFB		-4.70e-6(.0000)		
Prop income		-.015(.007)		
Constant	1.562(.990)	.884(.766)	1.873(1.009)	.888(.769)
Rho(ρ)			-.613(.161)**	

Note: ** indicates significant at 5% level
 * significant at 10% level

Table 7.OLS Regression on Proportion of Acres Enrolled for Bt OPV

Variables	Sub-cell S_4	Sub-cell S_2
Area eggplant	-.492(.712)	-.009(.132)
Area square	.087(.213)	.004(.042)
Total land	-.006(.011)	-.003(.002)
Family size	-.013(.013)	.004(.004)
Age	.0004(.006)	.001(.002)
Access banks	-.096(.166)	.030(.041)
Distance	.002(.005)	-.00007(.0003)
Years	.024(.017)	-.0001(.002)
Yield	.004(.001)	-.0003(.0004)
Credit	.103(.376)	.079(.068)
Education	.405(.194)*	.045(.044)
Crop intensity	-.029(.184)	-.016(.021)
Irrigation	.006(.007)	.001(.002)
District1	.357(.202)*	-.027(.056)
District 2	.468(.268)*	.110(.064)*
District 3	dropped	dropped
Bt heard	.290(.208)	.069(.044)
Expenses ESFB	2.45e-06(6.45e-06)	-9.85e-07(9.45e-06)
Prop income	.0009(.005)	.001(.001)
λ_{41}	-.145(.127)	
λ_{42}	-.274(.331)	
λ_{21}		.054(.107)
λ_{22}		-.273(.168)*
Constant	-.023(.413)	.186(.097)*
R^2	.77	.32
Observations	32	70

Note: ** indicates significant at 5% level
* significant at 10% level

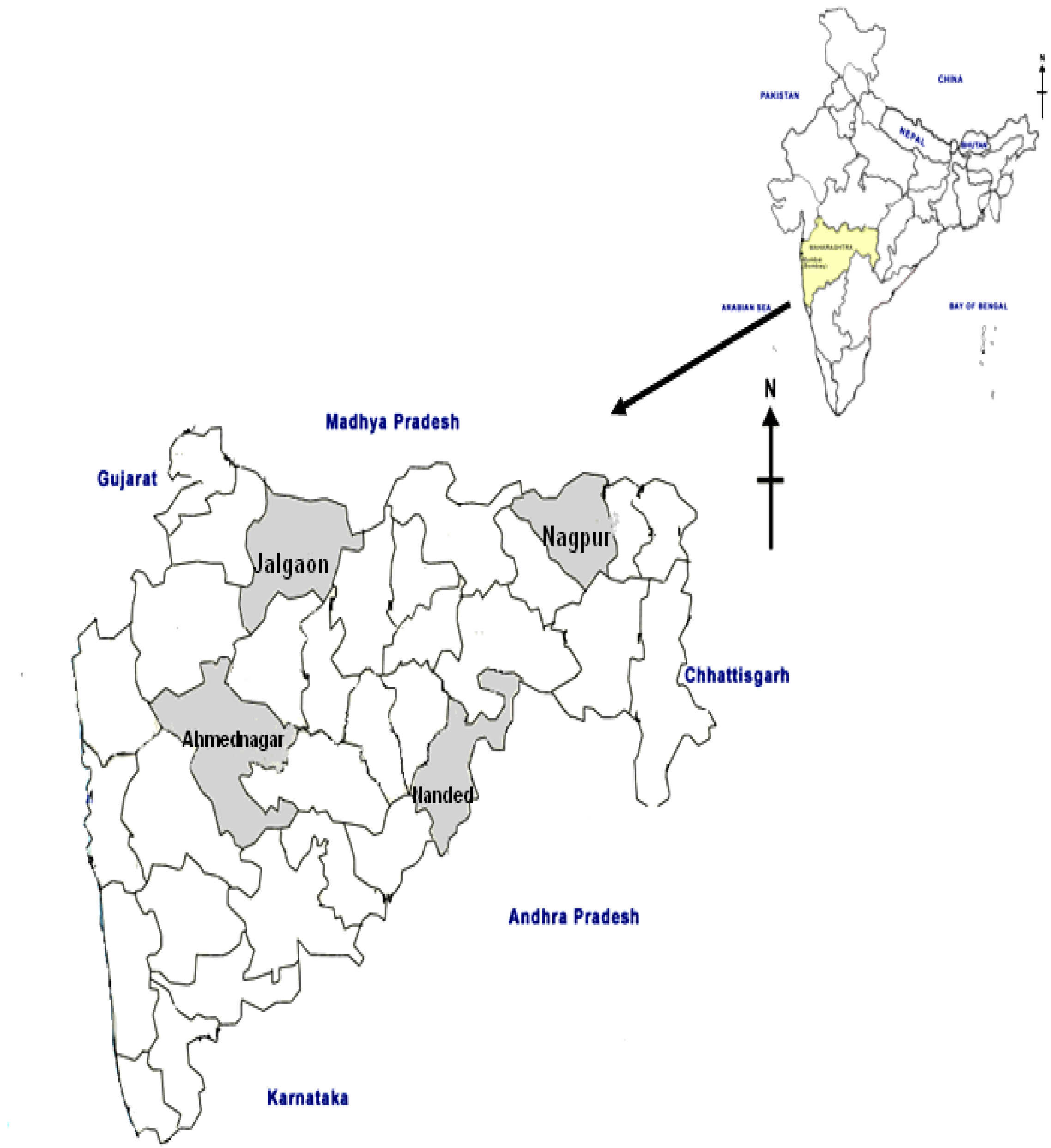

Fig.1 Map of the Study Area

Fig. 2 Size-Wise Distribution of Surveyed *Brinjal* Farmers

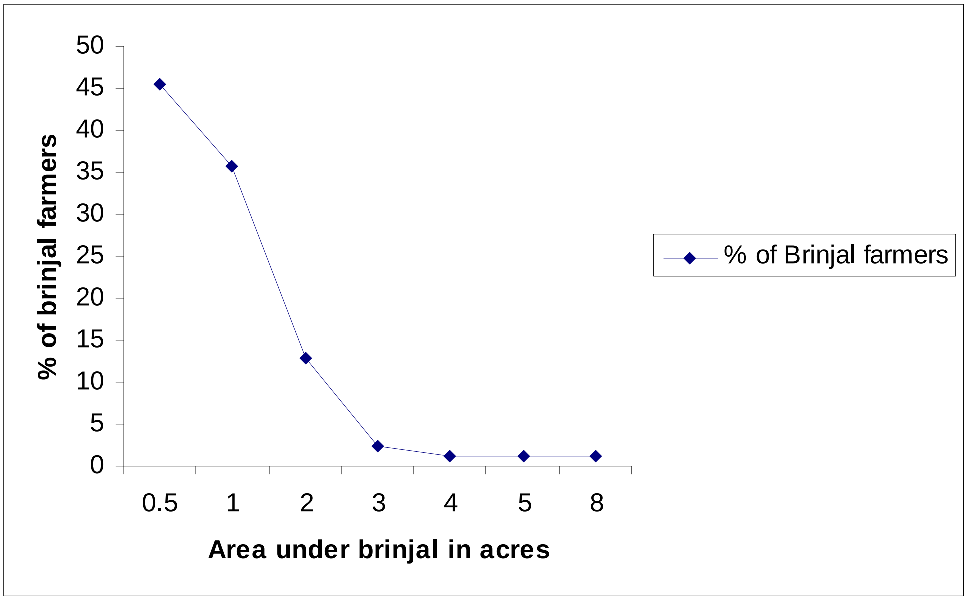

Fig 3.Size-Wise Distribution of Hybrid Eggplant Farmers