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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, crop system, approach and a limited-dependent variable econometric technique to model *in situ* conservation of both intra- and infra-species crop diversity in a context of heterogeneous ecological and market environments, using 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 and economic environments.

Crop genetic resources (CGRs) 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 modern and traditional varieties of principal staple crops (wheat, rice, maize, potatoes) to explore why traditional varieties persevere, *de facto*, in certain areas without being completely displaced despite their allegedly inferior yields (Brush *et al*., 1992; Bellon *et al*., 1998; Widawsky *et al*., 1998; Meng *et al*., 1998; Bellon and

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Taylor, 1993; Louette *et al*., 1997; Louette and Smale, 2000; Perales *et al*., 2003).

Genetic erosion, however, does not occur solely because of direct competition between traditional and improved varieties of the same species. It occurs at multiple levels that include both principal and secondary crops in multiple cropping systems. 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 for conservation, including beans, squashes, chilies, tomato, etc. When specialization 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 the context of multi-dimensional diversity and heterogeneous ecological and market environments.

1. Conceptual model

We define CGR conservation as 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 an 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 CGR 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, 2000). This model is estimated using limited dependent variable techniques in Section 2, below. A similar nested modeling approach was utilized by Smale *et al*. (1994) 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.

1.1. 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.

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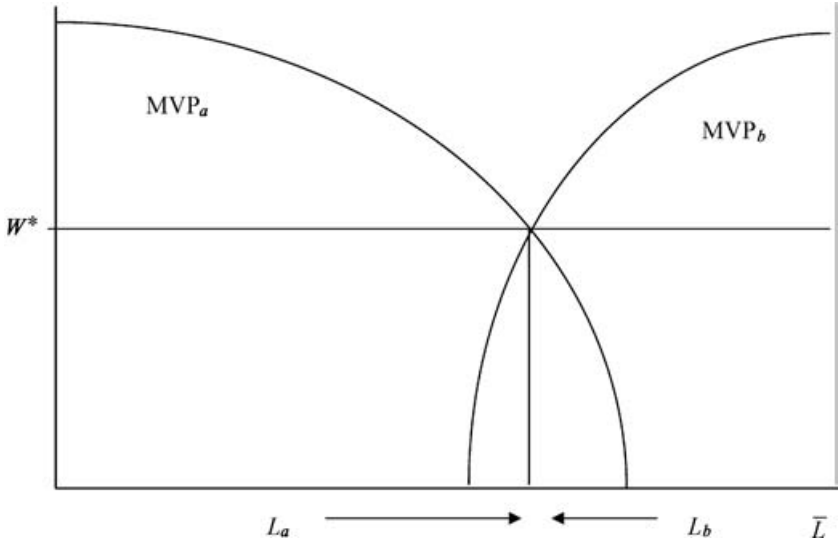


Figure 1. *Marginal Value Product (MVP) of crops a and b vs. a fixed factor of production*

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).

In figure 1, the factor input L, fixed at $\bar{L}$, 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^*.

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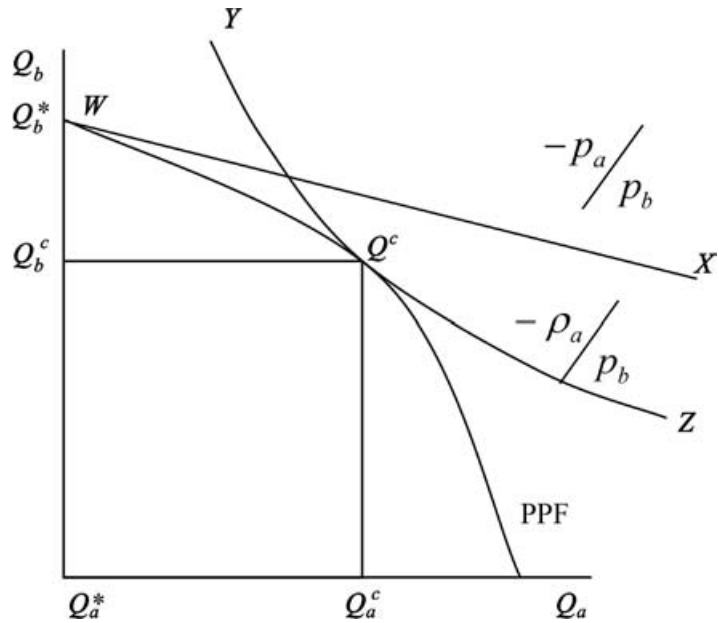


Figure 2. *PPF for two goods with outputs Q_a and Q_b, with a missing market for good a.*

Another example of decreasing returns to scale involves soil heterogeneity and the matching of varieties to soil conditions (e.g., Bellon and Taylor, 1993). 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. The marginal productivity of the principal staple variety may decline as inferior lands are brought into production, and an alternative variety may be superior under these (ecologically challenged) conditions. Decreasing quality at the extensive margin was precisely what Ricardo used to motivate concavity of the production function in his 1817 treatise *On the Principles of Political Economy and Taxation*.

Case 2: 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, 1989; de Janvry *et al.*, 1991). Figure 2 illustrates the effect of a missing market for an output, specifically, crop *a*.

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*, the slope of which equals the negative of the ratio of the price of crop *a* to

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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 (including a missing market for a specific quality or trait), all household consumption demand for crop 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_b^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 of this price line reflects diminishing marginal utility of household consumption of the non-market crop. Although it may not appear to be profitable based on regional output prices, the market-constrained household cultivates a certain amount of the crop 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 lead 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 YZ 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.

Missing markets for factor inputs may affect production choices. If hired labor is not available or is an imperfect substitute for family labor, the household is limited by its endowment of family labor available for crop 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.

1.2. 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

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where decisions and actions are taken that affect crop diversity. It is the consumer of both household production and goods purchased with income from production or wage labor. It is also the producer, combining its labor, land, and other capital with purchased inputs to produce agricultural commodities either for consumption or sale to markets subject to resource and market constraints (Singh *et al*., 1986; de Janvry *et al*., 1991; Taylor and Adelman, 2002). In the next section, an agricultural household model is presented to identify the effects of key variables on household CGR choices.

Basic model

In the basic model, the household obtains utility from consuming crops $i = 1, 2, \ldots, I$, any or all of which it may also produce.[1] Let X_i denote consumption of good i, and let consumption of all other market goods be denoted by Z.[2] Household utility is affected by exogenous socioeconomic, cultural, or other characteristics, which we denote as a vector Φ_{HH}. Households maximize utility subject to a full income constraint, with income composed of farm income, exogenous income $\bar{Y}$, and an endowment of family time T valued at the market wage, w.[3] Households choose which of j crops, $j = 1, \ldots, J$ to produce and the output of each crop, 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, $C(\mathbf{Q}; \Phi_{Prod})$, where Φ_{Prod} is a vector of exogenous farm characteristics. Market constraints on production and/or consumption are functions of exogenous characteristics Φ_{Market}.

This model can be represented mathematically as

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

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

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

Market constraints, represented by the functions $H(\cdot)$, could take many forms, but 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 own production; that is, if the constraint is binding, $Q_i - X_i = 0$. In this case, the market constraint would take the form, for $i = 1, \ldots, I$,

$$\begin{aligned} H_i(Q_i, X_i; \Phi_{Market}) &= Q_i - X_i \quad && \text{if market } i \text{ is missing,} \\ H_i(Q_i, X_i; \Phi_{Market}) &= 0 && \text{otherwise.} \end{aligned} \tag{3'}$$

[1] Consumption without production, of course, requires access to well-functioning markets for specific crops and qualities.

[2] Without loss of generality, we can normalize the price of this composite market good to one, so that Z can be construed in value terms.

[3] Inclusion of the time endowment in this full income constraint assumes a well-functioning labor market and availability of hired substitutes for family labor. If this is not the case, time is omitted from full income and the market constraint for labor (below) is binding.

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As motivated in figure 2 above, these constraints represent costs of transacting in markets for consumption goods. When the household can supply itself with good i in the market with no transactions costs, constraint $H(\cdot)$ drops out. However when transactions costs, characterized by Φ_{Market}, force the household to satisfy consumption from own production, the function $H(\cdot)$ is binding. The market characteristics Φ_{Market} determine whether a household faces transactions costs for each crop i the household consumes.

The household chooses a vector of consumption levels, $\mathbf{X}$, and output levels, $\mathbf{Q}$. Letting λ denote the shadow value of income and, γ, a $(1 \times I)$ vector of shadow values γ_i on the market constraints for goods $i = 1, \ldots, I$, the Lagrangian corresponding to this general model is

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

The first-order conditions are

$$\text{For all consumed goods } X_i \qquad U'_{X_i} = \lambda p_i - \gamma_i \tag{5}$$

$$\text{For all produced goods } Q_j \qquad C'_{Q_j} = p_j - \frac{\gamma_i}{\lambda} \tag{6}$$

$$\text{For all tradable goods} \qquad p_i = \bar{p}_i \text{ and } \gamma_i = 0 \tag{7}$$

where $\bar{p}_i$ is an exogenous market price.

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

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

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

As motivated in figure 2, above, constraint (3) represents transactions costs in obtaining consumption good X_i. When the household can transact for good i in the market without transaction costs, constraint $H(\cdot)$ drops out (i.e., the shadow value on the constraint, γ_i, is zero; note that this model collapses to the standard agricultural household model presented in Singh *et al*. (1986) when this constraint is not binding for all i). However, when transactions costs force the household to satisfy consumption from own production, the constraint is binding. The market characteristics, Φ_{Market}, determine whether a household faces transactions costs for each crop i.

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

$$\mathbf{Q} = Q_j^C(p, \Phi_{HH}, \Phi_{Prod}, \Phi_{Market}) \tag{10}$$

$$\mathbf{X} = X_j^C(p, Y^C, \Phi_{HH}, \Phi_{Prod}, \Phi_{Market}) \tag{11}$$

where Y^c denotes full income associated with the constrained-optimal production levels Q^c. For some crops the optimal production level may

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be zero; therefore, the outcome on Q^c will determine which of the j crops the household chooses to produce.[4]

Nested within this general solution is the special (theoretically usually unconstrained) case of perfect markets in which Φ_{Prod} affects only production and Φ_{HH} affects only consumption demand, but Φ_{Market} have no effect on either. That is

$$\mathbf{Q} = Q_j^*(p, \Phi_{Prod}) \tag{12}$$

$$\mathbf{X} = X_i^*(p, Y^*, \Phi_{HH}) \tag{13}$$

where '*' denotes unconstrained optima. In a model with perfect markets, a household will be more likely to end up at corner solutions, such as motivated in figure 2, and specialize. 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 (reflected in vector Φ_{Prod}), 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 within a given household is the result of the choice of which crops to produce, subject to constraints. This 'diversity outcome' in the constrained case takes the form of a derived demand for number of varieties, $D^C = D(Q_j^C(p, \Phi_{HH}, \Phi_{Prod}, \Phi_{Market}))$, 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 constraints and does not enter the model as a choice variable. In the special (and, we believe, usually unrealistic) case of perfect markets, the diversity outcome simplifies to the unconstrained $D^* = D(Q_j^*(p, \Phi_{Prod}))$. In short, the perfect markets case is nested within the general agricultural household model of both production and diversity. Note that $D^c < I (D^* < I)$ when $Q_j^c = 0\ (Q_j^* = 0)$ for one or more crops.

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; the effect of other variables on diversity outcomes is insignificant (Singh *et al.*, 1986). The

[4] Note that, assuming a positive marginal utility of income, expenditure on Z goods is a residual: $Z = Y^c - \sum_i p_i Xi$.

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null hypotheses to test for market separability are

$$\frac{\partial D}{\partial \Phi_{HH}} = 0, \quad \frac{\partial D}{\partial \Phi_{Market}} = 0 \qquad \text{(H1, H2)}$$

where Φ_{HH} and Φ_{Market} are vectors of exogenous variables other than market prices and production constraints (Benjamin, 1992; Skoufias, 1994).

If we reject the null hypothesis of non-separability, we then consider how the development of local markets affects household conservation of CGR. 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 (described below) 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 commodity markets for outputs of the *milpa* (or consumption substitutes) and the local labor market. Effects of commodity market imperfections 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. Commodity market integration may decrease the household's level of diversity by providing the household with access to diversity for consumption. However, 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). One explanation for the maintenance 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 fieldwork in the market at Cuetzalan, Puebla, revealed that some 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. One example of a missing market is the (perhaps not uncommon) case where households derive utility from growing their own food.

Non-separability due to imperfect commodity and/or labor markets will be tested by extending the approach proposed by Benjamin (1992) and Skoufias (1994) to diversity outcomes: under the null hypothesis of perfect labor and commodity markets, family demographic variables, including household size, should not affect diversity. 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. Finally,

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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. When a household has off-farm opportunities with a high wage (and possible low income variance), an inability to hire labor may induce a switch to a less labor-intensive cropping system.

We test whether market variables have differential effects on the probability of cultivating individual *milpa* crops, reflecting differences in market access on the input or output side. This is crucial for understanding potential sources of erosion of *milpa* CGR in the context of increasing market integration. Our key market hypotheses are

$$\frac{\partial D_{Maize}}{\partial \Phi_{Market}} = 0, \quad \frac{\partial D_{Beans}}{\partial \Phi_{Market}} = 0, \quad \frac{\partial D_{Squash}}{\partial \Phi_{Market}} = 0 \tag{H3}$$

Previous studies have focused on the principal staple crop and ignored possible loss of CGR in other crops. The model we estimate permits us to explore whether minor intercropped 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.

2. Data and field site

The data used in this paper are from an original household survey conducted in 1999 in the Sierra Norte de Puebla (SNP), a mountainous region of Mexico delimited and isolated by two major river valleys. Commerce in this 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 cool tropical mid-altitude, and below 1200 masl a humid tropical lowland. 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.

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 intercropping system for their existence in the *milpa*, and this may make them particularly sensitive to the availability of family labor, the key input to intercropping. Therefore, the effects of the economic variables can be different for each crop.

The survey was carried out as a part of the McKnight Foundation Collaborative Crop Research MILPA project, composed of a joint Mexico–US

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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

research team of botanists, biologists, crop breeders, and social scientists. The authors surveyed 281 households in 24 villages in the Sierra Norte de Puebla. The survey was structured to cover a representative sample of villages in the study area. The villages were chosen to incorporate a wide range of geographic, agro-ecological, agronomic, market, and cultural diversity. Within each village, households were selected at random. Further information on the survey is detailed in VanDusen (2000).

We use simple richness measures, or counts of the number of crops and varieties the household plants in the *milpa*, as our 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. While the total number of possible varieties is ten, the most grown by any household is nine. However the average number is far lower, at 2.4, and the median is lower still, at only two varieties per household.

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 under study. Therefore, the model is first fit to the most general specification with total varieties and the broadest set of regressors. The same specification is then used to model each individual crop group to test whether the same factors are driving diversity within groups.

2.1. Explanatory variables

Explanatory variables are classified 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. Following standard economics practice, the variable used here is the Mincer experience variable, which is defined as age − years of schooling of household head − 5. A quadratic experience term is also included.

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 of the effect of family size on CGR 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, 1992). Beginning-of-period wealth is proxied by an index constructed from the number of rooms in the home, the construction

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Table 2. *Household 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

materials of the floor, walls, and roof of the home, and the ownership of major durable goods. The wealth index excludes current income and investments in order to minimize endogeneity with current year household choices.

Farm characteristics, Φ_{Prod}, include variables that are hypothesized to affect production decisions (and thus diversity) in a separable agricultural household model (table 3). Typically, these variables would include total land holdings and input and output prices (Singh *et al*., 1986). There was insufficient price variation in the cross-section data to include prices in our regressions. We also include other agro-ecological constraints (fragmentation as well as size of land holdings and land quality).

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 variable for high altitude separates the study region into two major climate zones. The multiple slopes dummy variable equals one if the household farms two different parcels, one flat and one on a steep slope. This variable is used as a 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. Herbicide usage was recorded, and the researchers anticipated that this would be a major factor related to variety choice. However, only 8 per cent of the sample used herbicide, and the correlation with variety and crop diversity was insignificant. While the story of herbicide leading to a decline of intercropping is common in many areas of Mexico, it appears to not be the case at this study site. 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

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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
Village US migration	0.089	0.077	0	0.27

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 set of variables representing market constraints, Φ_{Market}, are used 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 market access 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 purchasing *milpa* products or their substitutes at these market centers. 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, 2000). 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 *et al*., 2003). The impact of migration, like local labor markets, on diversity is therefore ambiguous.

3. 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 framework involving a series of discrete decisions of whether to plant individual crops (Hellerstein and Mendelsohn, 1993). 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.

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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***

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

3.1. 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 implemented. Each group of variables – household, agro-ecological, and market – was found to be jointly significant at below the 0.01 per cent 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 to reject separability and suggest that diversity is shaped by various market imperfections.

An increase in the level of market integration decreases the level of total (inter- and infra-specific) diversity in a farmer's field. The three market variables, the proxy for transactions costs, hired labor intensity, and US migration, are all village-wide variables describing market contexts 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 *et al*., 2000). 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, suggesting that diversity in the *milpa* decreases as local labor markets develop. The impact of US migration networks on diversity is also significant and negative: households in villages with high levels of international migration, other things being equal, are less likely to cultivate a diverse *milpa* system. 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 insurance through off-farm work activities, 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. Decreasing risk aversion and greater ability to self-insure gives wealthy households less incentive 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. This raises the prospect that diversity may decline inter-generationally, as old farmers cease cultivation. The quadratic term for the age of the household head is negative, implying that the oldest farmers

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eventually decrease the number of varieties they grow (or exit the *milpa*; the turning point is at 60 years of age).

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 (Bellon and Taylor, 1993). 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 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.

3.2. Individual crop regressions

Agro-ecological characteristics dominate the regression results for 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 (1993) 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 in this sample.

Market variables, which strongly explained total *milpa* diversity, jointly but not individually 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 may explain the lack of significance of the coefficients on individual market variables in the maize diversity regressions, and it highlights the importance of modeling infra-species diversity in the context of other production decisions.

In contrast to maize, market variables are important in explaining diversity in beans and squash. The effects of the transaction cost proxy are positive and significant; that is, the closer the household is to a market center the more likely it is to grow only one bean variety or to exit 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 the extent of local agricultural labor markets decreases the number of bean varieties grown. Family labor is a crucial input in the production of intercropped beans. Finally, the level of wealth decreases the probability of growing multiple varities of beans, suggesting that wealthy households have less demand for expanding crop portfolios to minor crops than do

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poor households. Like maize, the number of bean varieties is significantly higher in the high altitude region and on 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 heterogeneous agro-ecological and market conditions. The effect of local hired labor intensity is again negative and significant: a greater reliance on family labor in local production corresponds to a larger number of squash varieties grown.

4. Conclusions

The crop systems approach to modeling CGR diversity and the econometric findings reported here have a number of implications for designing policies to conserve CGR in specific local contexts as well as for modeling household behavior with respect to crop and activity choices. They underline the importance of understanding diversity in the context of cropping systems and socioeconomic settings. The traditional explanation for diminishing CGR in centers of diversity focuses on the replacement of farmer cultivars by Green-Revolution type varieties. However, our findings reveal that, even without competition from new varieties, processes of economic development lead to a simplification of the agricultural system and loss of local CGR. Modeling diversity in the context of whole cropping systems and the broader socioeconomic landscape adds a new dimension to CGR conservation research.

We find that the key variables promoting diversity are market isolation, environmental heterogeneity, and generational effects. The centrality of markets in shaping diversity suggests a trade-off between development and diversity: as integration with outside markets increases, the level of diversity on farms is diminished. The same appears true of access to hired labor markets and migration. We also find that diversity is higher in marginal agro-ecological environments. The principal stewards of diversity are not only poor and isolated households but also older farmers. Young farmers are significantly more likely to gravitate towards specialization. This suggests an impending generational shift away from CGR conservation. Economists posit, and our theoretical model suggests, that opportunity costs influence diversity outcomes. If this is so, then in the short run, programs to promote *in situ* CGR conservation might do well by focusing their efforts in zones with limited market access and high levels of environmental heterogeneity, where the opportunity costs of diversification are relatively low. In the long run, however, opportunity costs of CGR conservation are almost certain to rise as even isolated areas become increasingly integrated with regional and global markets for goods and labor.

Most past research focused on CGR within crops, that is, the cultivation of landraces versus hybrid maize. Our econometric findings suggest that the forces shaping CGR conservation or erosion are not uniform between and within crops. Because of this, when studying CGR diversity and designing conservation policies, it is necessary to consider social and economic forces leading to specialization of the entire agricultural system as well as of its component parts. Diversity may decrease due to specialization

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within a crop (e.g., replacement of multiple landraces of maize with a hybrid) or due to elimination of entire crops from household 'production portfolios', a process that has been referred to as 'genomic erosion'. For instance, in the zone we studied, other things being equal, market integration significantly reduces overall diversity but not the number of maize varieties grown. Nevertheless, for the minor crops in the *milpa* system, both market integration and access to hired labor markets negatively affect diversity. When designing targeting strategies for *in situ* conservation of CGR, therefore, it is necessary to consider cross-crop as well as within-crop effects of conservation interventions and seek complementarities in conservation goals. In this respect, our findings echo innovations in US Conservation Reserve payments and multi-functionality in EU agricultural policy, which seek to achieve multiple conservation objectives with single policy instruments. Practical methodologies are needed to target and monitor conservation efforts in multi-crop systems.

On the methodological side, a useful lesson from this study is that it is important to incorporate both household and village context variables into models of CGR conservation. Diversity decisions occur at the household level, but household incentives and constraints are shaped by the economic, social, and environmental contexts in which farmers live. Household data can be used to construct village context variables. It is critical to complement household surveys with the collection of data at the village and regional levels. In some cases researchers and conservation agencies may be able to rely on secondary information available at the village level without the added costs of household-level data. However, in general, successful conservation targeting and monitoring need to utilize some combination of household and community data. Incorporating village-context effects into conservation analysis requires sampling households across multiple sites rather than at single locations. For example, variation in market access across the 24 villages in our survey is what made it possible to identify the negative effects of market integration on diversity.

Finally, the cropping system approach we propose may be useful for uncovering new ways in which crop choices impact CGR diversity. Intercropping may have greater ecological and diversity benefits than suggested by the sum of its individual parts. For instance, a related study in this region has documented wild-cultivated gene flow in beans, which would be more likely in an intercropping system (Gepts *et al.*, 2000). Future research using an even broader approach could more fully encompass the multiple levels of diversity in complex agricultural systems.

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