On farm conservation of rice biodiversity in Nepal

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ABSTRACT

This paper presents an empirical case study about farmer management of rice genetic resources in two communities of Nepal, drawing on interdisciplinary, participatory research that involved farmers, plant breeders, and social scientists. The decision-making process of farm households is modeled and estimated in order to provide information for the design of community-based conservation programs. A bivariate model with sample selection treats the simultaneous process of whether farmers decide to plant landraces or modern varieties, and whether the landraces they choose to plant constitute genetic diversity of interest for future crop improvement. Findings show that the two landrace choices are affected by different social and economic factors, indicating that they are separate decision processes. Policies to promote the conservation of local rice diversity will need to take both processes into account. Fitted equations are then used to compare the likelihood that households targeted for conservation according to one set of conservation criteria also meet other conservation criteria. Households most likely to plant landraces identified as important for crop improvement also grow richer, more spatially diverse rice varieties. In these communities, few policy trade-offs would result from employing one set of criteria instead of the other.

I. INTRODUCTION

On farm conservation of rice genetic diversity involves farmers deciding to continue managing landraces in agro-ecosystems and communities where they have evolved historically, known as centers of diversity. Nepal is an important center of genetic diversity for *Oryza sativa* ("Asian" rice). Farmers in Nepal maintain an estimated 2000 rice landraces in association with their wild and weedy relatives (Shrestha and Vaughan, 1989; Upadhyaya and Gupta, 2000). These landraces have evolved in response to wide variations in local conditions, combined with the careful seed selection and management practices of farmers.

Farmers choose to maintain the landraces they value by planting the seed, selecting the seed from the harvest or exchanging it with other farmers, and replanting. Their choices also determine whether or not genetic resources of social value for crop improvement continue to be grown *in situ*. Farmers may cease growing landraces if changes in the production or marketing environment cause them to lose their relative value. Designing on farm conservation efforts presents a number of policy challenges, including the identification of the social and economic forces driving the loss of landraces in a particular locality. Understanding the cost to farmers and to society of foregoing the opportunity to plant modern varieties is also fundamental, because there are many production environments of the world for which well-adapted modern varieties have not yet been bred.

Decades ago, Harlan (1972) and Frankel (1970) warned against the extensive displacement of landraces they observed during the early years of the Green Revolution, particularly in the more favorable agronomic regions where high yielding varieties were adopted first. Brush (2004) has cautioned that genetic erosion is not as broad a phenomenon as had been expected, but is a testable hypothesis worthy of study in longitudinal micro and regional studies. Nonetheless, the total number of landraces as well as the area planted to landraces in Nepal appears to be declining over time. In-depth group interviews with historical data confirm that in the villages studied here, modern varieties are indeed displacing landraces (Chaudhary et al 2004). One of the two villages, Bara, has an advanced degree of genetic erosion; the other, Kaski, has an incipient level.

Genetic erosion in crops occurs because privately optimal choices for farmers result in levels of crop biodiversity that are below a socially optimal threshold. There are multiple processes of genetic erosion. Previous applied economics studies about on farm conservation in developing economies have focused largely on either the competition between landraces and modern varieties (Brush, Taylor, and Bellon 1992; Meng 1997), or choices among landraces (Van Dusen 2000; Smale, Bellon and Aguirre 2001). In this paper we model two processes of genetic erosion simultaneously: 1) when a farmer switches to planting relatively more uniform or foreign “modern varieties;” and 2) when a farmer switches to less diverse landraces.

A conceptual approach drawn from a microeconomic model of farmer decision-making relates the two decisions to explanatory factors that may be influenced by public investments and policies. We test whether different farm, market, or social constraints influence the choice to grow landraces and the choice to grow a potentially valuable subset of the landraces. To cluster landraces into more or less diverse subsets, information is drawn from key informant interviews with rice scientists. Scientists classify landraces according to three conservation criteria: rarity, adaptability, and diversity. This information enables us to relate econometrically the varieties grown by farmers to possible resources of value to Nepalese society or to the world.

The purpose of this study is to assist in national plans for conserving agricultural biodiversity through investigating potential tradeoffs between the decisions of individual farmers and social outcomes (for previous work see Subedi et al. 2002). Nepal is a signatory nation to the Convention on Biological Diversity and has participated in the activities of the United Nations Food and Agriculture Organization on the International Undertaking of the Commission on Genetic Resources for Food and Agriculture. Compliance with these international norms, and the pursuit of national strategies for sustainable development, will require innovative approaches to on farm conservation.

The Nepal Agricultural Research Council (NARC), an office of the Nepal government, implemented this field study. NARC has combined the activities of increasing crop yields through plant breeding and extension with conserving crop diversity on the national scale. Similarly, the NGO that participated in rural communities, Local Initiatives for Biodiversity, Research and Development (LI-BIRD), has the joint mission of conserving biodiversity while improving farmer livelihoods. The research reported here was facilitated by the International Plant Genetic Resources Institute (IPGRI) global in situ project, in an effort to develop methodologies that can be shared across countries.

III. CONCEPTUAL APPROACH

The conceptual approach is based on the theory of the agricultural household (Singh, Squire, and Strauss, 1986). There is a long history of using household models in order to model the adoption of new agricultural technologies, which in this case study is represented as the decision to plant modern or traditional varieties of rice. A household model has been applied to analysis of crop biodiversity by Van Dusen and Taylor (2004) providing a framework to study the economics of managing crop genetic resources on farms (e.g. Meng 1997; Brush, Taylor, and Bellon 1992; Smale, Bellon and Aguirre 2001; Benin *et al.,* 2004; Birol 2004).

The adaptation of the household model depends on the aspects of farmer decision making that are modeled in each case. We focus in this paper on two processes: 1) whether farmers plant a general set of varieties (landraces), as compared to another set (modern varieties); and 2) whether farmers plant specific subsets of landraces. The two-stage, discrete nature of the decision process combines with the specific data structure to provide a unique application.

Following Van Dusen and Taylor (2004), the household obtains utility from consuming crops i=1, 2, ... I, any or all of which it may also produce, with levels of consumption represented by Xi, and consumption of all other market goods be denoted by Z. Household utility is affected by exogenous socioeconomic, cultural, or other characteristics, Φ_{HH}. Households maximize utility subject to a full income constraint, with income composed of farm income, exogenous income $\overline{Y}$, and an endowment of family time T valued at the market wage, w. The theoretical model can be represented mathematically as:

$$\max_{X,Q} U(\mathbf{X}, Z; \Phi_{HH}) \tag{1}$$

$$Z = p(\mathbf{Q} - \mathbf{X}) - C(\mathbf{Q}; \Phi_{Prod}) + \overline{Y} + wT \tag{2}$$

$$H_i(\mathbf{Q}, \mathbf{X}; \Phi_{Market}) = 0 \tag{3}$$

Households choose which of j crop varieties, j=1...J to produce and the output of each variety, Q_j. Farm income is the value of production (at market prices) net of market input costs. Household production is carried out subject to technological constraints embedded in a cost function, C(**Q**; Φ_{Prod}), where Φ_{Prod} is a vector of exogenous farm characteristics.

Market constraints on production and/or consumption are functions of exogenous characteristics Φ_{Market}. Represented by the functions H(·), market constraints could take many forms. For this model, it will suffice that under certain market conditions reflected in Φ_{Market}, such as high transactions costs, consumption demands must be met from household production.

$$H_i\left(Q_i, X_i; \Phi_{Market}\right) = Q_i - X_i \qquad \text{if market i is missing,} \tag{3'}$$

$$H_i\left(Q_i, X_i; \Phi_{Market}\right) = 0 \qquad \text{otherwise .}$$

The characteristics of the market (Φ_{Market}) determine whether a household faces transactions costs for each variety *i* that it consumes. When markets are not functioning well for a variety or its trade is associated with significant costs of transaction, then production and consumption decisions cannot be separated and a shadow price for the crop guides decision-making rather than its market price. This is clearly the case in the study area (Gauchan, Smale, and Chaudhary *forthcoming*).

The household chooses a vector of consumption levels, **X**, and output levels, **Q**. Letting λ denote the shadow value of income and $\boldsymbol{\gamma}$ a vector of shadow values on the market constraints, the Lagrangian corresponding to this general model is:

$$L = U\left(\mathbf{X}, Z; \Phi_{HH}\right) + \lambda\left[\left(p(\mathbf{Q}-\mathbf{X}) - C(\mathbf{Q};\Phi_{\text{Prod}}) + \overline{Y} + wT\right) - Z\right] + \boldsymbol{\gamma}(\mathbf{X}-\mathbf{Q};\Phi_{Market}) \quad (4)$$

The general solution to the household maximization problem when the constraints bind yields a set of constrained-optimal production levels, Q^c, and consumption levels, X^c:

$$\mathbf{Q} = Q_j^C(p, \Phi_{HH}, \Phi_{Prod}, \Phi_{Market}) \quad (5)$$

$$\mathbf{X} = X_i^C\left(p, Y^C, \Phi_{HH}, \Phi_{\text{Pr}od}, \Phi_{Market}\right) \quad (6)$$

where Y^c denotes full income associated with the constrained-optimal production levels Q^c. For some varieties the optimal production level may be zero; therefore, the outcome on Q^c will determine which of the j crops the household chooses to produce. In this study Q represents a menu of j possible landraces that the house could grow. The constrained choices Q^c which results in nonzero outcomes are the rice varieties which the household decides to plant.

In this application, we apply the model in order to investigate the decision to plant landraces, and the decision to plant a subgroup of landraces. Both are discrete choices. Variety traits are not explicitly incorporated because neither decision involves the choice of a specific variety. There are typically substantial differences in the on-farm performance of modern and traditional varieties, though this not always the case in marginal or heterogeneous growing environments. Differences are summarized in yield moments as part of the production technology (Equation 2), consistent with a substantial body of earlier literature on the adoption of modern varieties in Asia (Feder, Just and Zilberman, 1985; Just and Zilberman 1983). In the second stage decision, landrace subgroups were defined by breeder-defined criteria, rather than the criteria employed by farmers. By classifying landraces in this way, we use the econometric analysis to relate the decisions of farmers to choices of breeders, drawing implications for on farm conservation.

III. Econometric Approach

The random utility model enables the use of sample data to analyze the planting choices in Equation 5 in terms of two stages, each representing a process of genetic erosion. In the first stage, the household chooses to plant rice landraces if the utility the household expects to derive is greater than when not planting landraces ($U_L > U_{NL}$). In the second stage, the household chooses to grow a landrace (which happens to fall in one of the three breeder defined subsets) if the utility its members expect to derive is greater than for other available alternatives ($U_i > U_j$, for any j not equal to i). In each stage the decision is about a process of participation with zero outcomes for those households not participating.

Since utility levels (U) cannot be observed, the choices observed in the data reveal the alternatives that provide the greatest utility to households. Variation in these choices is explained systematically by the preferences of households and the constraints they face. Preferences and constraints depend on observable variables related to household, farm and market characteristics. Drawing data from a random sample of households provides a statistical context for predicting the probability that a household grows a landrace as a function of the systematic component ($\beta' X$) and random errors (ε):

Probability (Landrace *over* No Landrace) =

Probability ($U_L > U_{NL}$) = $\beta_{10} + \beta_{1H}'\Omega_{HH} + \beta_{1F}'\Omega_F + \beta_{1M}'\Omega_M + \beta_{1Y}\overline{Y} + \varepsilon_1$.

Probability (Landrace in group *i* chosen) =

Probability ($U_i > U_{not\ i}$) = $\beta_{20} + \beta_{2H}'\Omega_{HH} + \beta_{2F}'\Omega_F + \beta_{2M}'\Omega_M + \beta_{2Y}\overline{Y} + \varepsilon_2$.

If ε_1 and ε_2 are correlated a bivariate probit approach is used.

The decision to plant landraces is the first stage of the household decision process and the decision to plant a specific landrace is the second stage, with the decision in the second stage depending on the first. A bivariate probit with sample selection, known as the Heckman probit, is well suited to applications with two categorical variables, two processes influencing the same set of decision-makers, and one outcome conditional on the other. The model accounts for the censoring and generates unbiased coefficient estimates. Previous applications include Van de Ven, Wynand, and Van Praag (1981) and Boyles, Hoffman, and Low (1989).

The notation used here follows Greene (2000). Decisions are represented by α_1 for first stage choice and α_2 for the second stage choice. Simplifying the notation by using constrained optimal choice α_i and stacking the explanatory variables [Ω_{HH}, Ω_F ,Ω_M] into a vector of independent variables, X (X_i for each household i), For the general landrace choice,

$\alpha_{i1} = X_i\beta + \varepsilon_{i1}$, and

$\alpha_{i1} = 1$ if $\alpha_{i1}^* > 0$

$\alpha_{i1} = 0$ if $\alpha_{i1}^* = 0$

For the specific sub-group landrace choice,

$\alpha_{i2} = X_i\beta + \varepsilon_{i2}$, and

$\alpha_{i2} = 1$ if $\alpha_{i2}^* > 0$

$\alpha_{i2} = 0$ if $\alpha_{i2}^* = 0$

where α_2 is only observed where α_1 >0

The error terms, (ε_{i1}, ε_{i2}) are assumed to be distributed i.i.d. bivariate normal, with correlation ρ.

The likelihood function is:

$$\text{L}=\sum^{\alpha_2=1} \ln \Phi_2\left(\beta_1' x_{i1}, \beta_2' x_{i2}, \rho\right)+\sum^{\alpha_2=0} \ln \Phi_2\left(-\beta_1' x_{i1}, \beta_2' x_{i2},-\rho\right)+\sum \ln\left[1-\Phi_1\left(x_{i1}\beta_1\right)\right]$$

where Φ_1 is the univariate cumulative normal distribution and Φ_2 is the bivariate cumulative normal distribution.

IV. Data

Site descripton

Research was undertaken in two sites representing key rice-producing ecologies in Nepal (Figure 1). In most parts of Nepal, rice is grown on small family-based subsistence farms with an average size varying from less than 0.1 to 1.0 hectare. The Kaski site is located in a lake watershed and is comprised of a cluster of communities with moderate-to-high population density (155 persons per square km). The agroecosystem is mid-altitude (600-1600 masl) and warm temperate to subtropical, with a wide range in altitude and ecological features including upper and lower hill terraces. Precipitation per annum is about 3900 mm. Rice production is semi-subsistence and dominated by landraces that are grown in micro-niches, often in close association with their wild relatives found in the periphery of the two major lakes.

The Bara site is a lowlands river watershed, with higher population density (210 people per square km). Located on the flat and fertile Indo-Gangetic plain (Terai region) on the southern border with India, this agroecosystem is low altitude (80-150 masl) and sub-tropical, with an average rainfall of 886 mm/annum. Rice production is semi-commercial and is dominated by modern varieties with few farmers growing landraces. The Terai lowlands are the rice-bowl of Nepal, producing 75 percent of the national rice crop; hill and mountain regions produce the remaining 25 per cent (APSD, 200l). Bara farmers have easy access to high yielding modern varieties and information about modern technologies and markets from both local and external sources (Paudel et al. 2000).

Sample design

The sample survey research and analysis reported here builds on several years of intensive, participatory research with farmers as part of the Nepal national *in situ* conservation project. Initially the survey team listed all 1856 households in both sites. Through local contacts, they learned that some of the households were no longer engaged in farming, some were no longer located in the original settlement, and a few did not grow rice. A random sample representing 17.25% of actively farming, rice-growing households was drawn, numbering 159 in Kaski and 148 in Bara, for a total sample size of 307.

The survey instrument was a structured questionnaire administered in personal interviews. Questions covered social, demographic, and economic characteristics of farmers and their households, as well as physical characteristics of their farms, economic aspects of rice production, and market access. The principal researcher coordinated the survey with the support of experienced, local staff. Both men and women involved in rice production and consumption decisions were interviewed. To enhance data quality and uniformity, peer review of the questionnaires was undertaken in regular intervals to check for measurement errors, ambiguities and missing information. Households were revisited immediately for missing information and inappropriate responses immediately during survey period. To ensure uniformity in units of measurement and consistent terminology, the researcher and enumerators edited the questionnaires at the survey site.

Dependent Variables

There are major differences between modern varieties and landraces, but there are also differences within each category. Not all landraces are equally promising candidates for conserving diversity that will be of value to producers and consumers in the future. Measurement of local crop diversity has constituted a major challenge in the applied economics literature about on farm conservation, since more sophisticated metrics based on genetic data often correlate poorly with the units that are managed and recognized by farmers (Meng et al. 1998; Van Dusen 2000). Quantitative genetic studies do not provide a suitable framework for tests of economics hypotheses. Recent studies have applied simple metrics with a greater intuitive appeal, such as counts, abundance, or evenness indices constructed from variety area shares shown in the reduced form equation (7). These metrics are similar to the measures of spatial diversity that have been developed in ecological theory and population biology (Magurran 1988). Such indices are neutral or abstract in the sense that each unit (variety) is treated as equally important—and equidistant from another. Brock and Xepapadeas (2003) have argued that neither spatially-defined, ecological indices nor genetically-defined, distance metrics are inherently superior for economic analysis.

The approach used in this paper is straightforward. We link the private value of rice landraces, as these are named and recognized by farmers, to their potential social value in crop improvement, as assessed by rice scientists who have analyzed them genetically in on-farm trials and laboratories. The landraces recognized by farmers as distinct are classified by three criteria rice scientists consider to be important for crop improvement.

A survey of plant breeders involved in the national *in situ* project and rice research in Nepal was implemented. First, the criteria breeders use to select landraces as potentially useful were elicited in a focus group of 16. These included: diversity (expressed as a non-uniform, heterogeneous population); rarity (embodying unique or uncommon traits) and adaptability (exhibiting wide adaptation). Next, based on their own experience and knowledge, eight plant breeders were asked individually to classify rice landraces, based on their own experiences, according to whether or not they satisfy each criterion.

[Table 1]

Table 1 reports breeders' selection of subgroups for rice landraces grown in the study sites. Their preferences reflect their perception of the potential value of the varieties for future crop improvement, based on an expert assessment of the value to society as a whole.

[Table 2 – Dependent Variables]

Table 2 presents the percent of households growing rice landraces in the pooled sample and by site. The data reveal that 56% of households grow rice landraces, but this number is unevenly distributed. While only 10% grow landraces in Bara, 98% grow landraces in Kaski. The decisions of most households lead to corner solutions. That is, 118 grow only modern varieties while 135 grow only landraces. A much smaller number, 56 households, grow both.

The vast majority of households growing targeted landraces are also found in the Kaski region. The spread of households between the different subsets is also uneven.

Only 12% of households in the sample grow rare landraces, 27% grow landraces that are heterogeneous, and as many as 39% grow landraces from the adaptable subset. This variation is of policy interest if a targeting criteria leads to some different and some overlapping subsets of households.

Independent Variables

The independent variables to explain household planting decisions are presented in Table 3. While the survey yielded a large number of possible explanatory variables, a parsimonious model was necessary because of few observations. Problems of non-convergence also occurred in the full information maximum likelihood iterations. The adoption literature offers a wide range of possible theoretical explanations for seed choice; only a few are presented here because of the emphasis on a two-stage simultaneous model. Asterisks indicate when there is a significant difference in means between the two regions.

[Table 3]

Household characteristics affect crop diversity both through preferences and the household-specific costs of market transaction, as well as through labor stocks and opportunity costs. Age and the gender composition of households affect diversity through their preferences and experiences of cultivation. The age of production decision-makers may be positively related to rice diversity since older farmers are more likely to have experience and knowledge about cultivating a range of varieties, and particularly landraces. Similarly, active adult labor on-farm is hypothesized to have a positive effect on rice diversity since more labor allows households to engage in the cultivation of a larger set of rice varieties with differing management requirements. The proportion of active working females is thought to relate positively to rice diversity through variety preferences for consumption attributes. An earlier study by the project team revealed a greater role of women on rice seed maintenance and cultivation (Subedi et al, 2000).

Two economic variables were carefully constructed in order to model wealth and income, in order to avoid hazards of endogeneity between seed choices and economic choices. Total asset value was constructed from an index of household durable goods and is used as a proxy for household wealth. The effect of wealth could be negative if households substitute modern varieties for landrace production, or positive if landraces represent a luxury good in consumption. Current income is proxied by a variable constructed from average monthly household expenditures in the period preceding the growing season. On one hand, cash income enhances farmers' capacity to hire labor and purchase inputs in order to engage in a wider range of activities. On the other hand, it may imply that households are allocating household labor to non-farm activities or specializing in the production of a few modern varieties for the market.

Farm physical characteristics include farm fragmentation and land heterogeneity measured by the number of land types, distances among rice plots, and the percent of rice area irrigated. The more heterogeneous the conditions in which farmers' cultivate the crop, the higher the expected level of diversity since such heterogeneity leads farmers to choose a broader set of varieties to suit multiple classes of farm land and seasonal niches (Bellon and Taylor 1994).

Thus farmers are expected to maintain more diversity when they own and cultivate different land types. The ratio of total rice plot distance to total cultivated hectare is a measure of dispersion of rice plots around homesteads, or fragmentation. Since total farm plot distance was highly correlated with area cultivated, the two variables were combined into one to capture the effect of scattered plots while controlling for total hectares cultivated. The percent of rice area that is irrigated affects rice production potential by improving moisture availability and is expected to lead to the loss of landraces as modern varieties dominate in irrigated regions.

For the first stage landrace planting equation, a general instrument was created to account for the potential increase in yield variability from modern varieties. Expected yields and variances were calculated from triangular yield distributions elicited from farmers by variety (Hardaker, Huirne, and Anderson 1997). The coefficient of yield variation corrects yield variances for differences in expected yield levels. The ratio of coefficients of yield variation for modern varieties and landraces expresses the increase in variability farmers perceive in modern varieties, adjusted for expected yield levels. Since farmer perceptions depend on their own management and growing conditions, the ratio was constructed from the predicted values of an instrumental regression of yield moments on household and farm characteristics. (Variables in the instrumental regression included ecosite dummy, age and education of household head, family members available for agricultural work, availability of irrigation.)

The effect of this variable is expected to be positive, suggesting that farmers who perceive greater yield variability in modern varieties will continue to plant landraces. The values of the summary statistics are useful in interpreting the variable. In the entire sample the average is on, suggesting that farmers perceive the variation of the landraces and modern varieties equally at the mean. More importantly, in the agronomically favored ecosite of Bara, the mean value of the ratio is 0.83, while in the more marginal environment of Kaski, the mean value is 1.14. As expected, modern varieties are perceived as less risky in the better environment where adoption rates are high, and the are perceived as more risky in the more difficult environment where landraces are still grown by the vast majority of households.

Market variables affect diversity through the extent to which households trade their rice crop and purchase inputs, foods and other household needs in the market. The distance of the market from the homestead is a major component of the cost of engaging in market transactions. The more removed a household is from a local market center, the more likely it is to rely on its own production to meet its consumption needs. The prices faced by farmers are assumed to be endogenous due to market imperfections, and effects of endogenous prices are transmitted through household-specific factors (Ω_{HH}) and market conditions (Ω_{M}). Observed market prices (p) vary at the community level (not the household level) and both the difficulty of their operational measurement and the development of the hypothesis concerning diversity led to their exclusion.

V. Results

The first stage estimation included all 307 households and the second stage includes only the 172 households who planted landraces, but the equations are estimated jointly because the error terms in the two processes are thought to be correlated. The full information maximum likelihood estimation was performed in Stata with the landrace equation as the selection equation.

Results for the first stage, selection equation are presented in Table 4.

[Table 4]

The first two columns in Table 4 present the estimated coefficients from a univariate regression of the explanatory variables on the categorical variable for planting landraces, controlling for ecosite location. The second set of columns presents the results of the same regression without the site variable. Location in Kaski has an overwhelming effect on the regression because almost all landraces planted are in Kaski. The pooled regression reveals cross-ecosite information of empirical interest, although for statistical reasons, the regression controlling for ecosite effects was used in the bivariate formulation.

The findings are compelling evidence that different factors affect the decision to plant landraces and the decision to plant diverse, adaptable or rare landraces. In the first stage, variables for the geographic site, the number of family members working on the farm, and the percent of irrigated land are found to significantly increase the probability of planting landraces, and by large magnitudes. Family labor use has been linked to diversity in other studies (Benin et al. 2004; Gauchan 2004), and may reflect the labor intensive nature of growing landraces.

At first glance, the positive coefficient on irrigated land conflicts with the stylized facts of the green revolution. Landraces are believed to be at a disadvantage in areas were moisture conditions are more uniform. In the study sites, certain landraces in the study sites are varieties of paddy rice, however. The variable for plot distance is also positive and significant, indicating that farm fragmentation can lead to an increase in the probability of planting landraces.

More of the individual regression coefficients are statistically significant in the pooled regression, but the overall performance of the model is worse. In addition to family labor and the share of rice area under irrigation, other factors influence the decision to plant landraces across the two ecosites. Contrary to findings reported in several other studies (Van Dusen 2000; Birol 2004), when both sites are considered, younger farmers appear to be those that continue to plant landraces. A higher level of current, cash income leads to a greater probability that landraces are planted. This finding suggests that households may be growing landraces for consumption even as their ability to purchase other foods rises, indicating that rice products made from landraces are not inferior goods. The relative variability of modern varieties has no statistical significance when controlling for ecosite, but has the expected sign when both hillside and plain ecosites are considered. As the yield of modern varieties varies more, the probability of planting landraces increases—confirming the findings reported in Table 4, where variability of modern varieties is shown to be much higher relative to landraces in the Kaski site. The isolation of the household from the market has the expected positive and significant sign. As demonstrated repeatedly, remoteness increases the chances that farmers continue to plant landraces (Brush, Bellon and Taylor 1992; Meng 1997; Van Dusen 2000; Gauchan 2004; Birol 2004).

The bivariate regression generates three selection equations, each paired to a second stage regression. Coefficients in the bivariate selection equations were similar in sign and significance to those of the univariate equations, and are not presented to avoid redundancy. Second stage findings for the three bivariate probit regressions are presented in Table 5.

[Table 5]

Statistical results can be used in Stata to construct a robust variance-covariance matrix to account for cross equation correlations, even though the three probit regressions were not estimated jointly. The t-statistics and significance levels reported in Table 5 have been calculated with the "Seemingly Unrelated Estimation" Stata procedure. Diagnostic tests for the model are reported at the base of the table. Likelihood ratio tests (χ-squared tests of rho) for the conservation criteria of diversity and adaptability indicate that the bivariate specification is correct, but the same is not true for the rarity criterion. In other words, the data support the hypothesis that the correlation between the first and second stage equations is significant in two of the three decision processes.

In the second stage, in each of the three regressions, the variable for distance to markets, used as a proxy for transactions costs, is again found to be statistically significant, with large magnitudes. Clearly market isolation is a strong criterion for targeting households in conservation programs. When specific landraces such as those with wide adaptation or heterogeneous populations are considered, the participation of women in rice production is a positive and significant factor, supporting the findings of other researchers in these study sites that women play an key role in rice seed selection (Subedi et al. 2000). The coefficient for the variable for multiple land types is positive and significant in the rarity regression, and for the degree of fragmentation (distance) in the adaptability regression. Households appear to match varieties to specific agronomic conditions found in individual plots. The coefficient on the land types changes sign in the diversity regression, indicating a potential tradeoff in targeting conservation efforts. For example, some agronomic conditions can increase the probability that farmers plant a landrace of importance for one conservation criterion, while decreasing the chances that they continue to grow a landrace satisfying another criterion. Income is associated negatively with the propensity to grow heterogeneous landraces, and has no effect on the probabilities of growing other types, although it is positively related to growing landraces, in general. Preferences for growing this subset of or more heterogeneous landraces may not be associated with the same income effect as is found with other landraces. Promoting their conservation might entail some trade-offs in terms of other landraces, or vice versa.

Additional insights can be gained by using the results of the fitted model to examine the rice diversity patterns on the farms of households with high predicted probabilities of growing landraces. Households with predicted probabilities of growing landraces that exceed 80% of growing landraces were identified from the bivariate regression output, according to each conservation criterion. Indices of spatial diversity (richness, evenness, and inverse dominance metrics) were then constructed and summarized for each group of households, by conservation criterion. Means are presented in Table 6, where they are compared with the mean for the entire sample of households.

[Table 6 –]

The spatial diversity indices shown in Table 6 are applications of ecological measurement techniques to crop plantings. The richness index is a count of the number of varieties planted. The Shannon index is adapted from information theory, measuring both richness and evenness, calculated from the proportions of farm rice area planted to each variety. The index of inverse dominance, calculated here as a Berger-Parker index, is a measure of the degree to which farm rice area is distributed among different varieties rather than dominated by a single variety.

In all cases the count or area diversity for each subset is significantly higher than for the sample as a whole. This finding is of methodological and policy interest. Spatial diversity indices have been used as the unit of analysis in related empirical studies. These indices and the rice scientist criteria used in this paper represent alternative, potentially competing criteria for on farm conservation programs. In fact, no trade-offs are visible in these communities when the conservation goal is to maintain rice diversity by targeting households with the lowest opportunity costs. Households with a high probability of planting any of the landraces identified as contributing genetic diversity for crop improvement also have a higher level of spatial diversity among rice varieties.

VI. CONCLUSION

This case study illustrates one way that economics research can contribute practically in designing community-based programs to manage on-farm genetic resources sustainably. Local farmers, rice breeders, social scientists, and policy-makers interacted closely during the research project. The approach combines data from sample surveys undertaken with the farmers who manage rice landraces on farms and focus groups implemented with the rice breeders and geneticists who will use these resources for crop improvement.

The econometric approach treats simultaneously two decisions that drive the loss of local crop biodiversity: the decision to plant landraces, and the decision to plant the specific landraces that are identified as potentially valuable for crop improvement. Previous studies modeled either decision or both as a single process. The findings provide compelling evidence that the two decisions are generated by different underlying processes. Some factors influencing the decision to grow one type of landrace (e.g. one that is more heterogeneous) differ from those that affect others to decision to grow other types (e.g., rare landraces), although opposing effects generally are not statistically significant.

The econometric findings are consistent with those presented by other researchers who have used similar methods to study other crops. The intensity of family labor is fundamental to landrace planting, perhaps due to some specific qualities of landrace cultivation that require extra quality in planting and care. Distance to markets drives whether landraces of interest for conservation are planted, though in the communities studied, it has a negligible effect on whether farms plant landraces at all. Post-estimation calculations confirm that farmers who most likely to grow landraces identified as important for crop improvement are also those that maintain greater richness and evenness in the area they allocate among rice varieties. There are no apparent trade-offs among the various conservation criteria, including those developed from focus group interviews with rice scientists and those based on indices of spatial diversity, frequently applied frequently in other studies.

References

Bellon, M.R. and J.E. Taylor. 1993. ’Folk’ soil taxonomy and the partial adoption of new seed varieties. *Economic Development and Cultural Change* 41: 763-786.

Benin, S., M. Smale, J. Pender, B. Gebremedhin and S. Ehui. 2004. The economic determinants of cereal crop diversity on farms in the Ethiopian Highlands. *Agricultural Economics* 31: 197-208.

Birol, E. 2004. *Valuing Agricultural Biodiversity on Home Gardens in Hungary: An Application of Stated and Revealed Preference Methods*. University College London, University of London, London, UK.

Boyles, William J.; Hoffman, Dennis L.; and Stuart A. Low, 1989. “An Econometric Analysis of the Bank Credit Scoring Problem”, *Journal of Econometrics*, 40, pp. 3-14.

Brock W.A and Xepapadeas, A. 2003. Valuing Biodiversity from an Economic Perspective: A Unified Economic, Ecological, and Genetic Approach. The American Economic Review 93 , 1597-1614.

Brush, S. 2004. *Farmers’ Bounty Locating Crop Diversity in the Contemporary World* Yale Univesity Press, New Haven

Brush, S. B., Taylor, J. E., and Bellon, M. R. 1992. Biological diversity and technology adoption in Andean potato agriculture. *Journal of Development Economics* 39, 365-387.

Chaudhary, P., D. Gauchan, R. B. Rana, B. R. Sthapit, D. I. Jarvis (2004) "Potential loss of rice landraces from a Terai community in Nepal: a case study from Kachorwa, Bara"; PGR Newsletter 137, Rome IPGRI

Feder, G., R. Just and D. Zilberman. 1985. Adoption of Agricultural Innovations in Developing Countries: A Survey. *Econ. Dev.and Cult.Change.* 33: 255-297.

Frankel, O.H. 1970. Genetic dangers of the Green Revolution. *World Agriculture* 19: 9-14.

Gauchan, D. (2004) Conserving Crop Genetic Resources On-Farm: The Case of Rice in Nepal. PhD dissertation, University of Birmingham.

Gauchan, D. M. Smale, P. Chaudhary. (forthcoming). Market-Based Incentives for Conserving Diversity on Farms: The Case of Rice Landraces in Central Tarai, Nepal. *Genetic Resources and Crop Evolution* (Forthcoming).

Greene W.H., 2000. Econometric Analysis. Fourth Edition. Prentice Hall. USA.

Hardaker, J., Huirne, R. and J. Anderson. *Coping with Risk in Agriculture*. CAB International, 1997: 44-47.

Harlan, J.R. 1972. Genetics of disaster. *Journal of Environmental Quality* 1(3): 212-215.

Just, R.E. and D. Zilberman. 1983. Stochastic Structure, Farm Size and Technology Adoption in Developing Agriculture. *Oxford Econ. Pap.* 35: 28-37.

Magurran A.E., 1988. Ecological Diversity and its Measurement. Princeton, N.J. Princeton University Press.

Meng, E. 1997. Land allocation decisions and *in situ c*onservation of crop genetic resources: The case of wheat landraces in Turkey. Doctoral dissertation. University of California-Davis.

Meng, E.C.H., M. Smale, M. Bellon and D. Grimanelli, 1998. Definition and measurement of crop diversity for economic analysis. *In* Smale M. (Eds). Farmers, gene banks and crop breeding: economic analysis of diversity in wheat, maize and rice. Norwell, USA; Kulwer Academic Publishers (1998) xvi 270 pages. CIMMYT-Mexico.

Shrestha, G.L. and Vaughan, D.A. (1989) Wild rice in Nepal. Paper presented in the Third Summer Crop Working Group Meeting, National Maize Research Program, Rampur, Chitwan, National Agricultural Research Centre (NARC), Nepal.

Singh, I., L. Squire, and J. Strauss (eds). 1986. Agricultural household models: Extensions, applications, and policy. The World Bank and Johns Hopkins University Press, Washington D.C., and Baltimore.

Smale, M., M. Bellon, and A. Aguirre. 2001. "Maize Diversity, Variety Attributes, and Farmers' Choices in Southeastern Guanajuato, Mexico" *Economic Development and Cultural Change* 50(1): 201-225.

Subedi, A, Chaudhary P, Baniya B, Rana RB, Tiwari RK, Rijal DK, Jarvis D and Sthapit BR (2002). Who maintains genetic diversity and how? Policy implications for agrobiodiversity management. In: D Gauchan, and BR Sthapit, (eds.) *Nepal's Contribution to Agrobiodiversity Conservation* in-situ*: A Scientific Basis for Policy Recommendation*. IPGRI/NARC/LIBIRD.

Subedi, A., D.Gauchan, R.B.Rana, S.N.Vaidya, P.R. Tiwari and P. Chaudhary, 2000. Gender: Methods for Increased Access and Decision Making in Nepal. *In* D. Jarvis, B. Sthapit and L. Sears (Eds). Conserving Agricultural Biodiversity *Insitu:* A Scientific Basis for Sustainable Agriculture.IPGRI, Rome.

Upadhyay, M.P. and Gupta, S.R. (2000) The wild relatives of rice in Nepal. In: Jha, P.K. Karmacharya, S.B., Baral, S.R., and Lacoul, P. (eds) *Environment and Agriculture: At the crossroad of the new millennium*, Ecological Society, Kathmandu, Nepal, pp.182-195.

Van de Ven, Wynand P.M.M.; and Bernard M.S. Van Praag, (1981). "The Demand For Deductibles In Private Health Insurance: A Probit Model With Sample Selection", *Journal of Econometrics*, 17, pp. 229-252.

Van Dusen, E. 2000. *In Situ* Conservation of Crop Genetic Resources in Mexican Milpa Systems. PhD Thesis. University of California, Davis, USA.

Van Dusen, E. and J. E. Taylor 2003. Missing Markets and Crop Genetic Resources: Evidence from Mexico. A Manuscript. University of California, Berkeley, USA.

Vaughan, D. and T.T. Chang. 1992. *In situ* conservation of rice genetic resources. *Economic Botany* 46: 369-383.

World Bank, World Development Indicators 2003. The World Bank, Washington, D.C.

Table 1. Breeders' classification of rice landraces by conservation goal

Variety name	Diverse	Rare	Adaptive	Variety name	Diverse	Rare	Adaptive
Anadi Rato	0	0	1	Jhinuwa Ghaiya	0	1	0
Anadi Seto	0	0	1	Jhinuwa Kalo	0	1	0
Anga	0	1	0	Jhinuwa Pakhe	0	1	0
Badahari	0	1	0	Jhinuwa Seto	0	1	0
Basmati	0	0	0	Jhinuwa Tarkaya	0	1	0
Basmati	0	0	0	Juwari	0	1	0
Bayerni	0	1	0	Kathe Gurdi	1	0	0
Bayerni Jhinuwa	0	1	0	Kaude 1 (NL+KG)	0	0	0
Bhathi	0	1	0	Kaude 2 (Md+Mn)	0	0	0
Bichara Ghaiya	0	1	0	Kunchhale Ghaiya	0	1	0
Ekle	0	0	0	Madhese	0	0	1
Faram lalka	0	0	1	Mala	0	0	1
Gajale Jhinuwa	0	1	0	Mansara	0	0	1
Gauriya	0	1	0	Mansuli Ghaiya	0	1	0
Gurdi	1	0	0	Mut Mur	0	1	0
Gurdi Sano	1	0	0	Naulo Madhese	0	0	1
Gurdi Thulo	1	0	0	Pahenle	0	0	0
Jarneli	1	0	0	Ramani	0	1	0
Jarneli Dhave	0	1	0	Rato Ghaiya	0	1	0
Jarneli Pakhe	0	1	0	Sathhi	0	1	0
Jetho Budho	1	0	0	Seto Ghaiya	0	1	0
Jhinuwa	1	0	0	Tunde	0	1	0

1=of high potential value, 0 otherwise

Table 2. Dependent variables

	Ecosite		All
	Bara (N=148)	Kaski (N=159)	Pooled (N=307)
Stage 1			
Percent households growing any landraces	10.8	98.1	56.0
Stage 2			
Percent households growing diverse landraces	2	50.9	27.4
Percent households growing rare landraces	2.7	20.8	12.1
Percent households growing adaptive landraces	0.7	74.8	39.1

Table 3. Independent variables

	Bara	*Kaski*	*All*
Household characteristic			
Age of production decision maker (years)	48.27	46.20	47.20
Active adults working on-farm (number)	2.52	2.51	2.52
Percent female of actively-working adults	0.27	0.28	0.28
Exogenous income (average monthly household expenditure since preceding years last harvest)	2483	2581	2533
Total asset value (calculated from durable goods)	21964**	27160	24655
Farm characteristics			
Percent rice area under irrigation	0.42	0.39	0.407
Number of rice land types	1.54	1.49	1.517
Total walking distances (minutes) from house to rice plot, divided by cultivated hectares	120*	146	134.58
Variety Characteristic			
Ratio of coefficients of yield variation, modern varieties to landraces	0.83**	1.14	1.00
Market characteristics			
Total walking distance from house to local market (minutes)	163**	340	255.14

Note: Pairwise t-tests show significant difference of means at P< 1% (**) and P< 5% (*) between Kaski and Bara Ecosites with 2-tailed test, equal variance assumed.

Table 4. Probit Regression – Probability of Planting Landraces

	Coeff.	T-stat	Coeff.	T-stat
Kaski ecosite dummy	3.801	6.01***		
Age of production decision maker (years)	-0.021	-1.16	-0.091	-7.02***
Active adults working on-farm (number)	0.282	2.10**	0.244	2.26**
Total asset value (calculated from durable goods)	0.000	0.97	0.000	1.26
Income (calculated from previous monthly expenditure)	0.000	1.46	0.000	2.71***
Percent rice area under irrigation	0.787	1.65*	2.194	6.05***
Distance to Plot	0.003	1.82*	0.002	1.46
Increased Yield Variation of MVs	0.358	0.23	8.625	9.87***
Market Distance	0.001	0.60	0.001	2.00**
Constant	-6.846	-6.01***	-7.165	-7.74***
N	307		307	
Log-Likelihood	-51.8		-79.9	
Pseudo-RSq.	0.75		0.62	

Table 5. Bivariate Probit with Selection –
Probability of planting landrace subsets, by conservation goal

	Adaptability		Diversity		Rarity	
Age	0.007	0.73	-0.001	-0.08	-0.013	-1.35
Adult Workers	-0.329	-0.46	-0.618	-0.86	2.255	2.45**
Percent female workers	0.229	2.63***	0.117	3.38***	0.100	1.01
Total Assets Value	0.0000	1.18	0.0000	1.46	0.0000	-0.39
Exogenous income	-0.0001	-0.56	-0.0002	-1.94*	-0.0002	-0.99
Number of rice land types	-0.148	-0.58	-0.350	-1.76*	0.506	2.08**
Distance to rice plot	0.004	2.56**	0.000	-0.03	0.001	1.22
Distance to local market	0.002	2.47**	0.002	5.83***	0.001	3.28***
Constant	-1.003	-1.52	0.156	0.25	-2.206	-3.05***
N	172		172		172	
Log-Likelihood	-112.55		-138.23		-118.00	
χ^2Test of Rho	35.98 ***		17.95 ***		1.59	

* significant at 0.10 % level, ** significant at 0.05% level, *** significant at 0.01% level

Table 6. Spatial diversity of rice varieties on farms of households with high probabilities of growing landrace subsets, by conservation goal

	Entire Sample	Adaptability	Diversity	Rarity
Number of Households	307	33	26	5
Richness (Count of varieties)	2.84	5.55	5.69	7.6
Diversity (Shannon Index)	0.69	1.24	1.19	1.45
Inverse Dominance (Berger-Parker Index)	1.74	2.32	2.24	2.8

For all indices the high probability households are significantly higher than the total sample, notation for individual t-stats is not included.