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THE ECONOMIC DETERMINANTS OF CROP DIVERSITY ON FARMS IN RURAL BANGLADESH

SANZIDUR RAHMAN

The study examines the economic determinants of crop diversity using a survey of 406 farmers located in 21 villages in three agro-ecological regions of Bangladesh. The computed value of diversity indices of crop concentration (Herfindahl), richness (Margalef) and evenness (Shannon) confirm that farming system in Bangladesh is still relatively diverse despite four decades of thrust in the diffusion of a rice-based 'Green Revolution' technology. Results reveal that a host of price and non-price factors significantly influence farmers' decision to diversify. Likelihood of diversification increases with a fall in the prices of fertilizers, animal power services and modern rice and a rise in the price of cash crops. Crop diversification is positively influenced by farm size, livestock ownership, farming experience, education, membership in NGOs, regions with developed infrastructure and unavailability of irrigation. Also, diversification is higher among owner operators. Therefore, crop diversification can be promoted significantly by investing in rural infrastructure, farmers' education, and supporting NGOs working at the grassroots level. Price policies aimed at improving cash crop prices and reducing fertilizer and animal power prices will also promote diversification. In addition, land reform policies focusing on delegating land ownership to landless/marginal farmers and policies to improve the livestock sector in order to promote livestock ownership by individual farmers are also noteworthy.

Key words: Crop diversity, socio-economic factors, Tobit model, Bangladesh.

The economy of Bangladesh is largely dependent on agriculture. Although, rice production dominates the farming system of Bangladesh, accounting for 70% of the gross cropped area (BBS 2001), several other crops are also grown in conjunction with rice in order to fulfil a dual role of meeting subsistence as well as cash needs. Since the beginning of 1960s, Bangladesh has pursued a policy of rapid technological progress in agriculture leading to diffusion of a rice-based 'Green-Revolution' technology package. As a result, farmers concentrated on producing modern varieties of rice all year round covering three production seasons (*Aus* - pre-monsoon, *Aman* - monsoon and *Boro* - dry winter), particularly in areas that are endowed with supplemental irrigation facilities. This raised concern regarding loss of crop diversity, consequently leading to an unsustainable agricultural system. For example, Husain, Hossain and Janaiah (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 an erosion of crop diversity, thereby, endangering the sustainability of crop-based agricultural production system. Mahmud, Rahman and Zohir (1994) also noted that "the area under 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 rice and non-cereals". However, an analysis of the level of crop diversification between the two Agricultural Censuses of 1960 and 1996 reveals a different story.

Table 1 presents the cropped area, cropping intensity and the level of crop diversification between the Agricultural Censuses of 1960 and 1996, respectively. The former census just precedes the onset of Green Revolution while the latter census is the latest available to date, and is comprehensive in nature, scope and content. It is clear from table 1 that, although there were dramatic changes in the structure of the farms and rise in cropping intensity, the level of crop diversification changed only moderately over a 36-year period.

With a boom in population growth between the two censuses, the average operational size per farm shrunk dramatically. The large and medium farms gave way to small farms largely because of increase in the number of farms competing for a fixed amount of cultivable land. The decline in net cropped area by 12.7 percent is largely offset by a 26 percent rise in cropping intensity, thereby, leaving gross cropped area slightly positive (a 2.5 percent increase). An examination of the crop shares reveal that the share of cereals (rice, wheat and other minor cereals) increased by only 1.7 percent in 36 years. The main changes were in the composition of modern varieties of rice, which replaced the traditional varieties. Also, there was a five-fold increase in modern wheat area. The non-cereal crops used to account for 23.4 percent of the gross cropped area in 1960 and now accounts for 21.7 percent in 1996, a negligible decline of 1.4 percent in 36 years. However, there has been a shift in the composition of non-cereals over this period. The areas under pulses, cash crops and spices declined sharply, while areas under oilseeds and vegetables increased over this period. As a result, crop diversity in agriculture (as revealed by the computed Herfindahl index of crop concentration) declined only by 4.5 percent over a 36 year period, which can hardly be justified as a serious replacement of land area by rice monoculture. The Herfindahl index of crop concentration was computed at 0.59 in 1960 and 0.54 in 1996.

[Insert Table 1 here]

There is an apparent paradox in that many non-cereal crops (e.g., potatoes, vegetables, onions and cotton) are more profitable (both in economic and financial terms) than modern rice cultivation, which was mainly attributed to high risk as well as incompatibility of the existing irrigation system to produce non-cereals in conjunction with rice (Mahmud, Rahman and Zohir 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 will be more profitable and could lead to crop diversification as a successful strategy for the future growth and sustainability of Bangladeshi agriculture (Moa 1989; Mahmud, Rahman and Zohir 1994; PC 1998). The Fifth Five Year Plan (1997–2002) set specific objectives to attain self-sufficiency in foodgrain production along with increased production of other nutritional crops, as well as to encourage export of vegetables and fruits, while keeping in view the domestic needs (PC 1998). The Plan also earmarked Tk 1,900 million (US$ 41.8 million) accounting for 8.9 percent of the total agricultural allocation to promote crop diversification. Such an emphasis at the policy level points toward the importance of identifying the determinants of farmers' crop choice decisions, so that an informed judgment can be made about the suitability of crop diversification as a desired strategy for promoting agricultural growth in Bangladesh.

Given this backdrop, the present study is aimed at determining the underlying factors affecting crop diversity on farms in rural Bangladesh. We estimate a model of crop choice in a theoretical framework of the farm household model applying a micro-econometric approach.

Methodology

Theoretical Model

We develop a general model of farm production to examine the determinants of crop diversity. The farmer produces a vector Q of farm outputs using a vector of inputs X. The decision of choice, however, is constrained by a given production technology that allows combination of inputs (X) and an allocation of a fixed land area ($A = A^0$) among j number of crops, given the characteristics of the farm (Z). The total output of each farmer i is given by a stochastic quasi-concave production function:

$$Q_{ij} = f(X_{ijk} \ldots X_{ijk}, \varepsilon \mid A_i, Z_i) \qquad (1)$$

where ε is the stochastic variable indicating impacts of weather conditions or random noise. It is assumed that $f_{Xk}>0$ and $f_{XXk}<0$. Each set of area shares (α_j) among j crops sums to 1, $\sum_j^J \alpha_j = 1, j = 1,2,\ldots.J,$ which maps into the vector Q through physical input-output relationships. The choice of area shares implies the level of farm outputs. The profit of each farm i is given by:

$$\pi_i(Q,X,p,w \mid A_i,Z_i) = \sum_{j=1}^{J} p_j Q_{ij} - \sum_{k=1}^{K} w_j X_{ijk} \qquad (2)$$

where p is the vector of output prices and w is the vector of input prices.

The farmer is assumed to have a von Neuman-Morgenstern utility function, *U(W)* defined on wealth W with $U_W>0$ and $U_{WW}<0$. The wealth is represented by the sum of initial wealth (W_0) and the profit generated from farming (π). Therefore, the objective of each farm is to maximize expected utility as (Isik 2004):

$$EU(W_0 + \pi(Q,X,p,w \mid A_i,Z_i) \qquad (3)$$

where E is the expectation operator defined over ε. The choice variables in (3), the farm's input levels X_{ijk}, are characterized by the first-order conditions

$$\frac{\partial EU}{\partial X_{ijk}} = EU_w(p_j * f_{Mijk} - w_k) = 0 \qquad (4)$$

The second-order conditions are satisfied under risk aversion and a quasi-concave production function (Isik 2004). The optimal input mix is given by:

$$X_{ijk}^* = X_{ijk}^*(p_j, w_k, U \mid A_i, Z_i) \qquad (5)$$

And the optimal output mix, depending on (X_{ijk}^*) is defined as:

$$Q_{ij}^* = f(X_{ij1}^*, \ldots\ldots X_{ijk}^*) \mid A_i, Z_i) \qquad (6)$$

Factors Affecting Choice of Crops

To determine the factors affecting a farmer's choice of crops, we derive the equivalent wealth or income from the expected utility:

$$E_i = E(W_0 + \pi_i(Q,X,p,w \mid A_i,Z_i) \qquad (7)$$

This equivalent wealth or income in a single decision making period is composed of net farm earnings (profits) from crop production and initial wealth that is 'exogenous' to the crop choices (W_0), such as farm capital assets and livestock resources carried over from earlier period.

Under the assumption of perfect market, farm production decisions are made separately from consumption decisions and the household maximizes net farm earnings (profits) subject to the technology and expenditure constraints (Benin et al. 2004). Therefore, production decision of the farms, such as crop choices, are driven by net returns (profits), which are determined only by input and output prices, farm physical characteristics and socio-economic characteristics of the farm household (Benin et al. 2004). Therefore, the optimal choice of the household can be re-expressed as a reduced form function of input and output prices, market wage, farm size, initial wealth, and household and farm characteristics:

$$h_i^* = h_i^*(p_j, w_k, Z_i, A_i, W_{0i}) \qquad (8)$$

Eq. (8) forms the basis for econometric estimation to examine the factors affecting diversity of crops on household farms, an outcome of choices made in a constrained optimization problem. Diversity of crops (*D*) for each farm *i* is expressed in the following conceptual form (Benin et al., 2004):

$$D_i = D_i(\alpha_{ij}^*(p_j, w_k, Z_i, A_i, W_{0i}) \qquad (9)$$

Data and the Study Area

The study is based on farm-level cross section data for the crop year 1996 collected from three agro-ecological regions of Bangladesh. The survey was conducted from February to April 1997. Samples were collected from eight villages of the Jamalpur Sadar sub-district of Jamalpur, representing wet agro-ecology, six villages of the Manirampur sub-district of Jessore, representing dry agro-ecology, and seven villages of the Matlab sub-district of

Chandpur, representing wet agro-ecology in an agriculturally advanced area. A multistage random sampling technique was employed to locate the districts, then the *Thana* (sub-districts), then the villages in each of the three sub-districts, and finally the sample households. A total of 406 households[1] from these 21 villages were selected. Detailed crop input-output data at the plot level for individual farm households were collected for ten crop groups[2]. The dataset also includes information on the level of infrastructural development[3] and soil fertility determined from soil samples collected from representative locations in the study villages[4].

Dependent Variables: Diversity Indices

The dependent variables are the diversity indices, where each diversity index (*D*) is a scalar constructed from the vector of area shares allocated to crops. The crop groups are mentioned in footnote#2. We employ three indices, of which two have been adapted from the ecological indices of spatial diversity in species (Margalef and Shannon indices) and one from the marketing industry index of market concentration (Herfindahl index) (Table 2). Each index represents a unique diversity concept. Richness, or the number of crops observed is measured by a Margalef index. Evenness, which combines both richness and relative abundance concept, is measured by a Shannon index (Benin et al. 2004), and the concentration of crop type is measured by a Herfindahl index.

[Insert Table 2 here]

Independent Variables

Independent variables are operational measurements of the vectors shown in the right hand side of Eq. (6). The variables incorporated in the econometric models were: three output prices (modern rice, jute, cash crops[5]), four input prices (fertilizers, animal power services, labor, and pesticides), amount of land cultivated, livestock ownership, value of farm capital assets, irrigation, tenurial status, farmers' education, farming experience, subsistence pressure, extension contact in the past one year, membership in NGOs, index of underdevelopment of infrastructure, soil fertility index, and regional dummies for Comilla and Jessore. The definition and measurement of all these variables are presented in table 5. The justification for including these variables in the model is discussed below.

Land is the scarcest resource in Bangladesh, and farm size largely determines the level and extent of income to be derived from farming. Land also 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, greater farm areas can be allocated among more crops (Benin et al. 2004). However, the impact of tenancy on the extent of modern rice technology adoption among farmers is varied (Hossain, et al. 1990). Hence, the amount of land cultivated (to represent wealth) and the proportion of land rented-in (to represent tenurial status) were incorporated to test their independent influence on decisions regarding crop diversity.

Farmers in Bangladesh are not only land poor, but also resource poor. The farm capital asset variable (which includes the value of all tools and equipments used directly into farm operations) was included to examine its influence on crop diversity. Livestock, as a measure of wealth, have an ambiguous effect. Livestock ownership is expected to contribute positively to crop diversity through ensuring draught power for ploughing when needed (Benin et al. 2004).

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

Also, irrigation may decrease diversity through uniform moisture conditions (Benin et al. 2004).

Use of farmers' education level as explanatory variable in technology adoption studies is common (e.g., Nkamleu and Adesina 2000; Adesina and Baidu-Forson 1995). The education variable was used as a surrogate for a number of factors. At the technical level, access to information as well as capacity to understand the technical aspects and profitability related to different crops may influence crop production decisions. The justification of including farming experience is straightforward[6]. 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 was reinforced by the fact that many studies found a significant influence of extension education on adoption of land-improving technologies (e.g., Adesina and Zinnah 1993). Therefore, this variable was incorporated to account for its influence on adoption decisions.

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

The effect of the gender composition of the household is difficult to predict, while household size is expected to increase diversity through preference heterogeneity and labor capacity (Benin et al. 2004). We have, therefore, added proportion of male working members in the household in order to capture the influence of male labor capacity in crop choice decisions[7].

Infrastructure affects agricultural production indirectly through prices, diffusion of technology and use of inputs and has 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. Also, when improved market infrastructure reaches a village, new trade possibilities emerges, adding crops and production possibilities to the range of economic activities undertaken (Benin et al. 2004). This effect was captured by the index of underdevelopment of infrastructure.

Soil fertility is a key factor that exerts a positive influence on productivity (Rahman and Parkinson 2007), which in turn may influence decision to choose crops. Finally, we include two dummy variables for regional location as a determinant of diversity to capture the cultural and physical environment in which farmers make their decision (Benin et al. 2004).

Regression Structure

The general structure of the regression equation is given by:

$$D_i = a_i + b_i p + c_i w + d_i Z + e_i \qquad (10)$$

where D represents any one of the three indices, the Margalef index of richness or the Shannon index of evenness or the Herfindahl index of concentration, p is a vector of output prices, w is a vector of input prices, Z is a vector of farm and household characteristics, e is the error term controlling for the unobserved factors and/or random noise, and a, b, c and d are the parameters to be estimated.

A major estimation problem was encountered as a large proportion of households grew only one crop. In this case, both the Margalef and Shannon indices are censored at zero.

In such case, Tobit model is most appropriate because it uses all observations, both those are at the limit, usually zero and those above the limit, to estimate a regression line, as opposed to other techniques that uses observations, which are only above the limit value (McDonald and Moffit 1980). The stochastic model underlying Tobit may be expressed as follows (McDonald and Moffit 1980):

$$
\begin{aligned}
y_m \quad & = X_m\beta + u_m \quad && if\ X_m\beta + u_m > 0 \\
& = 0 && if\ X_m\beta + u_m \leq 0, \\
& && m = 1,2,......M, \qquad (11)
\end{aligned}
$$

where M is the number of observations, y_m is the dependent variable (diversity index), X_m is a vector of independent variables representing technology attributes and farm and farmer specific socio-economic characteristics, β is a vector of parameters to be estimated, and u_m is an independently distributed error term assumed to be normal with zero mean and constant variance σ^2. The model assumes that there is an underlying stochastic index equal to ($X_m\beta$ + u_m), which is observed when it is positive, and hence qualifies as an unobserved latent variable. The relationship between the expected value of all observations, E_y and the expected conditional value above the limit E_y* is given by:

$$E_y = F(z)\ E_y{*}$$

where $F(z)$ is the cumulative density normal distribution function and $z = X\beta/\sigma$.

On the other hand, when farm households grow only a single crop, the Herfindahl index is computed as 1. Also, none of the farm households in our sample could reach the perfect diversification score of 0. In our sample, the minimum value of the Herfindahl index of crop concentration was 0.18 while a substantial number scored a maximum of 1. Therefore, Ordinary Least Squares (OLS) regression is best suited for this model because it has the BLUE (Best Linear Unbiased Estimator) properties.

As a result, Tobit regression was applied to estimate the parameters of the crop richness (Margalef index) and crop evenness (Shannon index) models and OLS regression was applied to crop concentration (Herfindahl index) model. Parameters for all the models were estimated using NLOGIT-4 software program (ESI 2007).

Results

Level of Crop Diversification

Table 3 presents the existing cropping practice and the extent of crop diversity amongst the sampled households in each region. It is clear from table 3 that there are substantial variations among the regions with respect to each of the aspects considered. Although 51 percent of the total farmers adopted modern rice monoculture, a substantial 37 percent of the total farmers adopted both modern rice as well as a diversified cropping system. 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 3 presents the actual measure of crop diversity using the three indices of richness, evenness and concentration. All the three indices clearly indicate that cropping system in Bangladesh is relatively diverse, particularly in Jessore region, where the level of modern rice technology adoption is lowest.

[Insert Table 3 here]

Profitability and Input Use Rates of Diversified Farms

Table 4 presents the input use rates classified by the level of farm diversification. We designated farms censored at zero as the ‘specialized farms’ who happens to grow only a single crop of modern rice, and the others as the ‘diversified farms’. It is clear from table 4 that the operational size of diversified farms is significantly higher and the use rates of inputs per hectare, except pesticides and irrigation, are significantly lower. The use rates of labor, animal power services and fertilizers are 25, 13 and 19 percent lower among diversified farms compared with those of specialized farms[9]. Although the gross value of output is significantly higher for specialized farms, profits are similar between specialized and diversified farms, due to significantly lower use of inputs by the latter.

[Insert Table 4 here]

Determinants of Crop Diversity on Farms

Summary statistics of the variables used in the regression analyses are presented in table 5. The farm-specific variables provide a summary of the characteristics of these farms. The amount of land cultivated per farm is 0.98 ha. 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.

[Insert Table 5 here]

Table 6 presents the parameter estimates of all three regression models. Prior to describing the results, we discuss estimation diagnostics briefly. A total of 107 observations were censored on the left at 0, implying that these are the specialized farms. The presented models were able to explain 54 and 33 percent of the variations in crop diversity as reflected by pseudo-R^2 in crop richness and evenness models and 47 percent in the crop concentration model reflected by adjusted-R^2 value, respectively. Coefficients on 11 out of a total of 23 variables were significantly different from zero at 10 percent level at least in each of the models, indicating that the variables included in the models to explain crop diversity were correctly justified. The signs of the coefficients mirror each other in all three models indicating robustness of the results, although their magnitudes differ slightly across models[9]. Coefficients of the Tobit models cannot reveal the magnitude of the effect directly. Therefore, their marginal effects[10] were estimated and presented in table 7.

[Insert Tables 6 and 7 here]

The likelihood of crop diversity increases significantly by a decline in the prices of fertilizers and animal power services. For example, a one percent decline in the price of fertilizers will increase crop richness by 4 percent, evenness by 8 percent and diversity by 5 percent, respectively. This is expected because some crops, particularly vegetables and/or potatoes, require large amount of fertilizers and, therefore, a decline in fertilizer prices would induce the switch from conventional rice farming. Similarly, a reduction in the price of moder rice will significantly promote crop diversity. Alternatively, a rise in rice price will promote modern rice monoculture. Also, an increase in the cash crop price will significantly increase crop diversity as expected, although the magnitude of influence is quite low, about 1 percent.

Farm size is positively related to promoting crop diversity, as expected. The implication is that, as farm size increases, farmers are able to choose a diversified portfolio of crops which satisfies both consumption purposes as well as generate surpluses for the market by growing high value non-cereal and/or cash crops. Benin et al. (2004) also found significant relationship of farm size with crop diversity in Ethiopian highlands. In addition to farm size, livestock ownership also positively influences farmers to diversify, as expected. Benin et al. (2004) also found a similar significant relationship of oxen ownership with crop diversity. On the other hand, farm capital asset promotes specialization towards modern rice monoculture, although the magnitude of influence is very small.

Availability of irrigation is the single most important determinant of specialization towards modern rice monoculture, as expected (see the crop concentration model). This result corroborate with the finding of Hossain et al. (1990), who noted that access to irrigation is a major determinant of modern rice technology adoption in Bangladesh. In other words, cropping diversity is significantly higher in areas with no irrigation, which corroborates with the conclusions of Mahmud, Rahman and Zohir (1994) and Morris, Chowdhury and Meisner

(1996). In fact, wheat provides highest returns in non-irrigated zones and in areas that are unsuitable for *Boro* rice (Morris, Chowdhury and Meisner 1996). Benin et al. (2004) reported similar effect but its influence was not significantly different from zero.

Owner operators are more likely to diversify their farms as compared to the tenants, who tend to specialize towards modern rice monoculture, which corroborates with the finding of Hossain et al. (1990). This is because 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 the landlord varies across regions. Areas where such cost is shared (usually on a 50-50 basis), the arrangement is based on sharing of relatively scarce input, e.g., fertilizer, irrigation and/or animal power hire costs (Rahman 1998). Therefore, existing tenurial arrangement seems to work well when the tenant grows rice. However, when a diversified cropping system is adopted, it may exert a discouraging effect, because the amount to be received as output share cannot be clearly estimated *a priori*.

The education level of farmer and farming experience, both have a significant positive relationship with crop diversity, as expected. As mentioned earlier, the ability to process information increases with education as well as experience. Therefore, educated and/or experienced farmers choose to adopt a diversified cropping system in order to take advantage of all the potential benefits arising from making 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.

Farm households with membership in development NGOs are also likely to diversify. This is expected because most development NGOs in the rural regions of Bangladesh promote vegetable production by involving female clientele of the farming households, popularly known as kitchen gardens.

The likelihood of adopting a diversified cropping system is significantly higher in regions with developed infrastructure[11]. The influence of developed infrastructure in adopting a diversified cropping system is obvious. For example, vegetable production provides a significantly higher return (Rahman 1998), but is highly perishable and needs to be marketed immediately after harvest. The prospect of doing so increases only in regions with developed infrastructure.

Farmers in Comilla region has the lowest crop diversity and tends to specialize towards modern rice monoculture, which is also evident in table 3. This is because, Comilla region is a densely populated region with relatively small farm size and all technological innovations relating to 'Green Revolution' have been initiated in this region through BARD (the Bangladesh Academy of Rural Development) located in the central district of Comilla.

Discussions

Results of this study clearly reveal that a host of price and non-price factors influence farmers' decision to diversify. When a farm diversifies into a variety of crops, the farmer uses the opportunity to select enterprises that complement each other, given the nature of seasonality in demand for various inputs. The cropping system in Bangladesh is largely influenced by access to water. The cropping pattern can be broadly classified into cropping under rainfed and irrigated conditions, which again vary according to the degree of seasonal flooding. As mentioned earlier, an apparent paradox exists in that, although many non-cereals are more profitable than producing modern rice, their expansion has stagnated due to the incompatibility of the existing modern irrigation systems (Mahmud, Rahman and Zohir 1994). In fact, areas where modern irrigation is non-existent or unreliable, modern wheat is the desirable crop and provides higher profitability (Morris, Chowdhury and Meisner 1996). In general, the proportion of non-cereal crops is lower under irrigated conditions as compared to rainfed conditions (Mahmud, Rahman and Zohir 1994), which is also demonstrated in this study. For example, crop diversity is significantly lower in the Comilla region when compared with Jamalpur and Jessore regions. This is because some of our sampled households in Comilla region were located within the catchment area of the Meghna-Dhonagoda Flood Control, Drainage and Irrigation (FCD/I) project, where modern rice monoculture is the norm because of the assured availability of surface water for irrigation at a cheap rate (Rahman 1998). Also, as mentioned above, 'Green Revolution' towards modern rice monoculture is also initiated in Comilla region, which later expanded to every corner of Bangladesh.

An important issue that limits the scope to expand non-cereals is the existence of the price risk associated with uncertainties in marketing, particularly for perishable crops, such as vegetables. In fact, annual variability in harvest prices is as high as 15–25 percent for most fruits and vegetables (including potatoes) and 20–40 percent for spices as compared to only 5–6 percent for cereals (Mahmud, Rahman and Zohir 1994). This perhaps explains the decline in the area under spices between the census years (Table 1). Mahmud et al., (1994) further noted that the price shock is most severe at the level of primary markets during harvest seasons. Delgado (1995) stressed the need for addressing marketing issues and constraints as a priority option to promote agricultural diversification in sub-Saharan African regions. This is because in the absence of improved markets, the agricultural sector is likely to suffer from demand constraints as well as a weak supply response, thereby, affecting growth. One way to lower the price risk is through improvements in marketing, which in turn depends on the development of the rural infrastructure.

Our results clearly show that prices of modern rice and cash crops have significant bearing on farmers' decision to diversify. Also, developed rural infrastructure significantly promotes adoption of a diversified cropping system. Infrastructure development in turn may also open up opportunities for marketing, storage and resource supplies, which complements crop diversification. For example, Ahmed and Hossain (1990) concluded that farms in villages with relatively developed infrastructure use relatively greater amounts of fertilizer and market a higher percentage of their agricultural products in Bangladesh. Evenson (1986) noted a strong relationship between roads and increased agricultural production in the Philippines. He claimed that a 10 percent increase in roads would lead to a 3 percent increase in production in the Philippines. Ahmed and Donovan (1992) concluded that "the degree of infrastructural development is in reality the critical factor determining the success of market-oriented sectoral and macroeconomic policies in the developing world" (p39).

Also, it should be noted that the non-cereals produced by most farmers comprised largely traditional varieties, which are low yielding. Strategy to improve varieties of non-cereals, therefore, provides further potential to improve productivity gains from diversification. Conventionally, the R&D activities in Bangladesh are largely concentrated on developing modern rice varieties to the neglect of most other crops. Among the non-cereals, modern technology is only well established in potato cultivation (Mahmud, Rahman and Zohir 1994). The Bangladesh Agricultural Research Institute (BARI) is entrusted with the responsibility of developing modern varieties of all cereal and non-cereal crops except rice and jute. To date, a total of 131 improved varieties of various cereal and non-cereal crops have been developed and released by BARI (Hossain et al. 2006). The thrust in developing and releasing improved varieties by BARI actually gained momentum from mid-1990s, a complementary effort to government's emphasis on promoting crop diversification in its Fifth Five Year Plan document (1997–2002). However, there is a need to examine the impact of these new releases on farmers' portfolios of crop choices at the farm level, because the technical and socio-economic constraints on the diffusion of these technologies remain unexplored and less understood (Mahmud, Rahman and Zohir 1994).

Farmers' wealth status in the form of farm size and livestock ownership also has significant influence on crop diversity. Therefore, shrinking of farm size that we observed over the years is likely to adversely affect crop diversity. However, improvement in the livestock sector in order to promote livestock ownership by individual farmers could partially offset such a detrimental effect of shrinking farm sizes on crop diversity.

Conclusions

The aim of this study was to identify the economic determinants of crop diversity on farms in rural Bangladesh. The computed value of diversity indices of species concentration (Herfindahl), richness (Margalef) and evenness (Shannon) confirm that farming system in Bangladesh is still relatively diverse despite four decades of thrust in the diffusion of a 'Green Revolution' technology package aimed at promoting modern rice monoculture. Results reveal that a host of price and non-price factors significantly influence farmers' decision to diversify. Likelihood of diversification increases with a fall in the prices of fertilizers, animal power services and modern rice and a rise in the price of cash crops. Crop diversification is positively influenced by farm size, livestock ownership, farming experience, education, membership in NGOs, regions with developed infrastructure and unavailability of irrigation. Also, diversification is significantly higher among owner operators.

Policy Implications

The key policy implications that emerge from this study are that crop diversification can be promoted significantly by investing in rural infrastructural development, education targeted at the farming population, livestock sector, and supporting NGOs working in the rural areas. Also, price policies aimed at reducing fertilizer and animal power prices and increasing cash crop prices would significantly promote crop diversity. A diversified cropping system 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. Therefore, the present thrust at the planning level to promote crop diversification is a step in the right direction. Furthermore, appropriate land reform policies that focus on delegating land ownership to landless, marginal and small farmers as well as improvements in existing tenurial system, which is now biased towards favoring modern rice monoculture, would boost the number of owner operators, who are the most likely adopters of a diversified cropping system. Another area of intervention is in the livestock sector, which is a crucial input in the farming industry. The aim would be to promote livestock ownership by individual farmers which have a significant positive influence on crop diversity.

Footnotes

1 The sample households were selected based on the information on the total number of households including their land ownership categories, which were obtained from BRAC (a national non-governmental organization). Then a stratified random sampling procedure was applied using a formula from Arkin and Colton (1963) that maximizes the sample size with a 5% error limit. Farm size categories (large, medium, and small farmers) were used as the strata (for details, see Rahman 1998).

2 The crop groups are: traditional rice varieties (Aus – pre-monsoon, Aman – monsoon, and Boro – dry seasons), high yielding/modern rice varieties (Aus, Aman, and Boro seasons), modern/high yielding wheat varieties, jute, potato, pulses, spices, oilseeds, vegetables, and cotton. Pulses in turn include lentil, mungbean, and gram. Spices include onion, garlic, chilli, ginger, and turmeric. Oilseeds include sesame, mustard, and groundnut. Vegetables include eggplant, cauliflower, cabbage, arum, beans, gourds, radish, and leafy vegetables.

3 A composite 'index of underdevelopment of infrastructure' was constructed using the cost of access approach. A total of 13 elements are considered for its construction. These are primary market, secondary market, storage facility, rice mill, paved road, bus stop, bank, union office, agricultural extension office, high school, college, thana (sub-district) headquarters, and post office (see Ahmed and Hossain 1990 for construction details).

4 The 'soil fertility index' was constructed from test results of soil samples collected from the study villages during the field survey. Ten soil fertility parameters were tested. These are soil pH, available nitrogen, available potassium, available phosphorus, available sulfur, available zinc, soil texture, soil organic matter content,

cation exchange capacity of soil, and electrical conductivity of soil (for details of sampling and tests, see Rahman and Parkinson 2007; Rahman 1998).

5 This output price variable is constructed by summing up the gross value of all individual crops (excluding all types of rice and jute) and dividing by the total volume of output. Correlation among the three output prices used in these models (modern rice, jute and cash crops) is very low ($r<0.20$) and is not significantly different from zero.

6 We did not include age because it is mainly used to act as a proxy for farming experience, which we have already included.

7 Although female labor are also used to some extent in farming in Bangladesh (Rahman 2000), the dominant labor force in farming is still male.

8 The specialized farms are those which scored zero values for both Margalef and Shannon indices, which in turn scored 1 on Herfindahl index.

9 The Herfindahl index is an index of crop concentration. Therefore, a negative sign of the coefficient on the explanatory variable implies positive relationship with diversity and vice-versa.

10 Since, OLS model is used to estimate the parameters of the crop concentration model, the regression coefficient essentially depicts the marginal effects. Therefore, the regression result from table 6 was reproduced for this model in table 7.

11 The index reflects the underdevelopment of infrastructure, and therefore, a negative sign indicates positive effect on the dependent variable. In other words, the positive sign on the coefficient implies positive relationship towards crop diversification.

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Table 1. Changes in Cropped Area, Cropping Intensity and Crop Diversification Between Censuses of 1960 and 1996

Indicators	Census 1960	Census 1996	Inter-census change (%)
Number of farms	6,139,480	11,798,242	92.17
% of small farms (0.02 – 1.01 ha)	51.63	79.87	197.26
% of medium farms (1.01 – 3.03 ha)	37.68	17.61	-10.19
% of large farms (above 3.03 ha)	10.69	2.52	-54.63
Operated area (ha)	7,744,929	8,076,369	4.28
Net temporary cropped area (ha)	7,627,372	6,655,771	-12.74
Gross cropped area (ha)	11,283,169	11,580,666	2.64
Operated area per farm (ha)	1.26	0.68	-45.74
Net temporary cropped area per farm (ha)	1.24	0.56	-54.59
Gross cropped area per farm (ha)	1.84	0.98	-46.59
Proportion of cropped area under (%)			
Rice	75.76	72.80	-1.37
Wheat and other minor cereals	0.83	5.52	585.35
Pulses	6.31	4.63	-24.72

Indicators	Census 1960	Census 1996	Inter-census change (%)
Oilseeds	2.82	4.14	50.92
Cash crops	8.74	6.32	-25.77
Vegetables	2.22	3.55	64.49
Spices and other miscellaneous crops	3.33	3.04	-6.34
Cropping intensity (all farms)	148	174	26.00
Small farms	167	187	20.00
Medium farms	152	171	19.00
Large farms	135	154	19.00
Herfindahl index of crop concentration (all farms)	0.59	0.54	-4.50
Small farms	0.57	0.52	-4.59
Medium farms	0.59	0.55	-4.23
Large farms	0.60	0.59	-0.79

Source: Computed from BBS 1999 and MoFA 1962.

Table 2. Dependent Variables Used in the Analysis of Crop Diversity on Farms

Index	Concept	Construction	Explanation	Interpretation
Margalef	Richness	$D_M = (S-1)/\ln A,\ D_M \geq 0$	A = total area planted to all crops by the household, S is the number of crops.	Higher value of index denotes higher diversity
Shannon	Evenness or equitability (both richness and relative abundance)	$D_S = -\sum \alpha_j * \ln \alpha_j,\ D_S \geq 0$	α_j = area share occupied by the *jth* crop in A.	Higher value of index denotes higher diversity
Herfindahl	Concentration	$D_H = \sum \alpha_j^2,\ 0 \leq D_H \leq 1$	α_j = area share occupied by the *jth* crop in A.	A zero value denotes perfect diversification and a value of 1 denotes perfect specialization

Source: After Benin et al. (2004); Bradshaw (2004) and Llewelyn and Williams (1996).

Table 3. Extent of Crop Diversity Among Sampled Farmers

Variables	Comilla	Jessore	Jamalpur	All region
Proportion of farmers:				
Only modern rice adopter	0.51	0.27	0.65	0.51
Only diverse crop adopter	0.16	0.23	0.02	0.12
Adopter of both diversified crop and modern rice	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 indices of				
Species concentration (Herfindahl index)	0.69	0.46	0.63	0.60
Species richness (Margalef index)	0.28	0.43	0.24	0.30

Species evenness (Shannon index)	0.55	0.96	0.59	0.67
Number of observations (farm households)	126	105	175	406

Notes: The actual data were collected at plot level. Therefore, the total plot level observations of all types of crops grown by these 406 farmer stands at 1,448. Number of observations of 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.

Table 4. Profitability and Input Use Rates of Diversified and Specialized Farms

Variables	Diversified Farms	Specialized Farms	Mean Difference (Diversified vs. Specialized)	t-ratio
Land area cultivated (ha)	1.17	0.53	0.56	4.99***
Labor (days/ha)	92.62	123.86	-31.24	-6.85***
Animal power services (pair-days/ha)	26.34	30.37	-4.04	-4.45***
Fertilizer (kg/ha)	212.37	262.74	-50.37	-6.30***
Pesticides (Taka/ha)	288.96	306.50	-17.54	-0.38
Irrigation (Taka/ha)	1,587.16	1,528.68	58.47	0.44
Gross value of output (Taka/ha)	22,164.46	24,470.43	-2,305.86	-2.99***
Profits (Taka/ha)	12,616.01	13,202.84	-586.83	0.82
Number of farms	299	107		

Notes: Profits = (gross value of output – variable cost of all inputs). *** = significant at 1 percent level ($p<0.01$)

Table 5. Summary Statistics of the Variables Used in the Models

Variables	Unit of Measurement	Mean	Standard Deviation
Price variables			
Fertilizer price	Taka per kg	5.85	1.38
Animal power price	Taka per animal pair-days	83.56	17.34
Labor wage	Taka per person-day	44.67	8.22
Pesticide price	Taka per 100 gm/ml	1015.14	1300.95
Modern rice price	Taka per kg	7.57	2.61
Jute price	Taka per bale	9.59	0.88
Cash crop price (overall)	Taka per kg	4.95	2.35
Socio-economic characteristics of farm and household			
Amount of land cultivated	Hectare	0.98	1.02
Farming experience	Years	25.51	14.21
Education of farmer	Completed year of schooling	3.74	4.26
Family size	Persons per household	6.02	2.53
Ratio of working male member	Number	0.27	0.15

Value of livestock owned	Thousand taka	7.79	8.38
Other farm capital asset	Thousand taka	4.19	12.95
Amount of loan taken	Thousand taka	4.08	13.29
Tenurial status	Proportion of land rented in	0.20	0.29
Irrigation	Proportion of land under irrigation	0.62	0.30
Extension contact	Dummy (1 if had contact, 0 otherwise)	0.13	0.33
Membership in NGOs	Dummy (1 if member, 0 otherwise)	0.29	0.45
Infrastructure index	Number	33.32	14.95
Soil fertility index	Number	1.68	0.19
Jessore region	Dummy (1 if member, 0 otherwise)	0.26	0.44
Comilla region	Dummy (1 if member, 0 otherwise)	0.31	0.46
Diversity indices			
Species concentration (Herfindahl)	Number	0.60	0.27
Species richness (Margalef)	Number	0.30	0.27
Species evenness (Shannon)	Number	0.67	0.51
Number of observations		406	

Table 6. Economic Determinants of Crop Diversity on Farms

Variables	Tobit Model of Richness Index		Tobit Model of Evenness Index		OLS Model of Concentration Index	
	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
Constant	1.4006***	4.22	3.0168***	5.18	-0.4805**	-1.97
Price variables						
Fertilizer price	-0.0477***	-4.18	-0.0872***	-4.35	0.0379***	4.47
Animal power price	-0.0031***	-2.81	-0.0056***	-2.86	0.0024***	2.87
Labor wage	0.0018	0.63	0.0044	0.91	-0.0026	-1.29
Pesticide price	0.0001	0.12	-0.0001	-0.08	0.0001	0.21
Modern rice price	-0.0351***	-6.32	-0.0819***	-8.40	0.0394***	9.85
Jute price	-0.0209	-1.41	-0.0411	-1.57	0.0187	1.63
Cash crop price (overall)	0.0139**	2.42	0.0076	0.76	-0.0006	-0.13
Socio-economic characteristics						
Amount of land cultivated	0.0643***	3.53	0.1345***	4.20	-0.0444***	-3.23
Farming experience	0.0017	1.59	0.0034*	1.78	-0.0014*	-1.72
Education of farmer	0.0110***	2.88	0.0161**	2.40	-0.0065**	-2.27

Family size	-0.0017	-0.26	0.0039	0.34	-0.0029	-0.61
Ratio of working male member	-0.0343	-0.35	-0.1163	-0.67	0.0585	0.81
Value of livestock owned	0.0036*	1.85	0.0066*	1.92	-0.0021	-1.40
Other farm capital asset	-0.0019	-1.39	-0.0050**	-2.12	0.0022**	2.18
Amount of loan taken	0.0002	0.16	0.0020	0.95	-0.0011	-1.22
Tenurial status	-0.1325**	-2.42	-0.2781***	-2.91	0.1258***	3.22
Irrigation	-0.2399***	-4.84	-0.4451***	-5.11	0.1861***	5.13
Extension contact	0.0476	1.11	0.0972	1.29	-0.0368	-1.14
Membership in NGOs	0.0599*	1.92	0.0814	1.49	-0.0237	-1.02
Soil fertility index	-0.0804	-0.71	-0.2034	-1.03	0.0815	0.98
Infrastructure index	-0.0049***	-3.53	-0.0093***	-3.81	0.0039***	3.98
Jessore region	0.0455	0.78	0.1029	1.00	-0.0340	-0.80
Comilla region	-0.0381	-0.61	-0.1620	-1.49	0.0736*	1.65
Model diagnostics						
Log likelihood	-97.31		-273.55		-97.41	
$\chi^2_{(23, 0.99)}$	232.53***		274.53***		--	

$F_{(23, 382)}$	--	--	16.61***
Pseudo-R^2/Adjusted R^2	0.54	0.33	0.47
Uncensored observations	299	299	406
Left censored observations	107	107	--
Number of observations	406	406	406

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

Table 7. Marginal Effects of the Economics Determinants of Crop Diversity on Farms

Variables	Tobit Model of Richness Index		Tobit Model of Evenness Index		OLS Model of Concentration Index	
	Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
Constant	1.1633***	4.20	2.7194***	5.18	-0.4805**	-1.97
Price variables						
Fertilizer price	-0.0398***	-4.18	-0.0785***	-4.34	0.0379***	4.47
Animal power price	-0.0026***	-2.80	-0.0051***	-2.86	0.0024***	2.87
Labor wage	0.0015	0.63	0.0040	0.91	-0.0026	-1.29
Pesticide price	0.0009	0.12	-0.0001	-0.08	0.0001	0.21
Modern rice price	-0.0292***	-6.37	-0.0741***	-8.50	0.0394***	9.85
Jute price	-0.0175	-1.42	-0.0371	-1.57	0.0187	1.63
Cash crop price (overall)	0.0115**	2.40	0.0067	0.74	-0.0006	-0.13
Socio-economic characteristics						
Amount of land cultivated	0.0536***	3.53	0.1214***	4.20	-0.0444***	-3.23
Farming experience	0.0015	1.61	0.0031*	1.79	-0.0014*	-1.72
Education of farmer	0.0092***	2.90	0.0145**	2.40	-0.0065**	-2.27

Family size	-0.0014	-0.25	0.0036	0.35	-0.0029	-0.61
Ratio of working male member	-0.0288	-0.35	-0.1054	-0.67	0.0585	0.81
Value of livestock owned	0.0031*	1.86	0.0060*	1.93	-0.0021	-1.40
Other farm capital asset	-0.0016	-1.40	-0.0045**	-2.13	0.0022**	2.18
Amount of loan taken	0.0002	0.16	0.0018	0.94	-0.0011	-1.22
Tenurial status	-0.1101**	-2.41	-0.2513***	-2.91	0.1258***	3.22
Irrigation	-0.1997***	-4.84	-0.4026***	-5.14	0.1861***	5.13
Extension contact	0.0399	1.11	0.0873	1.28	-0.0368	-1.14
Membership in NGOs	0.0503*	1.94	0.0734	1.49	-0.0237	-1.02
Soil fertility index	-0.0655	-0.69	-0.1820	-1.02	0.0815	0.98
Infrastructure index	-0.0041***	-3.52	-0.0084***	-3.81	0.0039***	3.98
Jessore region	0.0381	0.78	0.0918	0.99	-0.0340	-0.80
Comilla region	-0.0313	-0.61	-0.1460	-1.49	0.0736*	1.65

Notes: *** = significant at 1 percent level (p<0.01); ** = significant at 5 percent level (p<0.05); * = significant at 10 percent level (p<0.10). Computing marginal effects of dummy variables in censored regression models are highly complicated. However, Greene (2007) claims that the default computational method of marginal effects (i.e., coefficient * probability of non-censored observations) for the dummy variables in NLOGIT-4 software provides a remarkably close guesstimate of the true effect (ESI, 2007).