Missing Markets and Crop Diversity: Evidence from Mexico

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Abstract

Recent micro-economic studies of in-situ conservation of crop diversity focus on competition between modern and traditional varieties of major food crops. Our paper offers a different perspective, by presenting a limited-dependent variable econometric analysis to model *in situ* conservation of both intra and infra-species crop diversity in a context of heterogeneous ecological and market environments, using a unique household-farm data from Mexico. Our findings reject separability and indicate that market integration significantly reduces crop diversity. They underline the importance of studying diversity in the context of larger cropping systems.

Missing Markets and Crop Diversity: Evidence from Mexico

Crop genetic resources (CGR) are the raw materials for crop breeding and a source of continuing advances in yield, pest resistance, and quality improvement. Researchers have documented genetic erosion, or the loss of crop genetic resources, in cradle areas of crop domestication where the loss of traditional cultivars accompanies the specialization and intensification of agricultural development. Some understanding of the processes of *in situ* conservation is emerging from a nascent literature that ties diversity outcomes in farmers' fields to the theory of agricultural households. Recent studies focus on competition between the modern and traditional varieties of major food crops to explore why traditional varieties persevere, *de facto*, in certain areas without being completely displaced despite their allegedly inferior yields (Brush, Taylor, and Bellon; Bellon, Pham and Sebastian; Widawsky; Meng; and Bellon and Taylor, Louette, Charrier and Berthaud; Louette and Smale; Perales Rivera).

Genetic erosion, however, does not occur solely because of direct competition between traditional and improved varieties of the same species. A more general understanding of *in situ* conservation requires accounting for the genetic erosion that potentially occurs at multiple levels, including both principal crops and secondary crops in multiple cropping systems and changing market environments. Secondary crops are of both economic and biological interest. For example, in the Mexican *milpa* (maize-bean-squash intercrop) system, diversity may be conserved within the principal crop, maize, but also within secondary crops of global importance, including beans, squashes, chilies, tomato, etc. When competition among, as well as within, species shapes diversity outcomes, studies focusing on a single species are likely to produce econometrically biased estimates and misleading policy prescriptions.

This paper develops a model and uses limited-dependent variable econometric methods with unique household-farm data from Mexico to model farmer behavior regarding *in situ* conservation in a context of multidimensional diversity and heterogeneous ecological and market environments.

1. Conceptual Model

CGR conservation encompasses the cultivation of multiple crop species within the *milpa* as well as multiple varieties of each species. Diverse and complex poly-cropping systems are part of the ecosystem that generates CGR in individual crops. The key conservation questions we address in this paper are (1) what variables explain cultivation of the *milpa* as a multiple-crop or inter-cropping system versus the alternative of specializing in single crops, and (2) which farmers continue to plant minor varieties, the ones most likely to be lost in a process of genetic erosion? The goal of the analytical framework presented here is to identify economic, behavioral, or ecological forces affecting farmer CGE conservation on a multi-dimensional level. This distinguishes the present paper from past research on CGR conservation, which focuses on diversity within individual crops.

Our unit of analysis is the farmer, who decides whether or not to plant an additional crop given a variety of potential objectives and constraints. Our conceptual analysis yields an empirical model that nests alternative objectives and constraints in order to test competing hypotheses (Just). This model is estimated using limited dependent variable techniques in Part II, below. A similar nested modeling approach was utilized by Smale, Just and Leathers to explore decisions between traditional and modern varieties of maize. We expand upon that analysis by analyzing CGR diversity on a multi-dimensional level and by emphasizing potential influences of market developments on conservation decisions.

I.1. Graphical Analysis

We begin by presenting a simple graphical treatment of the decision to cultivate multiple crops. In the presentation below we assume two crops, but the results are easily extended to multiple crops. The extension to a general model will be made in the model section.

I.1.a. Case 1 - Decreasing Returns to Scale

One rationale for growing multiple varieties is decreasing returns to scale in a given crop. An example in the case of the *milpa* is decreasing marginal productivity of land in maize production on a given farm. Decreasing returns to scale imply the existence of some other fixed factor of production, besides land, that must be allocated between crops. Some examples are farmer time, land quality, and distance from markets (resulting in increased transport costs).

[Figure 1]

In Figure 1, the factor input L, fixed at L1, is allocated between two crop activities, a and b. The optimal allocation equates marginal value products between crops and determines a shadow price or implicit rental rate, W*, for the fixed factor. A decreasing MVP reflects decreasing returns to scale with respect to the factor depicted on the horizontal axis.

Other fixed factors besides land may affect the cultivation of milpa crops. One of these is the endowment of family labor in an imperfect labor-market context. The household may be limited to using only family labor or, alternatively, family and hired labor may be imperfect substitutes (see discussion of missing markets, below). Letting L in Figure 1 denote family labor, the household allocates its labor to maize, L_a, and a second crop, L_b. If the household could only allocate labor to maize production, it would do so until the marginal value product of labor vanished (or became equal to some relevant household opportunity cost, i.e., the marginal utility of leisure). A fixed endowment of land, land quality, or other input results in a decreasing MVP of labor. If the household can allocate labor to a second crop, e.g., beans, it will do so until the marginal value products of family labor are equated between the two activities at an endogenous "shadow" family wage, w*.

Another example of decreasing returns to scale involves soil heterogeneity and the matching of varieties to soil conditions (e.g., Bellon and Taylor). Allocating all of a household's land to one maize variety might be optimal given homogenous land quality. However, farms often include an extensive margin with heterogeneous slopes, soils, exposure to sunlight, and/or transport costs for inputs and outputs. In this case, the marginal productivity of the principal maize variety may decline as inferior lands are brought into production, and an alternative variety may be superior under these (challenged) conditions.

I.1.b. Missing Commodity or Factor Market

Market imperfections are endemic in rural areas of less developed countries (LDCs). Missing or incomplete markets result from high transactions costs in factor or output markets (Stiglitz; de Janvry, Fafchamps and Sadoulet). Figure 2 illustrates the effect of a missing market for an output, specifically, crop A.

[Figure 2]

In Figure 2, a Production Possibility Frontier (PPF) represents the technologically efficient production mixes available to a household that allocates scarce resources between crops A and B. If there are markets for each crop, the household is guided by the (exogenous) market price line WX, whose slope equals the negative of the ratio of the price of crop A to the price of crop B. In the case illustrated here, optimality with perfect markets implies a corner solution (0, Q_b^*). However, if there is a missing market for crop A, all household consumption demand for A must be satisfied entirely from own production. The household's subjective valuation of good A is reflected in a shadow price, ρ_A, which is shaped by the household's marginal utility of the good as well as indirectly by the household’s production and consumption constraints. In Figure 2, the household shifts from using the exogenous prices (P_a,P_b) and producing only crop B to producing at the constrained level Q^c corresponding to the point of tangency between the price line YZ (now determined by the exogenous price of good B, P_b, and the endogenous price of good A, ρ_A) and the PPF. At this constrained optimum the household produces both crops (Q_a^c, Q_b^c). The curvature in the price line corresponding to the missing-markets case reflects diminishing marginal utility of household consumption of good A, for example, home produced maize. Although it may not appear to be profitable based on regional output prices, the market-constrained household, which lacks access to these prices, cultivates a certain amount of maize to satisfy its consumption demand.

A missing market brings the production of a good directly into the household's utility function (via the subsistence constraint); therefore, factors affecting the utility function also affect crop allocations. The unobserved household shadow price, ρ_A, transmits information from the household's consumption preferences and market constraints into its decisions about which and how much of each activity to participate in. Therefore, estimation of the determinants of household diversity should control and test for influences of variables related to household preferences and access to markets.

Risk or uncertainty, in the absence of a perfect insurance market, may also cause the household to plant a portfolio of varieties instead of specializing. Returning to Figure 2, in the absence of risk and assuming perfect product markets, the household would specialize completely in crop B. If crop B is characterized by high yield risk, however, the household's valuation of crop B, ρ_B, will be endogenous rather than market determined and, in the absence of insurance markets, will reflect the variance of yield and risk preferences. Graphically, as production of crop B increased, the household's subjective valuation of good B would diminish, and the relevant price line would resemble the curved line in Figure 2. This would induce the household to shift resources into the production of Crop A in order to reduce its exposure to risk. Factors affecting household risk aversion and exposure to risk, including access to formal or informal insurance, thus may influence diversity outcomes.

I.1.c. Missing Market for a factor

Other types of missing market, especially for factor inputs, may affect production choices. In the case of a missing labor market or imperfect substitutability between family and hired labor the household is limited by its endowment of family labor available for milpa (and other) production. Households also may be constrained by a lack of liquidity or access to credit to invest in market inputs like fertilizer or harvest labor.

In Figure 3, the household's production is limited by a missing market for a crucial factor (labor, credit, insurance). The unconstrained optimal production choice would be to specialize entirely in good B at point Qb', determined by the tangency of price line WX with the PPF. However, the production of good B is limited to Q_b^c by the constraint YZ, representing the missing input market. Rather than specializing in the production of good B, the household's constrained optimal choice is to also produce good A, which is not (or less) limited by the factor constraint. For example, a household may face a cash constraint that limits its ability to hire labor for labor-intensive maize production. In response to the constraint, it cultivates maize up to the point where it can satisfy all maize demands with family labor, and it allocates the rest of its land to another crop that is less labor intensive or whose labor demands do not coincide with those of maize.

[Figure 3]

Figure 3 illustrates how the introduction of a constraint changes the price line from the exogenously (market) determined one with slope $-p_a/p_b$, to a new price line determined by the tangency with the PPF at the point of the constraint, with slope equal to $-\rho_a/\rho_b$ reflecting the household's subjective valuation of the resource constraint. The constraint shifts production in favor of the activity in which the constraint is less binding (e.g., the crop less intensive in labor, with a lower liquidity demand, or entailing less risk); in the case illustrated, good A.

I.2. Household Model

The household-farm is the common starting point for modeling in situ conservation of CGRs. The household is the basic unit of management where decisions and actions are taken that affect crop diversity. The household is the consumer, consuming both household production and goods purchased with income from production or wage labor. It is also the producer, utilizing its own endowments of labor, land and other capital as well as purchased inputs to produce agricultural commodities either for consumption or sale to the market (Singh, Squire and Strauss). Finally, households face constraints in terms of their endowments, but specific resource or market constraints may affect crop choices (de Janvry, Fafchamps and Sadoulet, Taylor and Adelman). In the next section, an agricultural household model is developed, with a focus on variables explaining how the addition of the jth variety to a household's "crop portfolio" can influence household welfare.

I.2.1. Basic Model

In the basic model with complete markets, the household maximizes utility over a set of consumption levels, X_i, of own crops i=1, 2, ..., N, and all other market consumption represented by income, Y. Household utility is affected by Φ_{HH}, a vector of exogenous socioeconomic, cultural, or other characteristics that condition household consumption decisions. Household consumption is subject to a full income constraint, with income composed of farm income from producing j crops Q_j, j=1...J (net of market input costs), exogenous income $\overline{Y}$, and an endowment of family time T valued at the market wage, w (if a perfect labor market exists and hired and family labor are perfect substitutes). Household production is subject to a technology function and profits are subject to prices for inputs and outputs. Production constraints such as fixed factors, denoted by a vector of exogenous farm characteristics Φ_{Prod}, are arguments in the production function. Market constraints on production and/or consumption are functions of exogenous characteristics Φ_{Market}.

The general model is:

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

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

$$H(\mathbf{Q}, \mathbf{X}; \Phi_{Markets}) \qquad (\gamma) \tag{3}$$

In this basic formulation the household chooses a vector of consumption levels, **X**, and output levels, **Q**. Letting λ denote the shadow value of income and γ, the shadow value on the market constraint H, the Lagrangian corresponding to this general model is:

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

The first-order conditions are:

For all consumed goods X_i $$U'_{x_i} = \lambda p_i + \gamma_i \tag{5}$$

For all produced goods Qj $$C'_{Qj} = p_j - \frac{\gamma_j}{\lambda} \tag{6}$$

For all tradeable goods $$p_i = \overline{p}_i \quad \text{and } \gamma, \lambda = 0 \tag{7}$$

(where $\overline{p}_i$ is an exogenous market price)

For nontradable goods $$p_i = \rho_i \text{ and } X_i - Q_i = 0 \tag{8}$$

where ρ_i, the household shadow price, is determined by the internal equilibrium of supply and demand for good i.

$$\rho_i = \frac{U'_{X_i}}{U'_Y} = \frac{\gamma_i}{\lambda}, \qquad \lambda, \gamma > 0 \tag{9}$$

(Note that this model collapses to the standard agricultural household model presented in Singh, Squire and Strauss when constraint (3) is not binding.)

The general solution to the household maximization problem yields a set of optimal production levels, Q*, and consumption levels, X*:

$$Q = Q_i^*(p, \Phi_{HH}, \Phi_{Prod}, \Phi_{Markets}) \tag{10}$$

$$X_i = X_i^*\left(p, Y^*, \Phi_{HH}, \Phi_{\mathrm{Pr}od}, \Phi_{Markets}\right) \tag{11}$$

where Y* denotes income associated with the optimal production levels Q*.

Nested within this general solution is the special case of perfect markets in which Φ_{Prod} affects only production and Φ_{HH} affects only consumption demand, but $\Phi_{Markets}$ have no effect on either. When some markets are missing, production depends upon shadow prices, which, in turn, are functions of other variables shaping consumption and market access. If, as mentioned in the previous section, there are decreasing returns to scale in production activities, then even within the perfect markets case an interior solution for a diverse production set is possible. For example, if yields for different crops depend on land quality and the quality of the farm's land endowment is heterogeneous, a mix of crop activities is possible.

Assuming that the household does not value diversity for its own sake—that is, diversity is not explicitly in the utility function—the diversity outcome takes the form of a derived demand, $D = D\left(Q^*(p, \Phi_{HH}, \Phi_{Prod}, \Phi_{Markets})\right)$, resulting from the farmer's utility maximization subject to income, production, and market constraints. This can also be called latent diversity as the diversity outcome exists only as a result of the farmers' behavior given market prices and does not enter the model as a choice variable. In the special case of perfect markets, the diversity outcome simplifies to $D = D\left(Q^*\left(p, \Phi_{\mathrm{Pr}\,od}\right)\right)$. In short, the perfect markets case is nested within the general agricultural household model of both production and diversity.

I.2.2. Missing Markets

Markets may be present in some form, but households may not use them for transactions or base their activity-participation decisions on exogenous market prices. Individual households may face high transactions costs caused by geographic and cultural isolation. These transactions costs may cause market failures, which prevent a fully recursive, separable model solution. When transaction costs create a wide enough price band, households' internal equilibrium of supply and demand may fall within the band, leading to self-sufficiency and making household production and consumption decisions a function of subjective valuations or "shadow prices." This will force the household to satisfy all of its demand for the good through its own production. One explanation for the management of crop diversity is the lack of a market for quality of locally produced items. High quality maize may not be marketed, and low quality maize is marketed because its quality is hidden. The result is that the bad maize drives out the good. Our field work in the market at Cuetzalan, Puebla, revealed that merchants reported a local village as a source for maize that actually was imported. Inexpensive, low quality maize was imported both by the government store and by private traders. While farmers are able to market some of their maize through local channels, they are unable to sell large quantities and obtain a price premium for quality.

An important area where there may be high transaction costs is in the hiring of labor and availability of liquidity or credit to hire labor. When a household has off-farm opportunities with a high wage (and possible low income variance), inability to hire labor may induce a switch into a less labor intensive cropping system. Imperfect labor substitutability has potentially important ramifications for the milpa, an inter-cropping system that is more labor intensive (and less intensive in purchased inputs) than mono-cropping. It also may have ramifications within the milpa because of variations in labor intensity among milpa crops.

In order to test whether missing markets affect diversity outcomes, we include market and household characteristics in our models for diversity. The market conditions contained in Φ_{Market} reflect the degree of isolation or integration with respect to regional markets. A vector of household socio-demographic characteristics, Φ_{HH}, includes variables hypothesized to influence production under imperfect-market scenarios but not otherwise.

I.2.3. Testable Hypotheses

The starting point for determining diversity outcomes is to test for the separability of effects of consumption and production decisions on diversity. In a separable or recursive model, only market prices and production constraints affect production decisions (Singh, Squire and Strauss). This implies a null effect of other variables on diversity outcomes. The null hypothesis is:

$$\frac{\partial D}{\partial \Phi_{HH}} = 0, \quad \frac{\partial D}{\partial \Phi_{Markets}} = 0 \qquad \text{(H1)}$$

where Φ_{HH} and Φ_{Farm} are vectors of exogenous variables other than market prices and production constraints (Benjamin; Skoufias).

If we reject the null hypothesis of non-separability, we then turn to how the development of local markets can affect household conservation of CGRs. A missing market for one variety or for some trait embodied in that variety can induce a household to produce the variety if the household's subjective valuation of the variety (Equation 9) is sufficiently high. Given other resource (e.g., land and human capital) constraints, a change in production of one such variety may alter the household's entire set of production choices inside and outside the milpa. The survey that is the basis for our econometric analysis was carried out in a series of communities with varying degrees of market integration. This allows us to test whether the level of market integration affects the level of milpa diversity that a household maintains.

Different markets can affect the household's diversity behavior in different ways. Two key markets of interest are the commodity market, for outputs of the milpa or consumption substitutes, and the local labor market. Effects of commodity market imperfection will be tested by estimating the effect of transactions costs (proxied by distance to markets) on household diversity outcomes. In the perfect markets case these effects should be nil. Otherwise, they are ambiguous. Although we would expect commodity market integration to decrease the household's level of diversity, by providing the household with access to diversity for consumption, it could increase diversity by enabling the household to supply diverse varieties to the market and receive a price premium (e.g., for a favorable consumption characteristic). Labor market effects will be tested by extending the approach proposed by Benjamin and Skoufias to diversity outcomes: under the null hypothesis of perfect labor markets, family demographic variables, including household size, should not affect diversity. Finally, influences of imperfect credit and risk markets will be tested by estimating the effect on diversity of the level of household wealth, a proxy for risk aversion, exposure to risk, and probably also access to liquidity.

Within the milpa, we test whether market variables have differential effects on the different crops, reflecting differential market access on the input or output side. This is crucial for understanding potential sources of the erosion of milpa CGR in the context of increasing market integration. The relevant hypotheses are:

$$\frac{\partial D_{Maize}}{\partial \Phi_{Market}} = 0, \frac{\partial D_{Beans}}{\partial \Phi_{Market}} = 0, \frac{\partial D_{Squash}}{\partial \Phi_{Market}} = 0 \tag{H2}$$

Maize is the most commercial crop in the SNP. Although most households ultimately are net buyers of maize, many sell small quantities throughout the year, and maize makes up a large share of consumption expenditures. Nevertheless, there is a high volume of low quality substitutes for maize, including imported varieties available at government (DICONSA) stores. Beans are semi-commercial, almost entirely for home consumption, except for a seasonal green market for one variety. Squash is completely non-commercial and produced entirely for home consumption. Beans and squash are dependent upon the inter-cropping system for their existence in the milpa, and this may make them particularly sensitive to the availability of family labor, the key input to inter-cropping. Therefore, the effects of the economic variables can be different for each crop.

Previous studies have focused on the principal staple crop and ignored possible loss of CGR in other crops. The model we estimate below permits us to explore whether minor inter-cropped species are more at risk than the principal crop and whether given variables have differential effects across, as well as within, species. The possible value of this complex cropping system for generating diversity and maintaining ecological interactions motivates our comparison of the milpa system to its individual crop components.

II

Data and Variable Construction

The data used in this paper are from an original household survey of 281 households in 24 villages in the Sierra Norte de Puebla (SNP), a mountainous region of Mexico delimited, and isolated, by two major river valleys. Commerce in the region is dominated by two major regional markets at Cuetzalan and Zacapoaxtla, Puebla, which are connected by a federal highway. The region's agro-climatic conditions are divided into two major regions, each with different agronomic potential and commercial crops: above 1200 masl, a cold temperate region, and below 1200 masl a hotter sub-tropical region. The survey sample was structured to capture variation in levels of market integration in the region as well as to incorporate a wide range of geographic, agro-ecological, agronomic, and cultural diversity.

In this paper simple richness measures, or counts of the number of crops and varieties the household plants in the milpa, are the basic measures of CGR diversity at the household level. These variables are summarized in Table 1. The first variable, total varieties, is constructed by summing together the number of varieties of maize, beans and squash.

[Table 1]

The total varieties variable is useful for constructing and testing model specifications, as it takes into account the diversity generating process for all three crops of study. Therefore, the model is first fit to the most general specification with total varieties and the broadest set of regressors. Next, the same specification is run for each individual crop group to test whether the same factors are driving diversity within each group.

II.1. Explanatory Variables

The variables are divided into three groups, following the model specification: Household characteristics, Φ_{HH}, farm production characteristics, Φ_{Prod} and Market Characteristics, Φ_{Market}.

The set of variables Φ_{HH} describes household characteristics. These are defined and summarized in Table 2. The variable age is included to test whether older farmers have a higher propensity to conserve CGR diversity because of traditional practices or taste preferences. The variable used here is the Mincer experience variable, which is defined as experience = (age - years of schooling of household head - 5). A quadratic experience term is also included.

[Table 2]

Family size, or number of adults living in the household, represents the pool of family labor available to the household for cultivating the milpa and other activities. The sign for family size is expected to be positive if minor varieties of crops and the inter-cropped milpa system are intensive in family labor and perfect hired substitutes are not available (Benjamin). The wealth variable is an index constructed from the number of rooms in the home, the construction materials of the floor, walls and roof of the home, and the ownership of major durable goods.

Farm characteristics, $\Phi_{\mathbf{Prod}}$, include variables that would be hypothesized to affect production decisions (and thus diversity) in a separable agricultural household model. Typically, these variables would include total land holdings and input and output prices (Singh, Squire and Strauss). We include other agro-ecological constraints (fragmentation as well as size of land holdings and land quality). There was insufficient price variation in the cross-section data to include prices in our regressions.

[Table 3]

The number of plots that the household cultivates is a proxy for uniformity of land holdings and incentives to match varieties to different agro-ecological conditions (assuming these are different on different plots). A dummy for high altitude separates the study region into two major climate zones. The slope dummy variable equals one if the household farms two different parcels, one flat and one on a steep slope. This variable is used to proxy for multiple agro-climactic niches within farms. The soil quality index variable is the percentage of total household landholdings that are of a (subjectively) favorable soil quality.

Although the milpa may include multiple crops, maize cultivation is a defining characteristic of this production system. The last variable, area in maize production, is similar to what is used in other studies on the adoption and diffusion of agricultural technologies. However, to correct for possible endogeneity, we instrumentalize this variable using a regression of the number of maize hectares on exogenous household variables, including total landholdings.

The final set of variables represents market constraints, Φ_{Market}, to test the hypothesis that market integration influences household diversity. In order to develop proxy variables for the effects of missing markets and transactions costs, it was necessary to construct a set of village level variables.

[Table 4]

A proxy for transactions costs is calculated by the distance to the closer of either of the major regional markets at Zacapoaxtla or Cuetzalan. It reflects the cost to households of marketing their output or of going to the market to purchase milpa products or their substitutes. The hired labor intensity is a village-wide average of the hired-labor share of total labor used in the milpa. We assume that it reflects access—both on the supply and demand sides—to hired labor markets, which we expect to ambiguously affect labor-intensive milpa diversity. A measure of migration networks was also included to control for potential lost labor and remittance effects on production and thus diversity in a context of imperfect markets, as hypothesized by the new economics of labor migration (Taylor and Martin; Stark). This index is calculated as the percentage of households in the village with migrants in the year prior to the survey. Other things being equal, labor shortages due to migration are likely to have a negative effect on labor-intensive milpa activities if local labor markets are imperfect. However, income remittances from migrants could provide liquidity to purchase labor substitutes. (e.g., see Taylor, de Brauw and Rozelle). The impact of migration, like local labor markets, on diversity is therefore ambiguous.

III

Findings

Planting milpa crops is a basic condition for maintaining diversity. To model diversity of milpa plantings we use a Poisson regression because of the discrete, count nature of the dependent variable. This econometric approach can be linked to the theoretical model through a random-utility type framework involving a series of discrete decisions of whether to plant individual crops (Hellerstein and Mendelsohn). The count data specification has the additional advantage of providing flexibility to compare parameter estimates in a model of total system diversity as well as diversity within each crop.

Four Poisson regressions were estimated: one for the total number of milpa varieties and one each for the number of maize, bean and squash varieties cultivated by the household. The results are reported in Table 5. The primary results are for the total number of varieties in the milpa, followed by the results of the individual regressions for each crop.

III.1. Total Milpa Varieties Regression

The econometric findings confirm that all three groups of variables—household, production, and market—significantly shape milpa diversity. In order to test for separability of the model, a joint test for the significance of each group of variables was implementeded. Each group of variables— household, agro-ecological, and market—was found to be jointly significant at below the 0.01% level (chi-squared statistics of 14.61 (4 d.f), 52.98 (5 d.f.), and 48.37 (4 d.f), respectively. These findings lead us treject separability. They also suggest multiple explanations for a lack of separability in the model, related to various market imperfections.

The estimated coefficients on the market variables suggest that an increase in the level of market integration decreases the level of diversity in a farmer's field. It is important to remember that the first three variables, transactions costs, hired labor intensity and village US migration are all village-wide variables. The village variables are less direct than household specific variables, but they have the advantage of describing village markets and economic contexts that may be operating at above the household level. The coefficient on the variable for transactions costs, proxied by distance from a market center, is positive and significant: the more removed a household is from a major market center, the greater the number of varieties planted in the milpa. Transaction costs create price bands, increasing prices for buyers and reducing prices for sellers. Our findings are consistent with the hypothesis that price bands become wider at larger distances from market centers. The wider the price band becomes, the more likely the household will engage in subsistence production, guided by internal subjective valuations instead of by market prices (Key, Sadoulet and de Janvry). Our findings suggest that households distant from markets are more likely to produce a diversity of milpa products to satisfy demand for diversity in consumption.

The coefficient on the village hired labor intensity variable is negative and significant. This suggests that diversity in the milpa decreases as local labor markets develop. The impact of U.S. migration networks on diversity is also significant and negative: households in villages with a high village-wide level of international migration are less likely to plant a diverse milpa system. These negative labor market and migration effects may reflect rising opportunity costs of household time on the farm as labor and migration markets develop. They also may reflect income smoothing and income insurance through off-farm labor, which decrease households' need to self-insure through crop diversification.

The coefficient on household wealth is negative and significant. The greater the wealth of the household, as proxied by house construction and ownership of durable goods, the less likely the household is to plant a diverse set of milpa crops. This finding is consistent with a risk motivation for "investing" in diversity, where decreasing risk aversion and greater ability to self-insure gives wealthy households less of a need to invest in a portfolio of crop varieties. The wealth effect is not limited necessarily to risk. Wealth may be a proxy for networks, information, and access to outside market opportunities in the presence of various kinds of market imperfections.

Older farmers plant significantly more varieties than younger farmers. That is, the older generation of farmers are the principal stewards of CGR diversity in this study area. This raises the danger that diversity may decline inter-generationally, as old farmers cease cultivation. The quadratic term for the age of the household head squared is negative, which implies that the oldest farmers eventually decrease the number of varieties they grow (or exit the milpa).

The number of household plots, our index for fragmentation of the agricultural landscape, has a positive and significant influence on diversity, consistent with a process of matching varieties to diverse soil or micro-climatic conditions. Elevation is an agro-ecological variable that describes a number of different climactic conditions and agronomic possibilities. The estimation results show that a household located in the higher altitude zone is more likely to grow a more diverse milpa system. In this study area, maize dominates the agricultural landscape in the higher, temperate region (Tierra Fria) while coffee dominates in the lower, tropical region (Tierra Caliente). Tropical zones may experience more intense pressures both from weed competition and insectivore and microbial predation. The effect of our third agro-ecological variable, an indicator of whether the household cultivates different plots with different slopes, is also positive and significant. The instrument for total area in milpa is positive and significant—*ceteris paribus*, farmers plant a larger number of varieties in larger milpa areas.

III.2. Individual Crop Regressions

Agro-ecological characteristics dominate the regression results for the number of maize varieties. Mirroring findings from the total milpa varieties regression, the number of maize varieties cultivated is significantly higher for households in the high altitude zone, for households planting parcels with different slopes, and for households with greater total land area planted in milpa. The positive effect of multiple slopes on maize diversity is consistent with Bellon and Taylor's findings that farmers match maize varieties to agro-ecological conditions. The fact that multiple maize varieties increase with the instrument for area planted to maize may indicate the presence of economies of scale for diversity, at least in the range of land areas included in this sample.

The market variables, which strongly explain milpa diversity, do not explain the diversity of maize varieties within the milpa. Maize production and exchange are pervasive even in areas characterized by poorly developed labor markets and infrastructure. This makes it difficult to obtain significant coefficients on the market variables in the maize diversity regressions, and it highlights the importance of modeling infra-species diversity in the context of other production decisions.

By contrast, agro-ecological and market variables are all important in explaining diversity in beans and squash. The effects of transaction costs are positive and significant; that is, the closer the household is to a market center the more likely that it grows only one bean variety or exits bean cultivation altogether. It appears that minor crops such as beans are relatively easily replaced by market substitutes. The intensity of hired labor use or extent of local agricultural labor markets decreases the number of bean varieties grown. Family labor is a crucial input in the production of inter-cropped beans. Finally, the level of wealth decreases the probability of growing beans, suggesting that wealthy households have less demand for expanding crop portfolios to minor crops. Like maize, the number of bean varieties increases with location in the high altitude region and with parcels with heterogeneous slopes.

Household variables, agro-ecological variables and market variables significantly explain the number of squash varieties grown and indicate the adaptation of cropping systems to agro-ecological heterogeneity and market conditions. The effect of hired labor intensity is again negative and significant: a greater degree of family labor use in the milpa corresponds to a larger number of squash varieties grown.

IV

Conclusions

The findings reported above have implications both for designing policies to conserve CGR in specific local contexts and for modeling household behavior with respect to crop and activity choices. Our econometric results underline the importance of studying diversity in the context of larger cropping systems. The forces shaping CGR conservation (or erosion) are not uniform for principal and secondary crops. Modeling diversity in the context of whole cropping systems adds a new dimension to CGR conservation research based on single crops.

Findings from both multiple and individual crop regressions confirm the centrality of markets in shaping diversity. Integration into regional commodity as well as factor markets shapes diversity at the farm level. There appears to be a tradeoff between development and diversity: as regional markets develop and demand for local factors such as hired labor increases, the level of diversity on farms decreases. The traditional explanation for diminishing CGR in centers of diversity focuses on the replacement of farmer cultivars with Green-Revolution type varieties. However, our findings reveal that even without competition from new varieties the processes of economic development leads to a simplification of the agricultural system and loss of local CGR.

References:

Bellon, M. R., Pham, J., and Sebastian, J. S. (1998). "Farmers' Perceptions of Varietal Diversity: Implications for On-Farm Conservation." Farmers, Gene Banks, and Crop Breeding, M. Smale, ed., Kluwer, Boston.

Bellon, M. R., and Taylor, J. E. (1993). ""Folk" Soil Taxonomy and the Partial Adoption of New Seed Varieties." *Economic Development and Cultural Change*, 41(4), 763-86.

Benjamin, D. (1992). "Household Composition, Labor Markets, and Labor Demand: Testing for Separation in Agricultural Household Models." *Econometrica*, 60(2).

Brush, S. B., Taylor, J. E., and Bellon, M. R. (1992). "Technology Adoption and Biological Diversity in Andean Potato Agriculture." *Journal of Development Economics*, 39(2), 365-387.

Dejanvry, A., Fafchamps M., Sadoulet E. (1991). "Peasant Household Behaviour With Missing Markets - Some Paradoxes Explained." *Economic Journal* **101**(409): 1400-1417.

Hellerstein, D., and Mendelsohn, R. (1993). "A Theoretical Foundation For Count Data Models." *American Journal of Agricultural Economics*, 75(3), 604-611.

Just, R. (2000). “Some Guiding Principles for Empirical Production Research in Agriculture.” *Mimeo*, University of Maryland.

Key, N., Sadoulet E. and de Janvry A.. (2000). “Transaction Costs and Agricultural Household Supply Response.” *American Journal of Agricultural Economics* 82(2):245-259 (May).

Louette, D., Charrier, A., and Berthaud, J. (1997). "In situ conservation of maize in Mexico: Genetic diversity and maize seed management in a traditional community." *Economic Botany*, 51(1), 20-38.

Louette, D., and Smale, M. (2000). "Farmers' seed selection practices and traditional maize varieties in Cuzalapa, Mexico." *Euphytica*, 113(1), 25-41.

Meng, E. C.-H. (1997). "Land allocation decisions and In situ conservation of crop genetic resources : the case of wheat landraces in Turkey."

Perales Rivera, H. R. (1996). "Conservation and evolution of maize in Amecameca and Cuautla valleys of Mexico."

Skoufias, E. (1994). "Using Shadow Wages to Estimate Labor Supply of Agricultural Households." American Journal of Agricultural Economics **76**(2): 215-227.

Stiglitz, J.E. "Markets, Market Failures, and Development." American Economic Review 79(2):197-203, 1989.

Taylor, J. E., Adelman, I. (2002) "Agricultural Household Models: Genesis, Evolution and Extensions." Review of Economics of the Household, I(1), 2002.

Taylor, J. E., and Martin, P. L. (2000). "Human Capital: Migration and Rural Population Change." Handbook of Agricultural Economics, G. Rausser and B. Gardner, eds., Elsevier, New York.

Taylor, J. E., de Brauw A. and Rozelle S. (In Press). "Migration and Incomes in Source Communities: A New Economics of Migration Perspective from China." Economic Development and Cultural Change.

Widawsky, D., Rozelle, S., Jin, S., and Huang, J. . (1998). "Pesticide Productivity, Host-Plant Resistance and Productivity in China." *Agricultural Economics*, 19(1-2), 203-17.

Figure 1: Marginal Value Product (MVP) of crops A and B vs. a fixed factor of production.

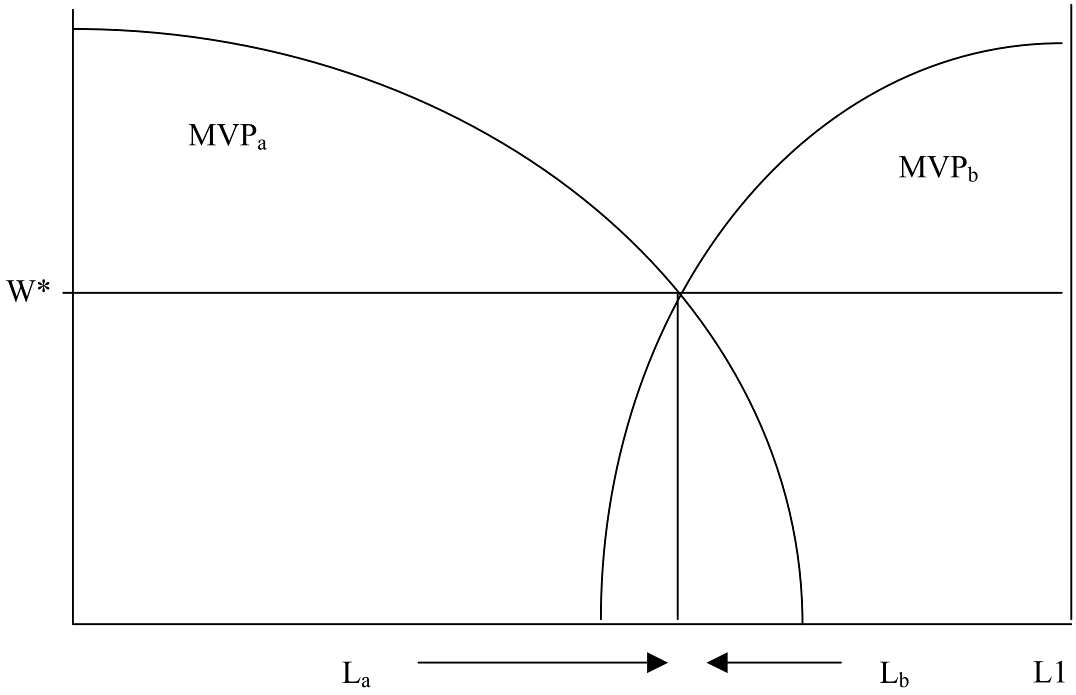

Figure 2: PPF for two goods with outputs Q_a and Q_b , with a missing market for good A.

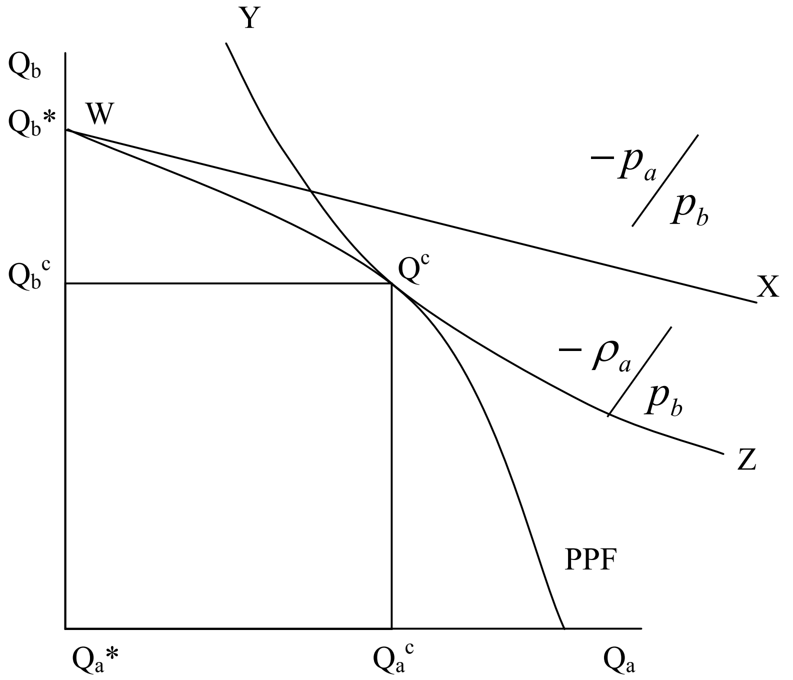

Figure 3 Constraint caused by a missing market for an input

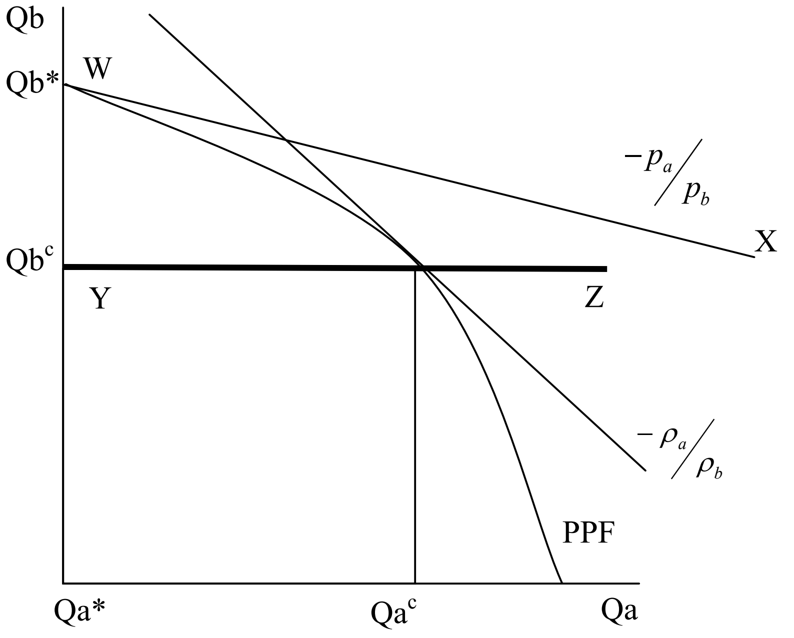

Table 1 : Dependent Variables

	Mean	Std.Dev.	Min	Max
Total Varieties	2.41	1.82	0	9
Total Maize Varieties	1.01	0.73	0	4
Total Bean Varieties	0.66	0.73	0	3
Total Squash Varieties	0.74	0.88	0	3

Table 2: HH Characteristics

	Mean	Std.Dev.	Min	Max
Age of HH head (Mincer Experience Variable)	43	15.31	6	91
Age Squared / 100	20.8	13.9		
Yrs of Schooling of HH head	3.33	2.83	0	15
Family Size (adults)	5.14	2.18	1	10
Wealth	6.86	3.93	0	28

Table 3: Farm Production Characteristics

	Mean	Std.Dev.	Min	Max
Number of Plots	1.15	0.90	0	4
High Altitude Dummy	0.420	0.49	0	1
Multiple Slopes	0.071	0.26	0	1
Soil Quality Index	0.656	0.45	0	1
Maize Hectares (Predicted)	0.76	0.65	0	5.7

Table 4: Market Characteristics (Village Level)

	Mean	Std.Dev.	Min	Max
Transactions Costs	6.67	4.34	0	15
Hired Labor Intensity	0.562	0.17	0.212	0.91
VillageUS Migration	0.089	0.077	0	0.27

Table 5 - Set of Poisson Regression Results

		Total Varieties		Maize Varieties		Bean Varieties		Squash Varieties	
		Coeff.	t-ratio	Coeff.	t-ratio	Coeff.	t-ratio	Coeff.	t-ratio
	Constant	-0.158	-0.39	-0.744	-1.19	-1.686	-2.14 **	-1.190	-1.63
HH variables	Age of HH head	0.037	2.65 ***	0.032	1.47	0.034	1.32	0.045	1.80 *
	Age Squared	-0.031	-2.08 **	-0.035	-1.48	-0.021	-0.80	-0.035	-1.31
	Yrs School HH head	0.062	2.85 ***	0.013	0.39	0.075	1.77 *	0.096	2.53 **
	Family Size	0.027	1.49	0.017	0.59	0.039	1.16	0.031	0.92
Agro-Ecological	Plots	0.113	2.17 **	0.118	1.48	0.090	0.91	0.100	1.07
	High Altitude Dummy	0.457	5.39 ***	0.268	2.07 **	0.562	3.50 ***	0.513	3.36 ***
	Multiple Slopes	0.489	3.95 ***	0.536	2.91 ***	0.410	1.72 *	0.505	2.24 **
	Soil Quality Index	0.045	0.49	0.042	0.30	0.102	0.59	-0.051	-0.31
	Maize Hectares	0.129	1.87 *	0.168	1.69 *	0.114	0.82	0.101	0.82
Market Variables	Transactions Costs	0.024	2.03 **	0.019	1.07	0.059	2.55 **	0.002	0.08
	Hired Labor Intensity	-1.317	-3.97 ***	-0.786	-1.58	-1.485	-2.33 **	-2.013	-3.33 ***
	Village US migration	-1.282	-2.36 **	-0.915	-1.10	-1.326	-1.32	-1.479	-1.51
	Wealth	-0.024	-2.03 **	-0.019	-1.07	-0.046	-1.99 **	-0.014	-0.68
	Deviance R Squared	0.30		0.24		0.23		0.14	

Hypothesis Tests

		LRT	Prob	LRT	Prob	LRT	Prob	LRT	Prob
Household variables = 0	(d.o.f. = 4)	14.61	0.994 ***	3.25	0.483	5.83	0.788	8.41	0.922 *
Agro-ecological variables = 0	(d.o.f = 5)	52.98	1.000 ***	20.28	1.000 ***	16.92	0.998 ***	17.30	0.998 ***
Market variables = 0	(d.o.f. = 4)	48.37	1.000 ***	10.40	0.966 **	32.50	1.000 ***	17.24	0.998 ***

Significance levels are denoted by * at the 10% level, ** at the 5% level, and *** at the 1% level.