Determinants of Crop Choices by Bangladeshi Farmers: A Bivariate Probit Analysis

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ABSTRACT

Using a bivariate probit model, the study jointly determines the factors underlying the probability of Bangladeshi farmers adopting a diversified cropping system and/or modern rice technology. Results reveal that the availability of irrigation is the single most important determinant of the decision to adopt modern rice technology, and adoption is higher among the tenant farmers. The exact opposite is true for the likelihood of adopting a diversified cropping system, which is significantly higher in areas with no irrigation as well as among the owner- operators. Furthermore, the diversified cropping system has a significantly higher rate of adoption in regions with developed infrastructure. Farmers' education, farming experience, farm asset ownership, and non-agricultural income all positively influence crop diversification. Also, small farmers are more likely to adopt a diversified cropping system. Significant regional variation exists in the level of crop diversification as well. The decision to adopt a diversified cropping system and/or modern rice technology is significantly correlated, implying that a univariate analysis of such decision is biased. Crop diversification can be promoted by investing in farmers' education as well as rural infrastructure development. Also, land reform policies focusing on delegating land ownership to landless and marginal farmers, and tenurial reforms are noteworthy.

INTRODUCTION

The economy of Bangladesh is largely dependent on agriculture. Although rice production dominates the farming system of Bangladesh, accounting for 70% of gross cropped area (Bangladesh Bureau of Statistics [BBS] 2001), several other crops are also grown in conjunction with rice in order to fulfill a dual role of meeting subsistence as well as cash needs. Since the beginning of the 1960s, Bangladesh has pursued a policy of rapid technological progress in agriculture, leading to the diffusion of a rice-based Green-Revolution technology package. As a result, farmers have concentrated on producing modern varieties of rice all year round covering three production seasons – namely, *Aus* (pre-monsoon), *Aman* (monsoon) and *Boro* (dry winter) – particularly in areas that are endowed with supplemental irrigation facilities. This has raised the concern that the loss of crop diversity would consequently lead to an unsustainable agricultural system. For example, Husain et al. (2001) noted that "the intensive monoculture of rice led to a displacement of land under low productive non-rice crops such as pulses, oilseeds, spices and vegetables, leading to erosion of crop diversity, thereby, endangering sustainability of crop-based agricultural production system". Mahmud et al. (1994) observed that the area planted to non-cereal crops "has continuously fallen since late 1970s, mainly due to the expansion of irrigation facilities, which led to fierce competition for land between modern *Boro* season (dry winter) rice and non-cereals". However, an analysis of the level of crop diversification between the Agricultural Censuses of 1960 and 1996 reveals that the level of crop diversity has actually increased by 4.5 percent over a 36-year period (BBS 1999; Ministry of Food and Agriculture [MOFA] 1962). The Herfindahl index of crop diversification is computed at 0.59 in 1960 and 0.54 in 1996.

There is an apparent paradox in the reduced cultivation of many non-cereal crops (e.g., potatoes, vegetables, onions, and cotton) since they yield more profits (both in economic and financial terms) than modern rice cultivation; the former has been mainly attributed to high risk as well as the incompatibility of the existing irrigation system to produce non-cereals in conjunction with rice (Mahmud et al. 1994). However, it has been increasingly recognized that, under non-irrigated or semi-irrigated conditions, better farming practices and varietal improvements in non-cereal crops would be more profitable and could lead to crop diversification as a successful strategy for the future growth and sustainability of Bangladesh agriculture (MoA 1989; Mahmud et al. 1994; PC 1998). The Fifth Five-Year Plan (1997–2002) had set specific objectives to attain self-sufficiency in foodgrain production along with increased production of other nutritional crops, as well as encourage the export of vegetables and fruits, keeping in mind domestic production and need (PC 1998). The Plan also earmarked Tk 1,900 million (US$ 41.8 million) – representing around 8.9 percent of total agricultural allocation – to promote crop diversification. Such an emphasis at the policy level points towards the importance of identifying the determinants of farmers' crop choice decisions, so that informed judgment can be made on the suitability of setting crop diversification as a desired strategy for sustaining agriculture in Bangladesh.

Given this backdrop, the present study aims to determine the underlying socio-economic factors influencing the decision of farmers in Bangladesh to adopt a diversified cropping system and/or modern rice technology. We use a bivariate probit model which has the advantage of taking into account the correlation between the error terms of the two equations, i.e., the diversified crop adoption and the modern rice adoption models.

The rest of the paper is divided into five sections. Section 2 provides the methodology and includes a description of the data source and the bivariate probit model. Section 3 presents the empirical model specification. Section 4 discusses the results. Finally, Section 5 concludes and draws the policy implications.

METHODOLOGY

Data and the Study Area

The study is based on farm-level cross-section data for crop year 1996 collected from three agroecological regions of Bangladesh. The survey was conducted from February to April 1997. The selected regions are Jamalpur (representing wet agroecology), Jessore (representing dry agroecology), and Comilla (representing both wet agroecology and an agriculturally developed area). Multistage random sampling technique is employed to locate the districts, then the *thana* (subdistricts), the villages in each of the three subdistricts, and finally the sample households. A total of 406 households from 21 villages (broken down into 175 households from eight villages of Jamalpur Sadar *thana*, 105 households from six villages of Manirampur *thana,* and 126 households from seven villages of Matlab *thana*) form the sample for the study. Detailed crop input-output data at the plot level for individual farm households are collected for ten crop groups[1]. The data set also includes information on the level of infrastructural development in the study villages.

The Theoretical Framework: Bivariate Probit Model

Several studies have analyzed the determinants of adopting modern/improved technologies (including HYVs of rice, wheat and/or maize) by farmers in Bangladesh and elsewhere. These are largely univariate probit or Tobit regressions of technology adoption on variables representing the socioeconomic circumstances of farmers (e.g., Hossain 1989; Ahmed and Hossain 1990; Shiyani et al. 2002; Floyd et al. 2003; and Ransom et al. 2003). The implicit theoretical underpinning of such modelling is the assumption of utility maximization by rational farmers, which is described below.

We denote the adoption of modern rice monoculture as *mv* and a diversified cropping system as *dv*, where $p = 1$ for adoption and $p = 0$ for non-adoption. The underlying utility function which ranks the preference of the i^{th} farmer is assumed to be a function of farmer- as well as farm-specific characteristics, Z (e.g., education, farm size, land ownership, infrastructure, irrigation, etc.) and an error term with zero mean:

$$U_{il}(Z) = \beta_l Z_i + \varepsilon_{il} \text{ for adoption, and}$$
$$U_{i0}(Z) = \beta_0 Z_i + \varepsilon_{i0} \text{ for non-adoption.}$$

Since the utility derived is random, the *i*th farmer will adopt an agricultural system if and only if the utility derived from adoption is higher than non-adoption, i.e., $U_{i1} > U_{i0}$. Thus, the probability of adoption of the *i*th farmer is given by (Nkamleu and Adesina 2000):

$$p(1) = p\,(U_{il} > U_{i0})$$
$$p(1) = p\,(\beta_l Z_i + \varepsilon_{il} > \beta_0 Z_i + \varepsilon_{i0})$$
$$p(1) = p\,(\varepsilon_{i0} - \varepsilon_{il}) < \beta_l Z_i - \beta_0 Z_i\,)$$
$$p(1) = p\,(\varepsilon_i < \beta Z_i)$$
$$p(1) = \Phi\,(\beta Z_i)$$

where Φ is the cumulative distribution function for ε. The functional form of Φ depends on the assumption made for the error term ε, which is assumed to be normally distributed in a probit model. Thus for the *i*th farmer, the probability of the adoption of a diversified cropping system and modern rice technology, respectively, is given by:

$$\Phi_{dv}(\beta Z_i) = \int_{-\infty}^{\beta Z_i} \frac{1}{\sqrt{2\pi}} \exp\left(\frac{-t^2}{2}\right) dt \qquad (1)$$

$$\Phi_{mv}(\beta Z_i) = \int_{-\infty}^{\beta Z_i} \frac{1}{\sqrt{2\pi}} \exp\left(\frac{-t^2}{2}\right) dt \qquad (2)$$

The two equations can each be estimated consistently with the single-equation probit method. However, such a commonly used approach is inefficient because it ignores the correlation between the error terms ε_{dv} and ε_{mv} of the underlying stochastic utility function of a diversified cropping system and modern rice monoculture, respectively (Greene 2003). We apply the bivariate probit model in order to circumvent this limitation. The bivariate probit model is based on the joint distribution of the two normally distributed variables and is specified as (Greene 2003):

$$f(dv, mv) = \frac{1}{2\pi\sigma_{dv}\sigma_{mv}\sqrt{1-\rho^2}}\, e^{-\left((\varepsilon_{dv}^2 + \varepsilon_{mv}^2 - 2\rho\varepsilon_{dv}\varepsilon_{mv})/(2(1-\rho^2))\right)}$$

$$\varepsilon_{dv} = \frac{dv - \mu_{dv}}{\sigma_{dv}} \text{ and } \varepsilon_{mv} = \frac{mv - \mu_{mv}}{\sigma_{mv}} \qquad (3)$$

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[1] The crop groups are: 1) traditional rice varieties (Aus, Aman, and Boro seasons); 2) modern/high yielding rice varieties (Aus, Aman, and Boro seasons); 3) modern/high yielding wheat varieties; 4) jutes; 5) potatoes; 6)pulses (include lentil, mungbean, and gram); 7) spices (include onion, garlic, chilly, ginger, and turmeric); 8) oilseeds (include sesame, mustard, and groundnut); 9) vegetables (include eggplant, cauliflower, cabbage, arum, beans, gourd, radish, and leafy vegetables); and 10) cotton.

where ρ is the correlation between *dv* and *mv*. The covariance is $\sigma_{dv,mv} = \rho\sigma_{dv}\sigma_{mv}$; while μ_{dv}, μ_{mv}, σ_{dv} and σ_{dv} are the means and standard deviations of the marginal distributions of *dv* and *mv*, respectively. The distributions are independent if and only if $\rho = 0$. The full maximum likelihood estimation procedure is utilized using the software program NLOGIT-4 (Economic Software, Inc. [ESI] 2007).

EMPIRICAL MODEL

A bivariate probit model is developed to empirically investigate the socioeconomic factors underlying the decision to adopt a diversified cropping system and/or modern rice technology. The dependent variable is whether the farmer adopts a diversified cropping system and/or modern rice technology. For a diversified cropping system, represented by *dv*, the variable takes the value 1 if the farmer has grown any of the range of non-rice crops (see note in Table 1) in the three growing seasons covering one crop year, and 0 otherwise. Similarly for modern rice monoculture, represented by *mv*, the variable takes the value 1 if the farmer has grown modern rice in any or all of the three growing seasons, and 0 otherwise. In other words, in a bivariate probit model, four possibilities are incorporated. These are: (i) the non-adoption of both cropping systems ($dv = 0$, $mv = 0$); (ii) the adoption of modern rice technology only ($dv = 0$, $mv = 1$); (iii) the adoption of a diversified cropping system only ($dv = 1$, $mv = 0$); and (iv) the adoption of both cropping systems ($dv = 1$, $mv = 1$).

The choice of variables representing the socioeconomic circumstances of the farmer is based on the existing literature of technology adoption which offers similar justifications. The socioeconomic variables selected to explain the adoption decisions are: amount of land owned, value of farm capital assets, proportion of area under irrigation, proportion of land rented-in, education of the farmer, farming experience, family size, extension contact in the past one year, share of non-agricultural income in total income, and index of underdevelopment of infrastructure[2].

Access to modern irrigation facilities is an important prerequisite for growing modern rice varieties, particularly, for the HYV *Boro* rice grown in the dry season. Lack of access to modern irrigation facilities has been identified as one of the principal reasons for the stagnation in the expansion of modern rice which currently accounts for a little over 50 percent of total rice area (Rahman and Thapa 1999; Mahmud et al. 1994).

The use of the farmer's education level as explanatory variable in adoption studies is fairly common (e.g., Nkamleu and Adesina 2000; Adesina and Baidu-Forson 1995). The education variable is used as a surrogate for a number of factors. At the technical level, the access to information as well as the capacity to understand the technical aspects and profitability related to different crops may influence crop production decisions. The justification for including farming experience is straightforward. Experienced farmers are more likely to be open to choices regarding crops, be it modern rice or non-rice crops.

Agricultural extension can be singled out as one of the important sources of information dissemination directly relevant to agricultural production practices, particularly in nations like Bangladesh where farmers have very limited access to information. This is reinforced by the

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[2] The index of infrastructure was constructed using the cost of access approach. The index consists of a total of 13 elements, namely: (1) primary market, (2) secondary market, (3) storage facility, (4) rice mill, (5) paved road, (6) bus stop, (7) bank, (8) union office, (9) agricultural extension office, (10) high school, (11) college, (12) thana (sub-district) headquarter, and (13) post office. A high index value refers to a highly underdeveloped infrastructure. [For details of the construction procedure, see Ahmed and Hossain (1990).]

fact that many studies find a significant influence of extension education on the adoption of land-improving technologies (e.g., Adesina and Zinnah 1993). Therefore, this variable is incorporated to account for its influence on adoption decisions.

According to the Chayanovian theory of the peasant economy, higher subsistence pressure increases the tendency to adopt new technology and this has been found to be consistent with the Bangladesh case (Hossain et al. 1990; Hossain 1989). The subsistence pressure variable, measured by family size per household, is incorporated to account for its influence on crop choices.

In Bangladesh, land ownership serves as a surrogate for a large number of factors as it is a major source of wealth and influences decision to choose crops. Also, the impact of tenancy on the extent of modern rice technology adoption is varied (Hossain et al. 1990). Hence, the amount of land owned (to represent wealth) and the proportion of land rented-in (to represent tenurial status) are incorporated to test their independent influence on decisions regarding crop choices.

The percentage of income earned off-farm is included to reflect the relative importance of non-agricultural work in these farm households. It may also reflect the farmers' increased ability to meet operational costs, particularly when choosing high-value cash crops.

Infrastructure affects agricultural production indirectly through prices, diffusion of technology, and use of inputs, and has a profound impact on the incomes of the poor (Ahmed and Hossain 1990). The state of infrastructure implies improved access to markets and institutions as well as better access to information and hence may influence farmers' crop choices. This effect is captured by the index of underdevelopment of infrastructure. Regional dummy variables for Comilla and Jessore are included to examine whether the farmers' adoption decisions vary across regions. The influence of the remaining region Jamalpur is subsumed in the intercept term.

RESULTS

Table 1 presents the existing cropping practice and extent of crop diversification among the sampled households of each region. It is clear from the table that there are substantial variations among the regions with respect to each of the aspects considered. Although 51 percent of the total number of farmers have adopted the modern rice monoculture, a substantial 37 percent of total farmers adopted both the systems using modern rice and diversified cropping. The implication is that the choice to adopt a modern rice technology is not strictly independent from the decision to choose a diversified cropping system, and hence justifies our approach to use a bivariate model. In terms of area allocated to crops, the non-rice crops cover an estimated 19 percent of gross cropped area. In fact, farmers produce a wide range of crops in a cropping year. The mean number of crops grown is estimated at 3.6 with a maximum of 11 crops in a year. The lower panel of Table 1 presents the final measure of crop diversification using a Herfindahl index[3] which is based on the area allocated to a particular enterprise. The overall Herfindahl index of crop diversification is estimated at 0.60 which indicates that the cropping system is relatively diverse, particularly in Jessore region, where the level of modern rice technology adoption is lowest.

Summary statistics of the variables used in the bivariate probit analysis are presented in Table 2, classified by adoption category. The farm-specific variables provide a summary of the characteristics

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[3] The Herfindahl index is represented as: $DV = \sum_{i=1}^{n} P_i^2$ where P_i is the proportion of farm acreage involved in a particular enterprise. The value of the Herfindahl index ranges between 0 to 1, denoting 0 for perfect diversification, and 1 for perfect specialization.

Table 1. Extent of crop diversification among sampled farmers.

Variables	Comilla	Jessore	Jamalpur	All regions
Proportion of farmers:				
Non-adopter of diversified crop and modern rice (*dv* = 0 and *mv* = 0)	0.00	0.02	0.01	0.01
Only modern rice adopter (*dv* = 0 and *mv* = 1)	0.51	0.27	0.65	0.51
Only diverse crop adopter (*dv* = 1 and *mv* = 0)	0.16	0.22	0.01	0.11
Adopter of both diversified crop and modern rice (*dv* = 1 and *mv* = 1)	0.33	0.50	0.33	0.37
Proportion of gross cropped area under:				
Modern rice only	0.65	0.32	0.63	0.56
Diverse crops (excluding all types of rice)	0.22	0.37	0.07	0.19
Traditional rice only	0.13	0.31	0.30	0.25
Average number of crops grown in one year	3.34	4.19	3.35	3.57
Standard deviation	1.57	2.16	1.73	1.85
Maximum number of crops grown in one year	8.00	11.00	10.00	11.00
Crop diversification index				
Herfindahl index of crop diversification	0.69	0.46	0.63	0.60
Number of observations (farm households)	126	105	175	406

Note: Actual data were collected at plot level. The plot-level observations of all types of crops grown by these 406 farmers total 1,448. The breakdown of the number of observations is as follows: modern rice = 622 (Aus = 25, Aman = 150, and Boro = 447); traditional rice = 324 (Aus = 37, Aman = 266, and Boro = 21); and diverse crops = 502 (wheat = 103, jute = 92, potatoes = 59, pulses = 70, spices = 47, oilseeds = 71, vegetables = 44, and cotton = 16). Pulses in turn include lentil, mungbean, and gram. Spices include onion, garlic, chilly, ginger, and turmeric. Oilseeds include sesame, mustard, and groundnut. Vegetables include eggplant, cauliflower, cabbage, arum, beans, gourds, radish, and leafy vegetables.Higher index values of crop diversification indicate specialization (in this case, towards modern rice monoculture).

of these farms. The amount of land owned per farm is 0.65 ha which is lower than the actual area cultivated (0.98 ha) implying that farmers are renting-in land to increase operational size and/or farm intensively[4]. In fact, the cropping intensity of the sampled farmers is estimated at 173, which is very close to the national average of 174 (BBS 1999). The average level of education is less than four years; experience in farming is 26 years; average family size is six persons; 22 percent of income is derived off-farm; and only 13 percent of farmers have had contact with extension officers during the past year.

Table 2 also shows the distinct features of farms based on their adoption status. The F-test results show that, except for the farming experience variable, significant differences exist across farm adoption categories with respect to the socioeconomic circumstances of these farm households. For example, the amount of area cultivated and asset ownership are significantly higher among the adopters of both cropping systems ($dv = 1$, $mv = 1$). These farms also had significantly higher level of extension contacts over the past year. On the other hand, the adoption of modern rice monoculture only ($dv = 0$, $mv = 1$)

[4] The amount of land owned is significantly correlated to the amount of land actually cultivated ($r = 0.81$, $p < 0.01$). Therefore, we excluded the amount of land cultivated from the estimation because the amount of land owned has a more intuitive interpretation.

Table 2. Summary statistics of the variables.

Variables	Unit of measurement	All sample		Only modern rice adopters (dv=0, mv=1)	Only diverse crop adopters (dv=1,mv=0)	Adopters of both (dv=1,mv=1)	F-test[a] for differences across adopter categories
		Mean	Standard deviation	Mean	Mean	Mean	
Amount of land owned	Hectare	0.65	0.77	0.50	0.55	0.90	13.03***
Farm asset	Thousand taka	55.38	116.85	24.95	44.32	101.18	20.53***
Proportion of land under irrigation	Percent	0.62	0.30	0.68	0.34	0.60	27.45***
Proportion of rented-in land	Percent	0.20	0.29	0.24	0.12	0.17	4.76***
Education of farmer	Completed years of schooling	3.74	4.26	2.84	3.89	4.88	10.54***
Farming experience	Years	25.51	14.21	24.40	28.89	26.03	1.99
Family size	Persons per household	6.02	2.53	5.70	6.70	6.28	4.07**
Index of underdevelopment of infrastructure	Number	33.32	14.95	37.84	19.46	31.26	34.77***
Extension contact	Dummy (1 if had contact, 0 otherwise)	0.13	0.33	0.09	0.09	0.19	4.58**
Share of non-agricultural income	Percent	0.22	0.31	0.18	0.38	0.23	7.61***
Comilla	Dummy (1 if Comilla, 0 otherwise)	0.31	0.46	0.31	0.45	0.28	
Jessore	Dummy (1 if Jessore, 0 otherwise)	0.26	0.44	0.14	0.52	0.34	
Number of observations		406		206	44	152	

Note: ***significant at 1% level ($p<0.01$).
**significant at 5% level ($p<0.05$).
[a] =One-way ANOVA using the generalized linear model (GLM).

is higher in farms with higher access to irrigation, lowest level of land ownership, lowest level of average education, and farmers located in regions with underdeveloped infrastructure. Farmers who adopt a diversified cropping system only ($dv = 1$, $mv = 0$) have the lowest access to irrigation and the highest level of subsistence pressure. They are also mainly owner-operators (reflected by the lowest level of land rented-in) and are located in regions with developed infrastructure.

Results of the full information maximum likelihood estimation of the bivariate probit model are presented in Table 3. The key hypothesis that the 'correlation of the disturbance term between two equations *dv* and *mv* is zero $\{\rho(dv, mv) = 0\}$' is strongly rejected at the 1 percent level of significance, implying that the use of a bivariate model to determine crop choice decisions among farmers is justified.

Globally, two variables have a significant relation with the decision to adopt modern rice technology while a host of eight variables have a significant relationship with the adoption of a diversified cropping system. Availability of irrigation, as expected, is the single most important determinant of modern rice technology adoption. Also, the likelihood of modern rice technology adoption is higher among tenant farmers. The result corroborates the finding of Hossain et al. (1990) who note that access to irrigation is a major determinant of modern rice technology adoption, and the incidence of tenancy increases with the adoption of modern rice varieties, thereby resulting in a transfer of land from large to small landowners. The exact opposite is true in the case of those adopting a diversified cropping system. The likelihood of adoption of a diversified cropping system is significantly higher in areas with no irrigation, which corroborates the conclusions of Mahmud et al. (1994) and Morris et al. (1996). In fact, wheat provides the highest returns in non-irrigated zones and in areas that are unsuitable for *Boro* rice (Morris et al. 1996).

The likelihood of adopting a diversified cropping system is significantly higher in regions with developed infrastructure[5]. The influence of a developed infrastructure on the adoption of a diversified cropping system is obvious. For example, vegetables, which are highly perishable but provide significantly higher returns than any other crops (Rahman 1998), require to be marketed immediately after harvest. The prospect of doing so increases only in regions with developed infrastructure.

Furthermore, farm assets significantly and positively influence the decision to adopt a diversified cropping system. The farm asset variable represents the value of all tools and implements used directly for the agricultural production process, including the value of owned livestock resources. Therefore, farmers with higher level of farm assets are in a better position to grow various crops which may require different specialized tools. Also, non-rice crops are usually grown in small areas and at different times, where tillage operation by hired animal power services is uneconomic and infeasible. However, for farmers with their own supply of bullocks, such tillage operations can be carried out effectively as and when required.

Both the education level of the farmer, and the farming experience have a significant positive relationship to the decision to adopt a diversified cropping system, as expected. As mentioned earlier, the ability to process information increases with education as well as experience. Therefore, the educated and/or experienced farmers choose to adopt a diversified cropping system with or without modern rice perhaps in order to take advantage of all the benefits arising from making

[5] The index reflects the underdevelopment of infrastructure; therefore, a negative sign indicates a positive effect on the dependent variable.

Table 3. A bivariate probit analysis of the decision to adopt modern rice technology and/or a diversified cropping system.

Variables	Adoption of diversified cropping system		Adoption of modern rice technology	
	Coefficient	t-ratio	Coefficient	t-ratio
Constant|	0.186	0.41	0.421	0.38
Amount of land owned	-0.243	-1.62	0.386	1.47
Farm asset	0.009	6.58***	0.001	0.67
Proportion of land under irrigation	-1.074	-3.75***	1.224	3.07***
Proportion of rented-in land	-0.532	-1.76*	0.680	1.66*
Education of farmer	0.067	3.34***	-0.041	-1.26
Farming experience	0.011	1.97**	-0.014	-1.40
Family size	0.001	0.04	-0.045	-0.84
Index of underdevelopment of infrastructure	-0.018	-2.60***	0.031	1.59
Extension contact	0.054	0.21	0.427	0.93
Share of non-agricultural income	0.653	2.30**	-0.216	-0.57
Comilla	0.300	1.42	-0.293	-0.45
Jessore	0.406	1.72*	-0.681	-0.96
Model diagnostics				
Correlation between the error terms: $\rho(dv, mv)$	-0.587	-3.64***		
Log likelihood	-303.314			
Number of observations	406			

Note: *** = significant at 1 percent level ($p<0.01$).
** = significant at 5 percent level ($p<0.05$).
* = significant at 10 percent level ($p<0.10$).

such a choice, e.g., high returns for a particular crop, low overall resource cost, and/or spreading of scarce family labor evenly over a crop year.

It is interesting to find that small farmers as well as owner-operators are more likely to adopt a diversified cropping system as implied by the significant negative coefficients on the "amount of land owned" (a weak $p < 0.15$ in this case) and the "proportion of land rented-in" variables. The tenurial system in Bangladesh is largely based on arrangements related to rice production. In the most common tenurial arrangement practiced in Bangladesh, the landlord receives one-third of the crop output share (mostly rice). The incidence of input cost share by landlord varies across regions. In cases where such cost is shared (usually on a 50-50 basis), it is linked to the sharing of relatively scarce inputs, e.g., fertilizer, irrigation, and/or animal power hire costs (Rahman 1998). Therefore, the existing tenurial arrangement seems to work well when the tenant grows rice (as seen in modern rice adoption model), but perhaps has a discouraging effect when a diversified cropping system is adopted, because the amount to be received as output share cannot be clearly estimated a priori, and hence realized in full.

The non-agricultural income share significantly influences the probability to adopt a diversified cropping system. This is because a higher non-agricultural income share reflects greater liquidity which perhaps allows farmers to adopt a diversified cropping system that is characterized by varying operational costs at different points of time during the production cycle.

There is a sharp regional variation in the probability of adopting a diversified cropping system. The likelihood of adopting a diversified cropping system is higher in Jessore, which can also be readily seen from the estimated Herfindahl index of crop diversification presented in Table 1. Jessore is conventionally a diversified cropping region hampered by poor access to irrigation facilities.

The actual and predicted frequency of the adoption of modern rice monoculture and/or a diversified cropping system is presented in Table 4. As can be seen from Table 4, the predictability of modern rice monoculture is very strong and becomes weaker when the farmer adopts a combination of modern rice technology and a diversified cropping system.

The main advantage of the bivariate probit model is the explicit appearance of the joint probabilities and the ease with which marginal effects on these can be calculated (Christofides et al. 1997). Table 5 presents the total marginal effects[6] decomposed into direct and indirect effects of the explanatory variables on the probability of joint adoption of a diversified cropping system conditional on the adoption of modern rice technology {i.e., $E[dv|mv = 1,\boldsymbol{Z}_1,\boldsymbol{Z}_2]$}. The predicted joint probability of adopting a diversified cropping system conditional on modern rice technology adoption is estimated at 0.51. The total marginal effect is composed of a direct effect and an indirect effect. Consider, for example, the 'irrigation' variable. There is a direct effect produced by its presence in the first equation, (i.e., *dv*), but there is also an indirect effect produced by its presence in the second equation (i.e., *mv*). The total effect of irrigation is therefore, the sum of these two parts. Numerically, the strongest effect appears to be exerted by the irrigation variable which has a coefficient of -0.388. This variable, however, cannot change by a full unit because it is a proportion (Greene 2003). An increase of 1 percent of land area under irrigation reduces the probability of adopting a diversified cropping system by only -0.004, given that farmers have already adopted the modern rice variety (i.e., $mv = 1$). On the other hand, consider the effect of 'farmers' education'. A 1 percent increase in one year of completed schooling will increase the probability of adopting a diversified cropping system by +0.03, conditional on modern rice variety adoption; by far, the farmer's

Table 4. Actual and predicted frequency of adopting a diversified cropping system and/or modern rice technology.

		Modern rice technology		Total
		Non-adopter	Adopter	
Diversified cropping system	Non-adopter	4 (0)	206 (255)	210 (255)
	Adopter	44 (25)	152 (126)	196 (151)
	Total	48 (25)	358 (381)	406 (406)
Accuracy of joint prediction (%):				
Non-adopter of any	($dv = 0$ and $mv = 0$)			0.00
Only modern rice adopter	($dv = 0$ and $mv = 1$)			85.92
Only diversified crop adopter	($dv = 1$ and $mv = 0$)			34.09
Adopter of both diversified crop and modern rice	($dv = 1$ and $mv = 1$)			51.97

Note: Figures in parentheses are predicted frequencies.

[6] The marginal means in the model are the univariate probabilities that the two variables equal one. NLOGIT-4 analyzes the condition mean: $E[dv|mv=1,\boldsymbol{Z}_1,\boldsymbol{Z}_2]$= Prob[$dv$=1|$mv$=1,$\boldsymbol{Z}_1$,$\boldsymbol{Z}_2$,$\rho$]/Prob[$mv$=1|$\boldsymbol{Z}_1$] (ESI, 2007).

Table 5. Marginal effects of the variables on decision to adopt diversified cropping system conditional on the adoption of modern rice technology.

Variables	Total effect		Direct effect		Indirect effect	
	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
Amount of land owned	-0.083	-1.33	-0.100	-1.62	0.017	1.38
Farm asset	0.004	6.69***	0.004	6.63***	0.000	0.63
Proportion of land under irrigation	-0.388	-3.38***	-0.442	-3.70***	0.053	2.39**
Proportion of rented-in land	-0.189	-1.54	-0.219	-1.76*	0.030	1.18
Education of farmer	0.026	3.17***	0.027	3.33***	-0.002	-1.17
Farming experience	0.004	1.75*	0.005	1.97**	-0.001	-1.10
Family size	-0.001	-0.09	0.001	0.04	-0.002	-0.82
Index of underdevelopment of infrastructure	-0.006	-2.12**	-0.007	-2.58***	0.001	1.31
Extension contact	0.041	0.39	0.022	0.21	0.019	0.90
Share of non-agricultural income	0.259	2.24**	0.269	2.32**	-0.009	-0.52
Comilla	0.111	1.28	0.123	1.43	-0.013	-0.48
Jessore	0.137	1.43	0.167	1.72*	-0.030	-1.09
Dummy variables						
Extension contact	0.036	0.35				
Comilla	0.109	1.28				
Jessore	0.130	1.35				

Note: The total marginal effect is decomposed into a direct effect produced by the presence of the variable in the first equation (i.e., *dv*) and an indirect effect produced by the presence of the same variable in the second equation (i.e., *mv*), respectively. The total marginal effects are the partial derivatives of the explanatory variables on the probability of adopting a diversified cropping system conditional on the adoption of modern varieties: i.e., $E[dv|mv = 1, \mathbf{Z}_1, \mathbf{Z}_2]$ = $\text{Prob}[dv = 1|mv = 1, \mathbf{Z}_1, \mathbf{Z}_2, \rho]/\text{Prob}[mv = 1|\mathbf{Z}_1]$. The joint probability of adopting a diversified cropping system conditional on the adoption of modern rice monoculture is 0.51. In the lower panel of the table, the effects of the dummy variables are computed using $E\,[dv|mv = 1, d = 1] - E\,[dv|mv = 1, d = 0]$, where *d* is the dummy variable (ESI 2007).
*** = significant at 1 percent level ($p < 0.01$).
** = significant at 5 percent level ($p < 0.05$).
* = significant at 10 percent level ($p < 0.10$).

education manifests the largest effect compared to all other variables. This is because the variable with the second highest value of coefficient is 'the share of non-agricultural income', which is also a proportion. Therefore, the actual marginal effect of a 1 percent increase in the share of non-agricultural income in the household will increase the probability of adoption of a diversified cropping system by only +0.003.

CONCLUSIONS AND POLICY IMPLICATIONS

The aim of this study was to identify the determinants of crop choices by farmers in Bangladesh, using a bivariate probit model. Specifically, the probability of adopting a diversified cropping system and/or modern rice technology was investigated. The model diagnostic revealed that the choice of a bivariate approach was more appropriate than the univariate approach that was commonly used in the literature. Availability of irrigation was the single most important determinant of adopting modern rice technology, and adoption was higher among tenant farmers. On the other hand, the probability of adopting a diversified cropping system was significantly higher in developed regions as well as areas with no irrigation. Also, farmers' education, farming experience, farm asset as well as the share of non-agricultural income were all significantly related to the adoption of a diversified cropping system. The small farmers and owner-operators were more likely to adopt a diversified cropping system. Significant regional variation existed in the level of crop diversification. Based on the analysis of joint marginal probabilities in a bivariate probit model, we saw that 'farmers' education' exerted the strongest positive influence on raising the probability of adopting a diversified cropping system conditional on modern rice variety adoption. The actual influence of 'irrigation' in reducing the probability of adopting a diversified cropping system was small.

The key policy implication that emerges from this study is that crop diversification can be promoted significantly by investing in education targeted for the farming population as well as in rural infrastructural development. Investment in irrigation need not be ruled out because of its positive influence on the adoption of modern rice varieties, a staple crop in Bangladesh diet[7]. However, the investment in irrigation should be targeted towards small farmers characterized by poor land and asset endowments, low level of education, and those located in underdeveloped regions.

Promotion of crop diversification is likely to have a positive impact on agricultural sustainability as it is clear from the literature that the Green Revolution technology based on modern rice monoculture is unsustainable in the long run. The thrust at the planning level to promote crop diversification is a step in the right direction. Another significant factor influencing crop diversification decisions is the 'share of non-agricultural income' of the household, which in turn improves with the development of rural infrastructure. Ahmed and Hossain (1990) have concluded that infrastructure had profound impacts on the income of the poor in Bangladesh, raising their income by 33 percent (which included the doubling of wages and increase in income from business and industries by 17 percent), thereby reinforcing our argument to improve rural infrastructure. Furthermore, appropriate land reform policies that focus on delegating land ownership to landless and/or marginal farmers and improving the existing tenurial system, which is now biased towards favoring modern rice technology adoption, would boost the number of small farmers and owner-operators, who are the most likely adopters of a diversified cropping system.

[7] The total effect of a 1 percent increase in the 'irrigation' variable on the probability of adoption of modern rice varieties conditional on the adoption of a diversified cropping system $E[mv|dv=1,\mathbf{Z}_2,\mathbf{Z}_1]$= Prob[$dv$=1|$mv$=1,$\mathbf{Z}_1$,$\mathbf{Z}_2$,$\rho$]/Prob[$dv$=1|$\mathbf{Z}_2$] is estimated at +0.002.

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