In Situ Conservation of Crop Genetic Resources in the Mexican *Milpa* System

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Abstract

This dissertation focuses on the theoretical modeling and empirical testing of household motivations for the in situ conservation of crop genetic resources (CGR). An original household survey is used to test whether the household diversity outcomes are different for the cropping system as a whole, for the principal crop, maize, or for the secondary crops, beans and squash. Agro-ecological characteristics and market characteristics are found to significantly affect the levels of diversity maintained by households.

A review of the economic literature relevant to modeling in situ conservation is presented. A theoretical model is developed in which a household's decision to plant a milpa variety is linked to household, agro-ecological, and market variables. A household farm model appropriate to CGR conservation is presented, and extended to the case of missing markets. The agricultural ecology of the Sierra Norte de Puebla is described, as well as the principal CGR in the milpa system. The empirical methodology uses a Poisson regression, for the total number of crop varieties and for each crop group separately. The econometric work is extended to a hurdle model for sample selection, and a SUR model utilizing a Shannon diversity index as a linear measure of diversity.

The results from the regressions of household level diversity show that a range of household, village, environmental, and market conditions affect the diversity outcomes.

Market integration, measured by distance to a regional market, use of hired labor, and international migration, were found to negatively affect diversity outcomes. Agro-

ecological conditions, measured by the number of plots, plots with different slopes, and the high altitude region, all were found to positively increase household diversity outcomes. The econometric findings were different for the combined milpa system than individual crops, and individual crops were affected by different factors. The principal crop, maize, seems mainly affected by the agro-ecological characteristics, while the levels of market integration are found to affect the minor crops, beans and squash. Conclusions are presented on the links between this study and conservation planning issues, and possible directions for future research are discussed.

Dedication

I would like to dedicate this thesis to my incredible and wonderful and beautiful wife, Kara Nelson. In gratitude for her support, her sacrifices, and her inspiration. It is also dedicated to our families, the trellis upon which this vine is allowed to grow.

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“…no, no sembamos maiz por la ganancia.
Sembramos maiz por cuestiones etnicas, cuestiones culturales…”

Xotchitlan, Puebla

“… lo bueno es que ahora tenemos el internet…”

- Zapotitlan, Puebla

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Chapter 1 – Introduction

Background and Motivation

Crop genetic resources (CGR) are the raw materials for crop breeding and a source of continuing advances in yield, pest resistance, and quality improvement. Genetic erosion has been documented in the cradle areas of crop domestication, where the loss of traditional cultivars accompanies the specialization and intensification that comes with the introduction and dissemination of modern, high-yielding varieties (FAO, 1996) . The conservation of crop genetic diversity in farmers' fields, *in situ*, is necessary to protect gains in crop breeding and provide for the possibility of further advances in the future. *In situ* conservation complements established *ex situ* collections by capturing dynamic, evolutionary genetic processes and the complexity of genetic interactions with selection factors in the agricultural ecosystem, both of which are lost in the abstraction of *ex situ* conservation (Brush, 1995).

The focus on competition between High Yielding Varieties (HYVs) and Traditional Varieties (TVs), which dominates the literature on *in situ* conservation, overlooks a critical and increasingly important cause of genetic erosion: simplification of the farming system. First, by analyzing only the competition within the principal crop, the studies may miss important consequences for secondary crops. Second, the loss of CGR may be due to a process of agricultural simplification that occurs as the household reallocates resources to other activities. This thesis models farmer behavior with respect to *in situ* conservation, extending the existing literature beyond competition within the principal crop to encompass a broader definition of on-farm diversity and testing the hypothesis that inter-activity competition reduces crop genetic diversity on farms.

An 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. These studies have focused on competition between the modern and traditional varieties of major food crops, often in order to understand why traditional varieties persevere in certain areas without being completely displaced despite their allegedly inferior yields. Key research in this area includes Brush, Taylor, and Bellon (1992) for the case of potatoes in Peru; Bellon (1998) and Widawsky (1996) for the case of rice in China and the Philippines, respectively; Meng (1997) for wheat in Turkey; and Bellon and Taylor (1993), Louette (1997, 2000), Perales (1998), *inter alia*, for maize in Mexico.

However, in reality, genetic erosion 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 may result when other crop production or income activities supplant traditional crop varieties. Furthermore, genetic erosion potentially occurs at multiple levels, including both principal crops and secondary crops in multiple cropping systems. These secondary crops are also of economic and biological interest. In the Mexican milpa 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 potentially will produce misleading policy prescriptions. Thus, there is a need for understanding *in situ* conservation and diversity outcomes both within and across species. This thesis will test for the effects of risk, wealth, level of market integration, and other household characteristics on farmer behavior regarding *in situ* conservation in a context of multidimensional diversity.

Policy Implications

In the early 1990s, the Mexican agricultural sector underwent a series of major liberalization steps. Subsidies to imports and agricultural capital were reduced, agricultural extension was cut back, the land reform was terminated and the social sector lands opened to privatization, and the price support for staples is being phased out over the next ten years. Furthermore, the Mexican economy is undergoing a broad transformation under NAFTA and a new environment of economic liberalization. There is a need to look at how national and regional changes affect the farming decisions that shape diversity. In this research, the effect of market variables on diversity conservation and competition with other crop or income opportunities is investigated; the results will inform future analyses of the effects of market changes and increased competition that accompany agricultural transformation.

It has been proposed that one of the most effective strategies for *in situ* conservation of traditional varieties is to increase the varieties' productive potential and therefore make them more competitive. While this seems feasible from a crop breeding point of view, the econometric findings from this project will be useful in understanding how variables besides biological ones drive diversity outcomes. A starting point for this research is that conservation is not static – it is an active and evolutionary process. Farmers experiment, trade seed, and adapt farming practices; both breeding and conservation programs need to take into account the economic contexts of farmer behavior. This includes understanding the economics of diversity demand.

Moreover this thesis is crafted to expand our understanding of *in situ* conservation in general. The conservation of CGR in farmers' fields is not solely a discrete decision of whether the farmer continues to plant a given variety. By focusing on the economic context of the inter-cropping system, a goal for conservation can be the preservation of the evolutionary processes that generate crop diversity (Perales, 1998). It is in the diverse cropping systems of Vavilov centers of crop diversity and domestication that crop genetic resources arose through millennia of selection and hybridization. The ecological context of the cropping system, such as the presence of wild relatives, complex biotic and abiotic selection pressures, heterogeneous environmental conditions, etc., all combine to give a diverse cropping system a conservation imperative greater than the sum of the discrete number of varieties planted.

Overview of Thesis

The starting point for this thesis was to integrate economic analysis with research from other fields such as ecology, genetics, and crop breeding. A review of the economic literature and empirical research that provided the motivation for the household model used to describe the economic context of CGR conservation is presented in Chapter 2. The framework for a household farm model is adapted from studies on technology adoption. A newer literature specific to *in situ* conservation is reviewed to present some of the key hypotheses and findings in this area, and in order to indicate where this thesis can expand both methodology and empirical measurement in this area. In Chapter 3, a theoretical model is presented in which a household's decision to plant a milpa variety is linked to household, agro-ecological and market variables. A simple graphical analysis is used to motivate some of the basic reasons that a household may choose to plant more than one variety. A household farm model appropriate to CGR conservation is presented, and extended to the case of missing markets. The household model is further extended to a trait-based model, which can be used to integrate the multiple traits that any given variety may contain. Finally, a series of hypotheses are generated to test in the empirical study.

In Chapter 4, the agricultural ecology of the Sierra Norte de Puebla is presented with a description of the region and the principal CGR that are the focus of this study. Descriptive statistics are reported from the survey sample to illustrate the context of household economies, farmer seed systems, and key constraints to milpa production. The empirical methodology is described in Chapter 5, and it is designed to test the hypotheses generated in the model chapter. The Poisson regression is introduced and related to the theoretical formulation. A hurdle regression, which can treat possible selection problems, and a linear model using a diversity index are presented as alternatives to the Poisson model. The variables used in the regression systems are also explained and discussed in relation to both the theoretical formulation and the hypothesis tests.

The results from the regressions of household level diversity on household, farm, and village characteristics are presented in Chapter 6. The results are discussed in terms of the hypothesis tests from the theoretical model and in terms of the implications for CGR conservation. Finally, in Chapter 7, concluding thoughts are presented on the links between this study and larger conservation issues, and possible directions for future research are discussed.

Chapter 2 - Literature Review

Technology Adoption Models

HYV varieties

The basic framework for household farm models of diversity is inherited from a literature that sought to explain the adoption of Green Revolution agricultural technologies. In reviews by Feder, Just and Zilberman (1985) and Hayami and Ruttan (1985), the variety of explanations and empirical analyses of the 1970s and 80s are oultined. Feder and Umali (1993) present a review of more recent technology adoption research, which uses more complex economic models and covers the second generation of Green Revolution technologies. These later studies help to explain the prevalence of partial adoption observed throughout the developing world, e.g., where only certain farmers within a region adopt a technology, where farmers adopt technologies on only part of their fields, or where farmers adopt only parts of a technology package.

Although the *in situ* conservation of traditional varieties could be modeled as the inverse of the adoption of modern varieties, the key to the present research is to understand the positive benefits of diversity for farmers as well as how choices between traditional varieties may shape diversity outcomes. The adoption literature is reviewed here to motivate the household activity participation model presented in the following chapter. The reasons presented for multiple possible outcomes in the adoption studies are utilized in the theoretical model as factors influencing a household's decision to plant multiple varieties in the milpa.

Adoption studies usually use a discrete dependent variable for adoption; some more recent studies model the amount of land devoted to each variety (Pitt and

Sumodiningrat, 1991; Meng, 1997). The adoption process among farmers in a specific region is often a focus, from who are the first to adopt, how the process spreads and what the upper limit of adoption is. The adoption curve has been theoretically modeled and found empirically to be caused by a variety of different factors, such as a Bayesian learning process where farmers update the subjective yield probability, risky inputs mixed with deterministic yield functions, large fixed costs of adoption or lumpy complementary inputs. However, the adoption process can be partial when only some of the farmers in a heterogeneous population adopt, or on a heterogeneous farm where the technology is only adopted on part of the farm (Caswell and Shoemaker, 1993). A "lumpy" technology with large transaction costs is adopted only by certain farmers as they meet a threshold for discrete adoption; a "divisible" technology with low transactions costs and no economies of scale is adopted only on certain plots of land as warranted by the productivity of that technology (Feder, 1982)

In Hayami and Ruttan's (1985) review, it is noted that adoption lags are not actually very long, and in places where HYVs dominate a new variety is adopted relatively rapidly and eventually adopted by everyone. However, the review by Feder, Just and Zilberman (1985) points to the fact that larger farmers are able to adopt first and take advantage of differential land values, such that the new technology has a significant equity implication. Feder and O'Mara (1981) suggest that the HYV technology is not inherently biased towards the larger farmers, rather the fixed costs of information give larger farmers an advantage because they can experiment and internalize transaction costs of adjustment more rapidly. Just and Zilberman (1983) introduce a tractable model for the comparison of the relative stochastic properties of the technology choice and the marginal probability effects of complementary inputs. The theoretical model uses properties of risk aversion to show how relative effects in yield distributions will affect the extent to which larger farmers are able to adopt first.

In a more recent review by Feder and Umali (1993), a later generation of Green Revolution studies of the aggregate diffusion process is presented. Many of these later studies are relevant to studying diversity because of their ability to tie adoption behavior to specific institutional, environmental, or infrastructure constraints faced by household farms. Farmers may adopt individual components of a technological package as they learn about the new technology (Leathers and Smale, 1991). The profitability of a new technology is found to drive adoption, but the profitability of each technology may be specific to each plot due to agro-ecological conditions (Pitt and Sumodiningrat, 1991). Barley farmers in Tlaxcala and Hidalgo, Mexico adopted each component of a technology package in a sequential process, and in later stages there were positive interactions between the components of the package (Byerlee and Hesse de Polanco, 1986). Finally, across many of the studies of the second generation of Green Revolution, Feder and Umali found that the agro-ecological conditions that create constraints to farm productivity are important explanatory components in any economic model of the adoption process.

Risk and Portfolio

Treatment of the demand for crop diversity as a risk issue has been inherited from a theme that has been central to the adoption literature. Among the most important for the application to the diversity modeling are safety first specifications, where consumption demand for a basic grain must be satisfied before the profit maximization decisions on other resources are made (Roumasset, 1979). Smale was able to show that the safety-first approach was warranted in the case where the difference between HYV and traditional maize was compounded by the effect of inputs (fertilizer) on both moments of the yield distribution. Expected utility models have been widely used, adapted to the familiar household utility maximization framework. These models are specified to include a Just-and-Pope disturbance term considering the first and second moments of the stochastic production function.

Rosenzweig and Binswanger (1993) modeled the ability of different farmers to bear weather related risks. The ability of wealthier farmers to smooth their consumption ex post increases their ability to adopt more risky technologies. This led Rosenzweig and Binswanger to conclude that poorer households suffer more from an efficiency loss due to production diversification, including presumably their failure to adopt superior but risky technologies. In the crop genetic diversity case, the fact that poor households are the guardians of traditional cultivars gives rise to equity implications that need to be investigated. However, when other crop income or off farm income provides risk hedging against crop variability, there is less need for crop diversity as a means for risk spreading.

The demand for diversity may reflect consumption demands for basic grains and the demand for cash income from the production of alternative crops. When households consume a large percentage of their production, an increase in price variability may lead households to dedicate a larger share of resources to producing the staple in order to cover subsistence needs (Finkelshtain and Chalfant, 1991). The continued cultivation of traditional varieties to satisfy the subsistence requirements of the household may reflect high transaction costs in the marketing for specific consumption traits that households prefer.

Transactions Costs

If traditional varieties are locally consumed goods, the effect of wealth on farm-level diversity will depend partly on whether the traditional varieties are normal or inferior goods (Meng, 1997). For instance, if a traditional variety is valued for family consumption or for ritual use it should receive a price premium. On the other hand, if a traditional variety or wild relative is an inferior good that will be displaced by substitution with an increase in the use of markets for consumption, the signs of the wealth effect are ambiguous. Furthermore, factor and commodity substitutability usually are constrained in the developing country cradle areas of diversity. The effects of high transaction costs on the substitution of hired labor for household labor and purchased food for domestically produced food have been shown to have drastic effects on the impacts of Green Revolution technical change (De Janvry, Fafchamps and Sadoulet, 1991). Missing markets decrease the own and cross price elasticities of supply for food crops; the market or policy effects on basic grain diversity will be less than those predicted by a model that assumes the existence of perfect markets.

Nested Multiple Explanations

The adoption literature has been extended by recent studies that take into account a combination of these effects (Feder and Umali, 1993). The nesting of a number of models to test for a multiple number of explanations by Smale, Just, and Leathers (1994) integrated questions of input fixity, portfolio behavior, safety first, and learning. Their study on Malawi HYV maize adoption found that a nesting of hypotheses had more explanatory power than any single model, showing the need to incorporate multiple hypotheses into explanatory models. Meng (1997) included missing markets, risk aversion, and environmental constraints in an inclusive model. Meng found that the factors affecting variety choice were more important than factors affecting post-choice diversity management; the significant explanatory environmental variables included regional effects, off-farm income and market integration.

Pitt and Sumodiningrat (1991) used a meta-profit function and a switching regression to model the choice between the traditional and modern varieties combining the seed choice with input choices for each technology. Making variety choice a continuous variable along with which other inputs are varied was used to make household response to input prices more realistic. Seed demand was modeled as a function of a conventional profit concept and farmer characteristics such as schooling, credit availability and infrastructure. Smale and Heisey extended this simultaneous approach to model technology adoption in terms of the discrete adoption of seed and the continuous application of fertilizer and compared simultaneous, recursive, and independent approaches.

Traxler and Byerlee (1993) showed that the complementary effects of diversity demand can actually determine variety choice. Dwarf wheat varieties produced so much less straw for fodder that profit maximizing farmers stayed with the traditional varieties unless the yield gains surpassed a straw/grain price threshold. In the case of diversity demand for multiple crops, the diversity of the system may have production complementarities across crops that will affect demand for total system diversity. The cross-crop effects of an inter-cropping system have been documented by agro-ecologists

(Altieri and Merrick 1988) and farming systems research, but they have remained largely outside of the agricultural economics literature, perhaps because of the perceived limited economic importance of traditional agro-ecosystems. However, these system effects can lead to a higher level of diversity demand and utilization. In *in situ* conservation, there may be important cross effects of the adoption of a technology package. Even if the adoption of an improved variety in the principal staple has no direct effect on secondary species, the adoption of complementary inputs such as herbicide or mechanical tillage may have adverse effects.

Diversity Models

The other principal literature that is relevant to the conservation of crop genetic resources are studies that model the economic valuation of biological diversity. Weitzman (1992) and Solow, Polasky and Braudus (1993) have adapted ecological models to the economic measurement of diversity. Weitzman outlined the desirable qualities that a diversity measure would have: monotonicity in species, monotonicity in distance, and twinning. These criteria are that a diversity measure must increase with the addition of a species and the increase of distance between species, but not increase with the duplication of a species, respectively. These indices depend upon biological knowledge of the phylogeny and taxonomy to structure the index, information that may be difficult or costly to generate, as in the case of the milpa. Weitzman (1992), and subsequent work by Solow and Polasky, developed a diversity measure that is closely related to the Shannon Index commonly used in ecology. These models of biodiversity are designed to allocate resources for conservation by comparing the diversity of two overall collections or by calculating the marginal contribution to diversity of a given species. In the case of CGR conservation, the indices can be used to determine which populations to target for conservation to maximize diversity or to model the services provided by diversity. Widawsky utilized the coefficients of parentage (which are documented by breeding programs) for Chinese rice varieties, and adapted the Solow and Polasky measure for agricultural applications by weighting the diversity measures by the area planted in each variety.

The valuation of biodiversity for use as a productive input was pioneered by Simpson, Sedjo and Reid (1996) for the case of pharmaceutical research and then extended to agricultural research by Simpson and Sedjo (1998). These are search models, based on statistical distributions; they take the crucial step from individual economically valuable traits to the collection that holds them. In the agricultural sciences there is an increasing recognition of the services of biological diversity for the productivity of modern agriculture, for example for Integrated Pest Management or soil erosion control. On the one hand the “option value” type of biodiversity models are used to assign value to unknown traits in an uncharacterized collection. On the other hand GIS tools, hedonic trait analysis, and crop ecology can be used to target populations likely to be of conservation value. Conservation of CGR will need t to integrate both kinds of values into overall resource allocation.

Bridging the gap between the biodiversity literature and agricultural economics, a few studies have attempted to measure the value of diversity in delaying the breakdown of genetic resistance to various important pests. Widawsky and Rozelle (1998) modeled the regional effects of varietal diversity and provided empirical evidence that varietal diversity can reduce regional yield variability. CIMMYT economists concerned with the impacts of the wheat breeding program have started to model the value of genetic diversity in agricultural production. A study on the Punjab of Pakistan measures the costs of increasing genetic diversity in terms of decreased yield. (Heisey, et al., 1997) The authors proposed a model of the tradeoff of yield and diversity on a hypothetical yield-diversity frontier. A socially optimal level of diversity would balance the benefits of delaying the breakdown of pest resistance against the costs of forgoing maximum short-term yields. A genetic case of similar relevance is the shift in the emphasis of CIMMYT's breeding program away from pest resistance based on "narrow" resistance to a specific race of pest to "broad" race-nonspecific resistance which has provided measurable benefits in terms of the rate of return to agricultural investment. (Smale, et al., 1998)

There is a need for the economics literature to model the indirect services that diversity provides to the productivity of the system. For this thesis it was necessary to look to the ecology literature to understand some of the issues of quantification and measurement. Biological diversity is not measured directly but through the construction of indices, and it is important to understand the ways measurement can affect the outcomes and implications of the model. Magurran (1988) comprehensively discussed the relevant indices used for measurement of diversity in ecological studies and offered some numerical examples to understand the differences between different constructions. Smale et al. (1998) discussed the different ways diversity indices can be applied to CGR and the implications of different kinds of diversity for policy analysis. Diversity indices have been used as the dependent variables in econometric analysis, and it appears that regressions were sensitive to the ways in which is diversity is measured (Meng, 1997 and Widawsky, 1996).

In situ Conservation Models - Other Crops

A series of studies have been undertaken with understanding the *in situ* conservation of CGR as either an explicit or implicit goal of the research. Several salient examples are discussed here in order to review both the methodology and the empirical finding relevant to this thesis.

Potato

Brush, Bellon, and Taylor (1992) studied the diversity of potato CGR in Peru and compared two valleys with different levels of market integration. They found that the level of market integration decreased the overall level of diversity, as commercial production increased the area under simplified production systems with improved varieties. However, Brush et al. propose that the level of diversity decreases to an asymptotic lower bound, at which even commercial households maintain a set of minor varieties in a reduced land area. Zimmerer (1991) examined the conservation of CGR of maize and beans in Peru and found competition between labor demands for migration and for local crop production. Zimmerer found that in certain cases the local CGRs that were conserved were those which had complementary maturation cycles to the seasonal labor market. By measuring the labor requirements of different traditional varieties of both maize and potatoes, Zimmerer was able to document which varieties were most at risk to social change through labor market integration.

Wheat

As mentioned above, Meng's 1997 study of the diversity of wheat varieties in Turkey integrated several possible explanations into a comprehensive model. Market variables were important explanatory factors in the probability of planting landraces. Transactions costs, price differentials, and the isolation from market centers all increased the probability of planting traditional varieties. An important institutional presence was the government purchasing board, which eliminated price premiums for local landraces with particular consumption characteristics and thus discouraged market forces from acting in favor of landraces. Meng also examined the effects of the same variables on the levels of diversity within a farmer's field, using both a Shannon index composed from morphological measurements of samples grown out under uniform conditions, and a Coefficient of Variation of yield based on experiment station measurements. The Shannon Index and CV measurement produced different results, demonstrating the difficulty of condensing such information into a single index.

Rice

Widawsky (1996) focused on the diversity of modern rice varieties that had been released by the Chinese agricultural research system. Widawsky was able to integrate both a genetic measure of diversity (based on coefficients of parentage) and an area weighted measure (based on shares of area in each township surveyed) into a single measure. As mentioned previously, Widawsky et al. (1998) used these data to test whether both the mean and variance of yield are affected by township level diversity. An innovative economic-ecological linkage was to test whether the level of diversity in varieties can prolong host-plant resistance to pests and thus correlate to decreased pest pressures.

Bellon et al (1998) studied farmers' perceptions of varietal diversity in rice in the Philippines. The survey was stratified across a range of ecological, socio-economic and infrastructure conditions to capture a broad range of behavior towards local CGRs. Farmers were able to describe each variety as a bundle of traits or characteristics that matched local consumption preferences and agro-ecological conditions. Implications for on-farm conservation of CGRs were drawn from the tradeoffs farmers made between yield and quality characteristics.

In situ Conservation - Maize in Mexico

In the past five years a new body of work has developed on the *in situ* conservation of maize CGRs in Mexico, a center of origin and domestication. These studies have been based on strong empirical work that integrates the household and village factors affecting CGR conservation with quantitative measurements of farmers seed systems. Many of these studies have some connection to the economics program at CIMMYT, where I spent time during the course of my dissertation. I was able to meet and interact with most of the researchers working in this field, and many of the following studies directly influenced this dissertation.

Sierra de Manantlan

A seminal study of maize with implications for *in situ* conservation is the work of Dominique Louette in the Sierra de Manantlan, in a watershed situated within a biosphere reserve but nearby a commercial agricultural area, in the state of Jalisco. Louette et al. (1997) offered a definition for "seed lots" as a set of seeds selected by the farmer, planted, and used for selection in the next generation and maintained as distinct from other seed lots. This definition of "seed lots" is distinct from definitions of a variety or a landrace that imply community consensus on the correspondence of a name to some specific characteristics. Many other studies have used "seed lots" as the basic unit of farmer's behavior and it provides the unit of analysis for this thesis.

Louette and Smale (2000) discussed the key findings about farmer seed systems and farmer behavior concerning seeds and the effects on maize populations. The rate of households using inter-cropping of other milpa crops was similar to the rate found in this dissertation, 57% planting squash and 84% planting beans. The local seed systems appear very dynamic, with some farmers showing little preference for their own seed and many changing seed regularly to "renew" it. One interesting result was that farmers who sowed mostly their own seed sowed a greater number of varieties. For this two possible explanations were offered: that the transactions costs of finding each new seed lot means that less acquired varieties get planted, or that a few conservative farmers rely on a greater number of saved varieties. Documenting the history of seed lots shows that a single seed lot may multiply and spread, whereas a new introduction may be subsumed into a local population and lose its distinctiveness. Louette et al (1997) and Louette and Smale (2000) concluded that diversity in local seed populations is constantly being generated, and that due to farmer seed flows and field pollen flows it is unclear what the appropriate scale for conservation is. While the large number of varieties found in the communities studied by Louette seem atypical compared to this dissertation and many other studies, the developments of methodology and integration of surveys and crop genetics are very useful.

Sierra Santa Marta

Rice et al. (1998) documented the life-cycle of farmers' seed lots and local seed systems in an indigenous community in southern Veracruz state. Among the key conclusions were that the overall trends of seed management are complex, and that the borders between traditional and modern varieties are not well defined. Because of trade and flows of seeds between households, the unit of population relevant for conservation appears to be larger than the household. Furthermore they concluded that landraces are an unstable unit for conservation as such, due to the unintentional loss of seed lots, as well as the infusion and trial of new seeds.

Guanajuato

The study by Aguirre et al. (1999, 2000) of maize diversity in southeastern Guanajuato state began by classifying a collection of maize races for calculation into diversity indices. The theoretical model in Aguirre (1999) starts out with a household farm framework, where the households maximize the level of consumption, and these levels are translated into the consumption attributes through a set of technical coefficients. One conclusion from the empirical test of this model is that attributes are more important than varieties (and the attributes are not observed in the shelled grain market). The specification of the household model was used to jointly test different sets of characteristics affecting diversity outcomes. Regional, community and varietal characteristics were found to be jointly significant, while household characteristics were not found to be jointly significant. The sample was structured across two main vectors, productivity potential and level of infrastructure. Productivity potential increased levels of diversity wheras market integration through infrastructure decreased diversity. Finally, an incremental increase in regional diversity levels was calculated from each household's own diversity outcomes, and it was concluded that households do not take into account their contribution to overall regional diversity.

Vincente Guerrero, Chiapas

Bellon and Risopolous (1999) returned to the ejido in central Chiapas nine years after the work in Bellon and Taylor (1993) and Bellon and Brush (1994). A similar general pattern was observed with modern varieties being viewed by farmers as "a variety for the rich" because of the need for timely application of inputs like fertilizers and weeding. Landraces and intermediate varieties were viewed as more "sturdy" because of a lower yield variance, lower need for inputs, and increased resistance to pests and drought. The statistical analysis measured the effects of agro-ecological and socio-economic characteristics on the probability of planting modern, intermediate, or traditional varieties. The modern varieties were planted predominantly by wealthier farmers, but those with lower levels of off-farm labor. This seems to follow a hypothesis that the off-farm labor competes with family labor for relatively family-labor intensive activities (in this case sowing relatively "delicate" modern varieties). However this diverges from the hypothesis elsewhere in rural migration literature, e.g. Taylor (1999) and Rozelle et al (1999) that off-farm income eases cash constraints for purchased inputs. Bellon and Risopolous found that both rich and poor farmers plant traditional varieties, and that landraces also are cultivated on all soil types. However modern varieties continue to be planted principally on the better soil type and the intermediate varieties (locally adapted modern varieties) on intermediate soils.

Valley of Chalco and the Valley of Cuautla

Perales (1998) examined the conservation and competitiveness of landraces in four communities on the outskirts of Mexico City, in the states of Mexico and Morelos. This study was particularly influential to this thesis because of the fact that it was a part of the McKnight MILPA project; my participation and observation of the early stages of Perales' fieldwork helped to shape this dissertation. The survey sample was constructed to compare two major climate zones, two villages in a high altitude area dominated by landraces, and two villages in a low altitude zone with competition from modern varieties and cash crops. Perales found that although farmers did mention particular traits, landraces were conserved mainly due to competitiveness in yield and yield stability. One local landrace, which was the product of local selection for consumption characteristics, commanded a price premium as an ingredient in a seasonal specialty dish, pozole. Perales differentiated between a "major" variety, which would dominate for yield and predominate throughout each community, and "minor" varieties, preferred for cultural reasons and maintained on smaller plots by a minority of farmers. Basic calculations of the cost of inputs and the value of the output showed that net income from maize is centered around zero, with the average household not profiting from maize production. In the end Perales concluded that farmers are continue to grow maize despite apparent negative income because of cultural and historical reasons. While landraces are conserved and thrive in the face of many apparent threats, according to Perales the question for conservation turns to crop evolution and whether the conditions will remain to provide the evolutionary pressures and harness evolutionary potential within crop populations.

Agro-ecology

A variety of reasons have been advanced for why the diversity of the whole cropping system may increase overall yield across crops. Quantitative research on inter-cropping and multiple cropping has been advanced in the fields of agro-ecology and farming systems research, but has remained largely outside of the agricultural economics literature. While it is not the purpose of this thesis to model and test the effects of inter-cropping per se, it is important to review the salient points linking crop diversity to productivity.

Researchers working on inter-cropping have proposed a system of measurement to compare the yields obtained under inter-cropping to the yields obtained under single cropping. The Land Equivalent Ratio (LER) is the sum of the ratios for each crop of the amount of land required under sole cropping to the amount of land required under inter-cropping to produced a fixed quantity of output (Francis, 1986). While the ratio of any individual crop is less than one because of the fact that competition reduces crop yields, when the combined ratios of the different crops sum to a number greater than one, the inter-cropping system is considered more productive per unit of land than sole cropping. The LER is the principal statistic used to compare different cropping systems, and has been extended to the Income Equivalent Ratio (IER) by using crop prices. Other possible extensions may be made to nutritional outcomes such as calories, proteins or micro-nutrients. Finally, it would be useful to construct an index of the variance of total output (or total income). Whereas there are both portfolio reasons and physiological reasons for the variance of the crop systems to be less than for an individual crop (Trenbath, 1986), there is little data to objectively measure cropping system variability.

The principal reasons that an inter-cropped systems can yield a higher combined output than an equal area planted to each are because the crops are able to segment the use of resources either spatially or temporally to reduce competition (Davis, 1986) . Spatial complementarity is the increased efficiency through plant architecture so that each crop takes advantage of different inputs of sunlight, soil moisture or soil nutrients (Altieri, 1995) . In the milpa system, the squashes and quelites are able to grow under the maize, and take advantage of the residual sunlight reaching to the ground level. Temporal complementarity is an efficiency throughout the cropping cycle that takes advantage of different periods of maturity for each crop. In the milpa system, maize is the first to reach physiological maturity, followed by beans, which use the maize stalks as guides to grow to their physiological maturity, and finally squash reaches maturity at the end of the cropping cycle. Furthermore, the collection of quelites throughout the cycle, from amaranths just after the field is tilled, to the blossoms and shoots of beans and squash as each flowers, is a form of temporally segmenting the food output of the milpa.

Several other reasons have been proposed to explain the productivity of inter-cropping systems. One commonly known aspect of the milpa system is that the beans are able to fix nitrogen and thus reduce their competition with maize for soil nitrogen. Other aspects are the reduction of pest pressures, either through allelopathic affects of crops or through the reduced densities of a mixed stand of crops, both of which have important effects on pest population dynamics (Gleissman, 1986; Altieri and Lieberman, 1986). Important long term aspects include building the soil through increased biomass production and protection from soil erosion by having the soil covered for longer periods of the cropping cycle (Holt-Gimenez, 2000).

All of these aspects relate to the conservation of CGR on farms because they point to direct values that a higher CGR system could have for farmers. Unfortunately the large number of possible effects, the overlapping of different functions, and the difficulty in separating individual aspects has made it difficult for scientists to quantitatively measure benefits of inter-cropping (Trenbath, 1986). Applied research on agro-ecology has been carried out within the field of farming systems research that relies on a systems perspective and is distanced from the experiment station breeding and conventional experimental design (Lynam et al., 1986). Because there may be significant genotype by cropping system effects, there may be a role for decentralized or participatory breeding (as proposed *inter alia* by the McKnight MILPA project) to improve yields within the farming system used by farmers.

A major constraint to inter-cropping is labor; mechanization and herbicides are two possible causes of reduction in cropping system diversity in the milpa, and both are transformations of agricultural technology to decrease labor intensity. While research on cropping systems generates information on the ecological benefits of inter-cropping and how to maximize production on a single hectare under low-input marginal conditions, a continuing constraint to adoption will be family labor as labor markets develop and agriculture’s share of family labor time diminishes.

Chapter 3 - Model Introduction

This chapter presents a theoretical model to analyze household farm motivations to conserve crop genetic resources focusing on the planting of multiple species and multiple varieties. This model provides the conceptual framework for econometric analysis of crop variety diversity that will be introduced in Chapter 5. A graphical analysis will be developed to show the intuition behind the multiple product models. A basic theoretical model will be presented and extended in order to take into account the particular case of CGR conservation.

This thesis uses as the starting point of CGR conservation the planting of the multiple species within the *milpa* and the planting of multiple varieties of each species. This is motivated by the fact that diverse and complex poly-cropping systems are a part of the ecosystem that generates CGR in individual crops. The conservation question can be phrased as asking which farmers plant the *milpa* as a multiple-crop or inter-cropping system, as opposed to the specialization into a single crop type. Another conservation question is to identify which farmers are continuing to plant minor varieties, which are most likely to be lost in the process of genetic erosion. The analytical framework developed here is to identify which forces, economic, behavioral, or ecological are affecting farmer decisions. Hypotheses will be developed in order to test these effects upon household diversity outcomes.

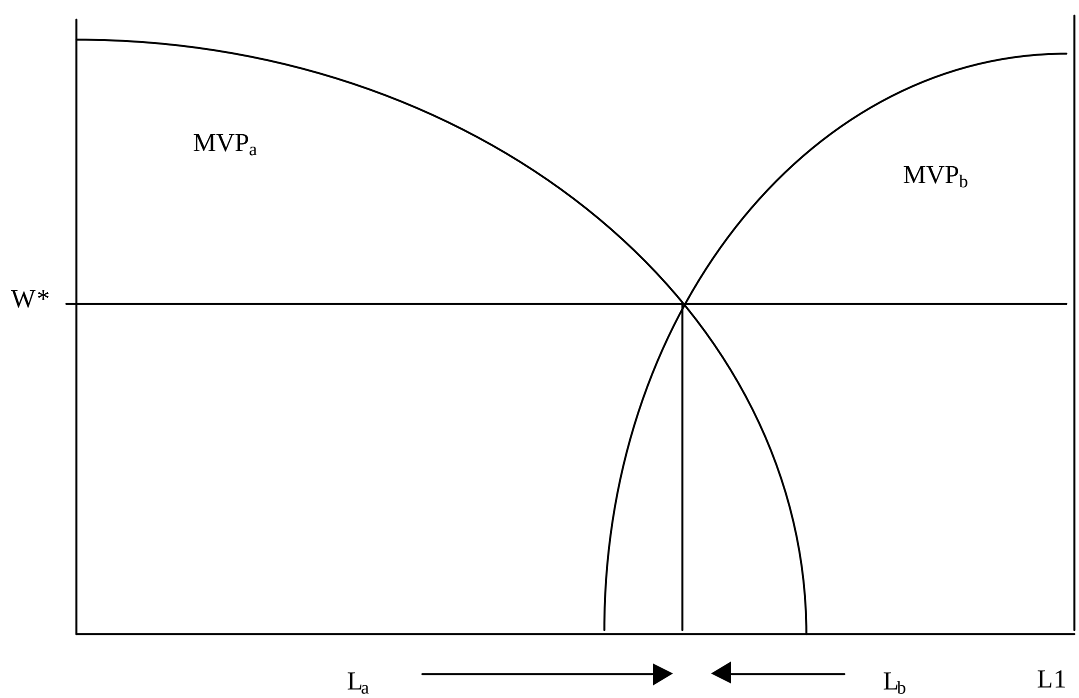
Graphical Analysis - Why would a HH plant multiple varieties?

Throughout the modeling process the unit of analysis will be the decision whether to plant an additional crop, because this provides the most direct link between farmer behavior and the resulting empirical model. A simplified case which is useful for graphical analysis is to look at why a household would plant a combination of two different crops instead of simplifying production to a single crop. The extension from the two-good case to a general model will be made in the model section.

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 labor in maize production on a given plot (or plots) of land. Decreasing returns to scale implies the existence of some other fixed factor of production, besides land, that must be allocated between different crops. Some examples are farmer time, land quality, distance from markets (resulting in increased transport costs), etc.

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



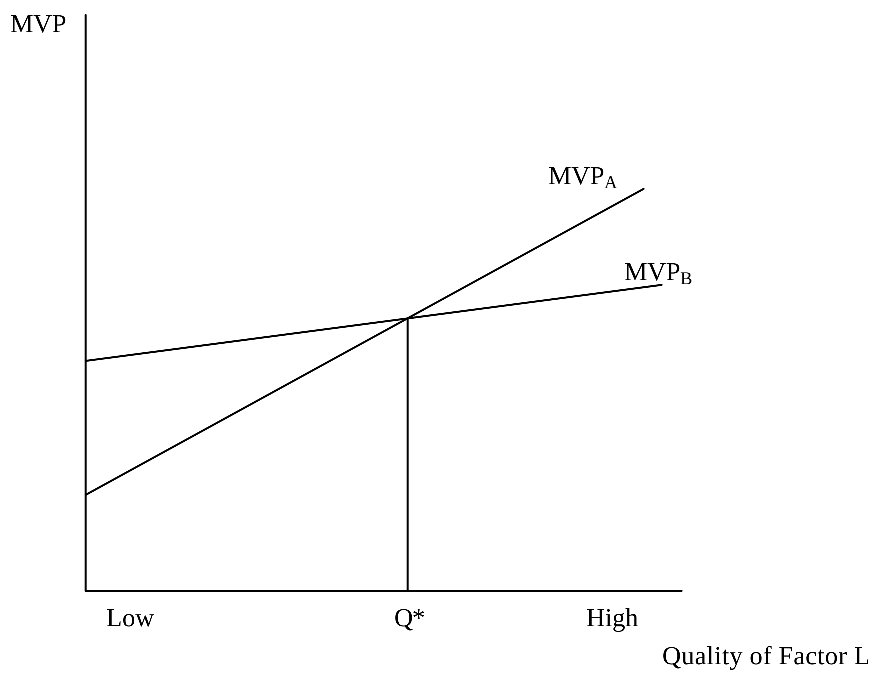
In this figure, the factor input L, fixed at L1, must be allocated between crop activities. The point where the Marginal Value Product (MVP) of an additional unit of input L to crop A is equal to the MVP of an additional unit of input L to crop B determines the allocation of L between the two crops, and a shadow price, W*, for the fixed factor. The decreasing MVP with respect to factor L reflects decreasing returns to scale with respect to that factor within that activity.

One fixed factor that may affect the planting of milpa crops is a fixed endowment of family labor. (Whether the household is limited to using family labor, or whether there are other income activities for family labor to be allocated to, is the subject of missing markets which will be covered in another section.) Letting L denote family labor in Figure 1, the household allocates labor to maize, L_a. If the household could only allocate labor to maize production, it would do so until the marginal value product of labor drops to zero (or some relevant household shadow wage, i.e., the marginal utility of leisure). A fixed endowment of land results in the MVP of labor decreasing, as each additional day spent tending the maize plants will yield a smaller increment in production. If the household is able to allocate labor L_b to a second crop, e.g., beans, it will do so until the marginal value product for working on maize is equal to the marginal value product for working on beans, implying an endogenous "shadow" family wage, w*.

Within the milpa system, another example of decreasing returns to scale could be soil heterogeneity and the matching of varieties to soil conditions. The planting of all of the household's land endowment in one maize variety might make sense given a homogenous plot. However, frequently the farm has an extensive margin that includes conditions such as steeper slopes, soils with a greater clay content, a lower organic matter composition, a higher soil pH, a more direct exposure to sunlight, or higher transport costs for inputs and outputs. In this case, the marginal productivity of the principal maize variety may decline as marginal lands are brought into production, and a different maize variety may be superior under other (challenged) conditions. The endowment of family labor and the heterogeneity of the land endowment will be two factors to test for in the econometric model.

Another possible way to look at the fixed factor of production is if there is a range of different soil types, each conducive to growing a different variety.

Figure 2: Marginal Value Product of crops A and B vs a factor of varying quality

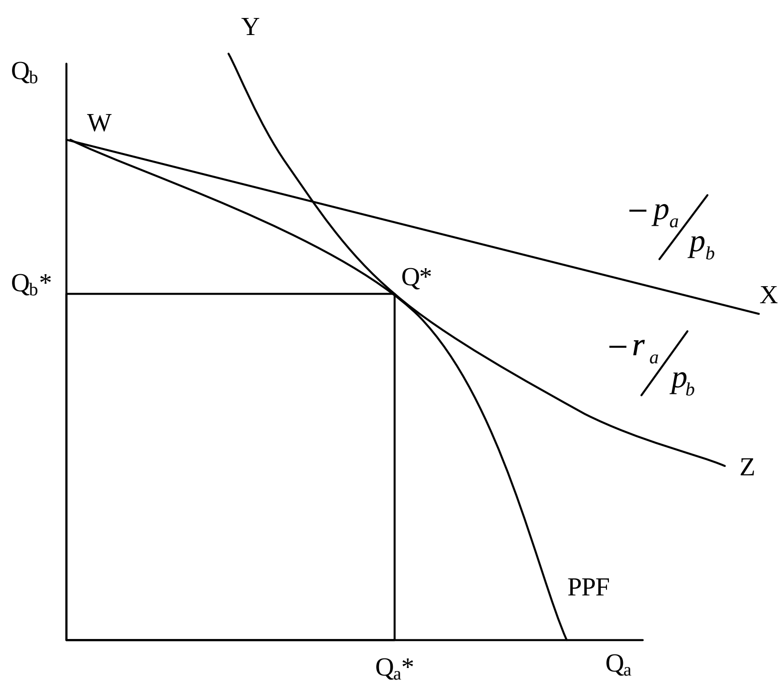


In this case the quality of the factor L ranges from low to high, and in Figure 2 the factor is arranged according to quality along the X-axis. When the quality of L is low the MVP of crop B exceeds crop A, and at high quality the MVP of crop B exceeds that of crop A. A household with an endowment of land that includes land of all qualities will set the MVP equal across the types of factor L and produce at Q*. In the case of the milpa this may be the matching of soil types where the household has a flat, valley plot with lands favorable for one variety, while another plot on a hillside with clay soils may be more favorable for another variety. One example of this is Bellon's finding in Vincente Guerrero, Chiapas that landraces were grown mainly on hillside lands (pedregal) and advanced generation modern varieties were grown on fertile valley lands (arado).

Missing Market for one good

In many cases in developing countries there are imperfect markets due to high transactions costs in purchasing factor inputs, e.g., labor, and selling outputs e.g., food. Here we will illustrate at a missing market for food, specifically, crop B.

Figure 3: PPF for two goods, Q_a and Q_b , with a missing market for good A.



In Figure 3, a Production Possibility Frontier (PPF) represents the production choices that a household makes between crops A and B. If there are markets for each crop, the household follows the (exogenous) market price line WX, which is set by the ratio of the price of crop A to the price of crop B. However, if there is a missing market for crop A and the household demands some of crop A for consumption, all of the consumption of crop A must come entirely from household production. The household's subjective valuation of good A is reflected in a shadow price r_A that is affected by the household's desire to consume that good, as well as indirectly by the household production and consumption constraints. In Figure 3: PPF for two goods, Q_a and Q_b , with a missing market for good A. the household moves from using the exogenous prices (P_a,P_b) and producing only crop B, to producing at Q*, the point of tangency between the price line YZ (which is set by exogenous price of good B, P_b, and the endogenous price of good A, r_A) and the PPF, thus producing both crops at (Q_A^*, Q_B^*). The reason the endogenous price r_A causes the price line to be curved is that the household is demanding some of the good in its consumption, and as the quantity of good A decreases, the value to the household of consuming that good increases. A simple example for the case of the milpa is if the household desires to consume a certain amount of home produced maize. While the household may consume mostly purchased maize, it may produce a small quantity of local maize at a level of factor input that reflects an endogenous valuation of maize far above the market price. In this case good B could be the coffee, and good A, maize. Although it may not be profitable to grow maize, the household may continue to grow a certain amount because of its taste preferences.

A missing market for good A brings the production of that good directly into the household's utility function, and therefore factors affecting the utility function affect the crop allocations. The unobserved household shadow price r_A brings information from the household's consumption preferences and market integration into the activity choice decision of which and how much of each activity to participate in. Therefore, the empirical tests of the determinants of household diversity should include characteristics of the households preferences and access to markets.

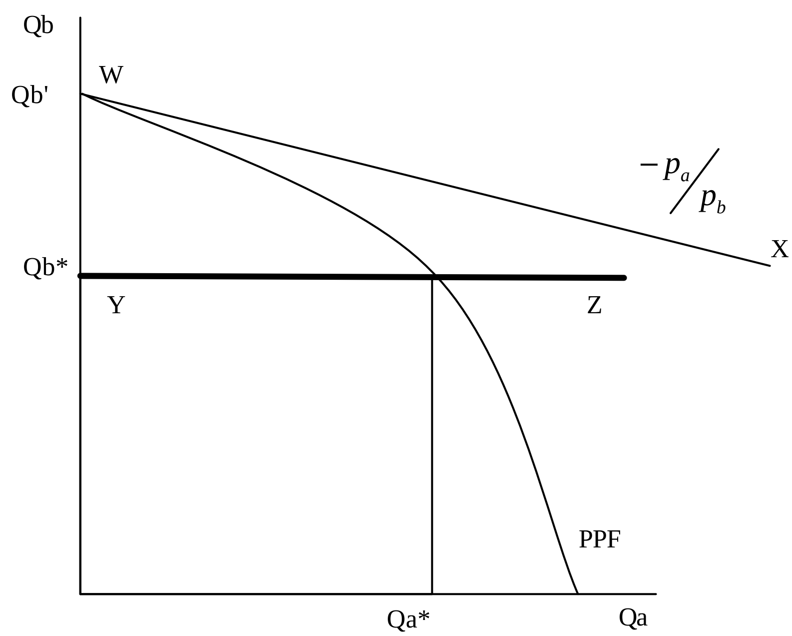
Risk or uncertainty may also cause the household to plant a portfolio of varieties instead of specializing. Returning to Figure 3, in the absence of risk the household would specialize completely in crop B. If crop B is characterized by yield risk however, the price of crop B will become r_B, an endogenous household price that includes the variance of yield and the households risk preferences. Graphically, at increasing specialization in crop B, the household valuation would drop and the relevant priceline would resemble the curved line in Figure 3. Therefore, the household would want to produce a certain amount of Crop A to reduce its exposure to the risky crop. This brings factors affecting the household's level of risk aversion and exposure to risk into the hypothesis test on diversity outcomes.

Missing Market for a factor

Other missing markets may exist, especially for important factor inputs in production One example provided above is if there is a missing labor market, and the household can only is limited to its endowment of family labor for milpa production. Another example would be a cash or credit constraint, where households are unable to specialize in a single activity (e.g., maize) if they lack the credit to invest in inputs like fertilizer or harvesting labor.

In Figure 4, the household's production is limited by a missing market for a crucial factor in the production process. The household's unconstrained production choice would be to specialize entirely in good B at point Qb' determined by the tangency of price line WX with the PPF. Due to the missing market the production of good B is limited to Qb* by the constraint YZ. Therefore, the household will also produce good A, which is not limited by the factor constraint. An example for the milpa would be a cash constraint that limits the hiring of labor for the harvesting of maize, especially if labor markets became tight during the time of maize harvest. The household would then plant maize up until the point that it could harvest with family labor, and plant another crop that could be harvested at a different time when labor would not be a limitation.

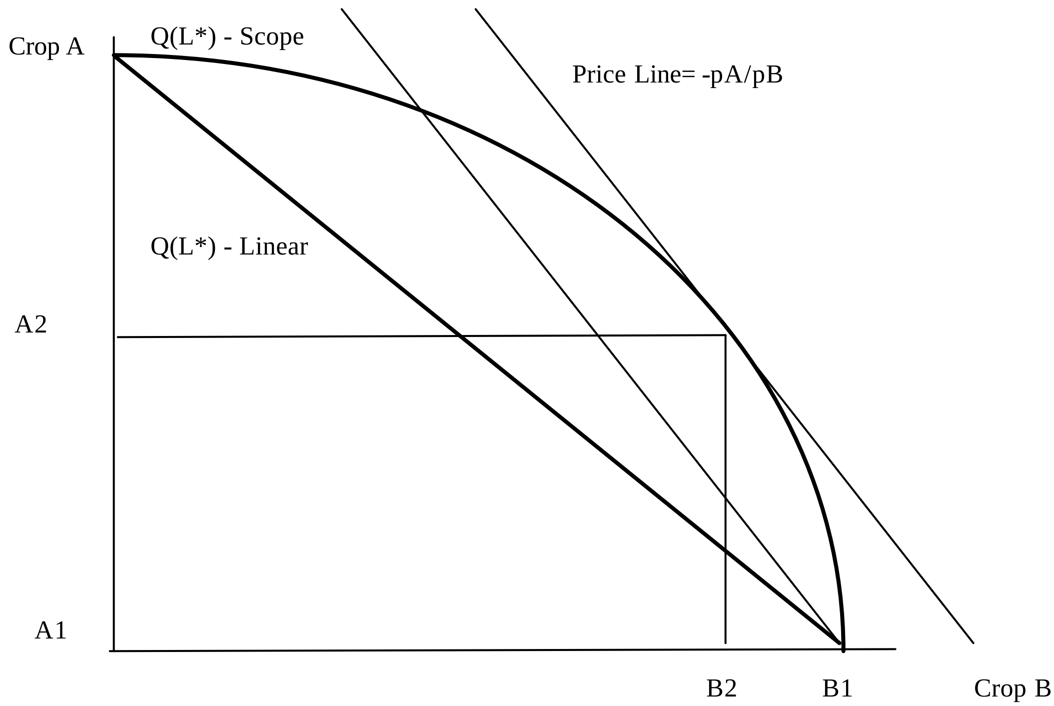
Figure 4 Constraint caused by a missing market for an input



Economies of Scope

In the economic theory of the firm, there are efficiency reasons for the production of multiple products. There may exist complementarities in production that make it more profitable to produce two goods jointly than each good separately. Economies of scope are another reason that the production possibility frontier (PPF) can be concave. In the case of decreasing returns to scale the PPF is concave because of decreasing productivity with increased intensity of the use of a fixed factor. With economies of scope the PPF is concave because productivity is greater for production of both goods where some factor is shared in the production of each.

Figure 5: Iso-product lines for two goods with and without economies of scope



In figure 5, two possible cases are presented, with and without economies of scope. In the case of no economies of scope, production is linear, represented by the lower bold line. Given a level of input L* the firm has to choose a point of production along this Iso-production frontier. The level of production is determined by the tangency to the price ratio line, –pA/pB, in this case all of production is in Crop B at output levels (A1,B1). The curved bold line represents the case of an economy of scope, where a non-linearity in the iso-production frontier leads to an optimal interior solution. The point of tangency with the price line leads to the production at output levels (A2,B2). Mathematically, the essence of the economy of scope is represented by the inequality $f(A+B) > f(A)+f(B)$, the production of both crops yields more than the production of either crop (at a given level of inputs). To actually measure or test for economies of scope would require detailed cost or productivity measurements that are impossible under the field conditions in the sample region. However, the focus on this model is for derived demands for diversity resulting from production decisions on crop choice. The possibility of economies of scope gives us a reason to test whether a more diverse system may be chosen over a simplified system.

In the case of the milpa there are several possible interpretations of the economies of scope in production. The first would be for agro-ecological effects across crops where the yield of the maize-bean intercrop would be greater than the per unit yield of each. Some examples of agro-ecological effects are beans providing nitrogen for the maize, or providing soil cover and reduced soil erosion, while the maize can provide a guide for the beans to grow on. Another economy of scope would be the complementarity in the labor input across crops; farmers weeding the fields for maize can select and encourage a squash plant, or at the same time that farmers double the maize stalks for drying they can string up the bean vines. Finally the inter-crop can show an economy of scope as a partitioning of inputs temporally throughout the agricultural cycle. Although the crop decision is modeled as a one time decision on what to plant on a given plot throughout the year, the milpa in effect segments the inputs of sunlight and soil moisture throughout the year, as the crops reach their vegetative climax in succession, first the maize, followed by beans, and then squash.

Basic HH Model

The graphical analysis has provided various reasons that the household may choose to produce more than one crop. The goal of the household model is to provide a mathematical framework that will allow multiple possible explanations to be included and tested.

Diversity and Conservation in the Model

The diversity of the milpa and the conservation of secondary crops and minor varieties will be considered to be a function of the participation in activities j, each consisting of planting a specific species or variety. A Diversity function must be increasing with respect to the number of species and the number of varieties within each species. The simplest function is a count of milpa species N for crops i, i=1…N. More sophisticated measures of diversity can be composed from an indicator vector I, which is a vector of zeros and ones for the relevant species, and which is weighted by area planted or proportion of total. For this study the weighting is problematic because of the need to compare diversity across crops and within crops. Furthermore, the inter-cropping makes the area weighting lose relevance because of the different planting densities of the different crops.

Household Model used to discuss which are relevant parameters

The household-farm is the common starting point for the modeling of in situ conservation of CGR. The household is the basic unit of management, where decisions and actions are taken which affect crop diversity. The household is the consumer, consuming both household production and purchasing goods with income from the farm or wage labor. The household is also a 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. Finally households face constraints in terms of their endowments, but also specific resource or input or output market constraints that can affect crop choice outcome. 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 increase household welfare above what it otherwise would be.

Basic Model

HH maximizes welfare

In the basic model with complete markets, the household maximizes utility over a set of consumption levels, X_i, of own crops i, X_1, $X_2 \ldots X_N$, 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 consumption X_j) , exogenous income $\overline{Y}$, and an endowment of family time T valued at the market wage, w. The household production is subject to a technology function and profits are subject to prices for inputs and outputs. Production constraints such as fixed input factors are embedded within the production technology equation. Production technology and conditions are characterized by a vector of exogenous characteristics Φ_{Farm}.

$$\max_{X,Q} U(Xi, Y; \Phi_{HH}) \tag{1.1}$$

$$p_q(Q_i - X_i) - C(Qi;\Phi_{Farm}) + \overline{Y} + w\overline{T} = \sum_{i=1}^{I} p_i x_i \tag{1.2}$$

$$G(Q;\Phi_{Farm}) \tag{1.3}$$

In this basic formulation the household chooses a vector of consumption levels, **X**, and output levels, **Q**. This model assumes that there is no risk, i.e., neither production nor prices are stochastic, and the household faces perfect markets (i.e., exogenous prices) for all consumption goods and variable inputs. Family labor is a perfect substitute for hired labor and the household is indifferent between on-farm and off farm labor. In this case the household is a perfect neo-classical farm household, and farm decisions are solved recursively; that is, farm input and output decisions are made first and the resulting income is used to solve the consumption decisions. The solution of the household maximization problem yields a set of optimal production levels, Q*, income level, Y*, and consumption levels, X*:

$$Q = Q_i^*(p,\Phi_{Farm}) \tag{1.4}$$

$$X_i = X_i*(p,Y,\Phi_{HH}) \tag{1.5}$$

In this case, the diversity outcome takes the form of a simple derived demand, $D = D(\mathrm{Q}^*(\Phi_{\mathrm{Farm}}))$, resulting from the farmer's profit maximizing production decision. This can also be called latent diversity as it exists only as a result of the farmers' behavior given market prices and does not enter the model as a choice variable. The only exogenous parameters necessary for the activity choice estimation are those contained in (p,Φ_{Farm}), i.e., exogenous input and output prices and farm characteristics. If, as mentioned in the previous section, there are decreasing returns to scale in production activities, then 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.

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 in the SNP 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."

An important area where there may be high transaction costs are in the hiring of labor and the availability of credit to hire labor. A missing market for labor may mean that when a household has off-farm opportunities with a higher wage (and possible lower variance of income) an inability to hire in non-household labor may cause households to switch into a less labor intensive cropping system. A missing market for labor does not mean an absence of a labor market, but can arise from the imperfect substitutability of family for hired labor. This is important for the milpa because of the fact that the inter-cropping is a more labor intensive system than mono-cropping; as land is already allocated and minimal purchased inputs are used on inter-crops, labor is the sole input into inter-crops. Furthermore, in the use of hired labor the MVP of labor could be different for each milpa crop. For example, a farmer may want to use a team of hired labor to move quickly through to weed a field or double the stalks in one day, but care taken to manage inter-crops may slow the labor for maize.

Missing Market for Consumption Good

An interesting case with important implications for modeling diversity demand is where there is a missing market for a crop that supplies diversity. This could be a commodity with a consumption trait which the family may value but for which high transactions costs create a missing market, forcing the household to satisfy all of its demand for the good through its own production. If households demand diversity in their consumption of staples, high transactions costs for staples tend to promote on-farm diversity in staple crops.

Markets may exist, and in the SNP they do exist for almost anything, but many are "thin" markets with few buyers and sellers and thus increasing search and information costs. If there is a level of risk in the product's availability and in prices at the time of demand, both can create price bands the width of a certainly equivalent, making the price higher for products sold and lower for products purchased. This can be exacerbated in village economies where all households harvest at the same time; a high harvest for everyone will decrease the opportunities to sell, exactly when the opportunity to sell is highest.

A particular case for the management of crop diversity is the lack of market for particular quality of locally produced items. A moral hazard exists if quality is difficult to determine or verify in the marketplace (Akerloff, 1970). High quality maize may not be marketed, and low quality maize is marketed again because the quality is hidden. This was observed in the market at Cuetzalan, Puebla, where merchants reported a local village as a source for maize, when it was actually imported. This is also highlighted in the SNP by the massive importation of cheap low quality maize, both by the government store DICONSA, and by private traders. While farmers are able to market some maize through local markets, they are unable to sell large quantities with a price premium for the local, higher quality.

Simplifying the model in (1), the household derives utility from consuming self-produced goods, Xi, and all other consumption goods with market prices represented by total income Y. For any non-tradable good X_{NT} consumption is constrained to exactly equal own production. A vector of exogenous characteristics that describe access to markets and transactions costs, Φ_{Market}, characterizes this missing market constraint. The market characteristics describe the degree of integration into regional markets and affect whether the household will be able to use the market for consumption of that good. The farm technology function is simplified to a cost function, and the reduced farm profit function is substituted into the cash income constraint, a combination of farm profits (from production of tradables) and exogenous income $\overline{Y}$. In the case of one or more missing markets, the household maximization problem (subject to income and market constraints) becomes:

$$\max_{X,Q} U(Xi, Y; \Phi_{HH}) \tag{1.6}$$

$$Y = \sum_{i \notin NT} p_q (Qi - Xi) - C(Qi; \Phi_{Farm}) + \overline{Y} \qquad (l) \tag{1.7}$$

$$Q_{NT} = X_{NT}(\Phi_{Markets}) \qquad (g) \tag{1.8}$$

where l and g are the shadow prices on the cash income and missing market constraints, respectively.

The first order conditions for all commodities except the market-constrained good are:

$$for\, i \neq NT : Uy\left(pi - C'\left(Qi\right)\right) = 0 \; or \; pi = C'\left(Qi\right) \tag{1.9}$$

In the case of the subsistence good, however, the first order conditions include another term which reflects the need to meet the subsistence constraint:

$$for\, i = NT : \; Uy(C'(Q_{NT})) + U_{XNT} = 0 \; or\, C'(X_{NT}; \Phi_{Farm}) = r_{NT} \tag{1.10}$$

where

$$r_{NT} = \frac{-U_{x_{NT}}}{U_Y} = \frac{g}{l} \tag{1.11}$$

Similar to a safety first formulation in the risk literature, the right hand term is the household shadow price or subjective valuation of the subsistence crop. The endogenous household shadow price, r_{NT}, is affected by household and market characteristics, and becomes the price that is used in making household production and consumption decisions. The solution to the household's maximization is

$$Q = Q_i^*(p, r_{NT}, \Phi_{Farm}) \tag{1.12}$$

$$Xi = Xi^*(p, r_{NT}, \overline{Y}, \Phi_{HH}) \tag{1.13}$$

$$r_{NT} = r^*(p, \Phi_{HH}, \Phi_{HH}, \Phi_{Markets}) \tag{1.14}$$

Thus, the derived demands $Q^*(p, \Phi_{HH}, \Phi_{Farm}, \Phi_{Markets})$ now are functions of variables influencing this subsistence demand (e.g., household demographics and preferences), and the level of diversity $D = D(Q^*(p, \Phi_{HH}, \Phi_{Farm}, \Phi_{Markets}))$ is no longer a production-derived demand but rather is affected by both consumption and production characteristics of the household, as well as market conditions. In order to test whether missing markets affect diversity outcome, and to test whether the model reflected in Eqs. (1.12) and (1.14) is an improvement over that represented by Eqs. (1.4) and (1.5), we will test whether markets or household characteristics affect the derived demands for diversity. The market conditions contained in Φ_{Market} will be measured by the degree of isolation or integration to regional markets, which will determine whether Eqs. 2.7 and 2.9 affect household diversity outcomes.

Risk in Crop Choice

Another interesting case, which has received considerable attention in the partial adoption literature, is that of a farm household operating under risk, where production is stochastic but prices are exogenous. An obvious starting place to model risk is on the production side; farmers may conserve multiple varieties to spread risk across a portfolio. A traditional certainty equivalence approach can show the demand for a portfolio to decrease risk: given two crops with equal mean and variance of net profitability, $m_{\Pi 1} = m_{\Pi 2}$ and $s^2_{\Pi 1} = s^2_{\Pi 2}$, and with a correlation ρ,farmers decide the share, α, to dedicate to each crop. The certainty equivalent for profit is $\Pi^* = +a m_{\Pi 1} + (1-a) m_{\Pi 2} - \frac{1}{2} A s^2_{\Pi} \{a^2 + (1-a)^2 + 2a(1-a) r^2\}$, where A is the Arrow Pratt coefficient of absolute risk aversion. The derivative with respect to α is $\frac{\partial \Pi^*}{\partial a} = A s^2_{\Pi} (1-2a)(1-r^2)$, which vanishes at the optimum. As long as the correlation in profits across crops is not perfect, the household will reduce the overall profit variance by allocating some resources to each crop. In this oversimplified case, α =.5 . The extent to which the household looks to its agricultural portfolio as a source of overall risk management can certainly influence crop choices, and thus diversity outcomes.

If some non-crop component of full income (e.g., non crop production or migrant remittances) is subject to risk as well, a certainty equivalent for income can be represented more generally as $Y^* = \bar{Y} - \frac{1}{2} A s_y^2$, (where $\bar{Y} = E(Y)$,) that is, in terms of the mean and variance of income and the Arrow-Pratt absolute risk aversion coefficient A. In this case, the cost, in risk terms of adding an agricultural activity i would take the form: $Y'^* - Y^* = m_{\Pi i} - \frac{1}{2} A(s_{\Pi i}^2 + 2Cov(\bar{Y}, \Pi i))$, and thus will depend on the correlation with risks in other income activities. Thus, diversity choices are influenced by correlation between net income from diversity-enhancing crops, on the one hand, and both exogenous income and competing activities (income from wage or craft labor or even other crop income), on the other. The demand for diversity depends on its contribution to the variability of total income (which equals the variability of total wealth if asset values are known). The contribution of an individual crop to income variability may be small depending on the total income diversification of the household.

Introducing uncertainty into crop yields, crop prices, or market availability of crops (or their substitutes) changes the household maximization problem outlined above. The household now maximizes the expected utility of a consumption bundle:

$$E(U(X; \Phi_{HH}; \Phi_{Risk})$$

$$l : \tilde{p}X = \tilde{\Pi}(\tilde{Q}(F; \Phi_{Farm}) + \bar{Y}$$

The household maximizes its consumption levels subject to a stochastic income level $\tilde{Y}$ because of uncertainty in crop prices $\tilde{p}$, farm profits $\tilde{\Pi}$ and farm output, $\tilde{Q}$.

Furthermore the manner in which the variability interacts with the household utility function, the degree of risk aversion, introduces a new set of explanatory variables to the crop choice decision, Φ_{Risk}. The most important determinant of risk aversion as mentioned above is either the level of household wealth or net household income including income from other activities. Another important interaction in risk and household utility is the degree of self sufficiency, or the degree to which the uncertainty affects the consumer part of the equation rather than the producer side. Looking at price risk alone, Finkelshtain and Chalfant have shown that households consuming a large share of their output will increase production given an increase in price variability. When looking at the behavior of primarily subsistence producers, the downside risk is weighted more heavily that the upside risk. This has led to safety-formulations with formulations that affect crop choice behavior increasingly as the subsistence level is threatened (Smale, Just, and Leathers, 1994). Also, variables like agro-ecological conditions which affect farm output, now influence the distribution of returns from each variety, not only the mean returns.

There are three main ways that the important uncertainty effects can be introduced through the missing market model outlined in the previous section. First, uncertainty in market availability and the quality of milpa crops is a form of transactions cost that leads to the price bands which are a major reason for market failure (de Janvry, Fafchamps, and Sadoulet, 1991). Second, the trait based model could be used to introduce the variance of yield (and even higher moments of the yield distribution) as crop traits that are part of the farmer's choice set. Finally the fact that the household is subject to variability of farm profit could be seen as a missing market for insurance on crop yields.

Testable Hypotheses

Effects on Different Crops

The model developed thus far is for a crop choice to be across all of the possible crop choices in the milpa. However, the different classes of milpa crops, maize, beans and squash, may interact differently with the production system, market constraints, and overall household welfare. The model will be used to test whether the determinants of diversity outcomes are significant and whether their signs are the same for diversity of the multiple-crop system as within each crop.

The null hypothesis is:

$$\frac{\partial D_{Milpa}}{\partial \Phi} = \frac{\partial D_{Maize}}{\partial \Phi} = \frac{\partial D_{Beans}}{\partial \Phi} = \frac{\partial D_{Squash}}{\partial \Phi} \qquad \text{(H1)}$$

where D_{Milpa} is the interspecies diversity of all of the crops in the milpa cropping system, and D_{Maize} is the infra-species diversity within each of the principal species, here maize. The reason that this is an important hypothesis to test is because previous studies have focused on the principal staple crop and ignored the possible loss of CGR in other varieties. Thus there are two principal questions to underlying this hypothesis, are minor inter-cropped species more at risk than the principal crop, and are there different economic explanations for these crops disappearing. The possible ecological values of the complex cropping system for generating diversity and containing ecological interactions motivate the need to compare the milpa system to the individual crop components.

Effects of separability

From the structure of the household-farm model, the starting point for determining diversity outcomes is to test for the separability of consumption and production decisions. If the model is separable, the household-farm makes decisions recursively. First the crop choice decisions are made within the production context, and then consumption decisions are made given net income. If the model is found to be non-separable, a range of consumption, market, and income effects may be important determinants of farm-level diversity

The null hypothesis is:

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

where Φ_{HH} and Φ_{Farm} are the exogenous variables affecting crop choices in the production decisions. If the null hypothesis is true, the model is considered separable and crop choices set by exogenous market prices and production constraints (Benjamin, 1992).

Hypotheses Tests within the general model

For the analysis and policy relevance for the design and administration of conservation programs, the sign and significance of individual coefficients are of interest. Some may be directly related to policy instruments, while others may involve larger processes. It will be important to look at the determinants of diversity in relation to the larger processes of rural development and other welfare effects that may be involved.

To avoid omitted-variable bias, it is necessary to use a general model holding constant confounding effects. For, example it is necessary to hold constant the agro-ecological effects in order to test for possible economic effects of markets or household characteristics on diversity decisions. The nesting of the separable model within the non-separable model will also serve to isolate these different types of effects.

Agro-Ecological effects

Previous studies have used the degree of fragmentation of landholdings or agro-ecological constraint to show why households continue to grow traditional varieties (Bellon and Taylor, Meng). This study will test whether the degree of fragmentation or agro-ecological heterogeneity has an affect both on cropping system diversity as well as diversity within each crop. From Equation 2.6 the first order conditions of the Trait-based model, a crop will be planted if it embodies a trait that confers a production advantage (in the model formulation, a lower production cost) related to some constraint or characteristic of the farm (Φ_{Farm}). If the household's land endowment includes two soil types, and a different variety can perform better on each soil type, the household will plant two varieties. Even households with a greater degree of market integration when faced with agro-ecological production constraints may choose to conserve diversity in order to match heterogeneous conditions. The hypothesis to test is whether the agro-ecological conditions increase diversity at the household level, (holding household and market characteristics constant).

$$\frac{\partial D}{\partial \Phi_{\text{Agro-Ecological}}} > 0 \qquad \text{(H3)}$$

Market effects

If the model proves to be non-separable, the analysis will focus on how the development of local markets can affect household conservation of CGRs. In Equation 2.6 we saw that a missing market for a variety, or some trait embodied in that variety, can lead a household to choose to produce a variety if the household's subjective valuation of the variety leads it to supply its own consumption of that variety. While we cannot measure for missing markets directly we can use different measures of market integration to proxy for the effects of missing markets. Because the survey that is the basis for the econometric analysis was carried out in a series of communities with varying degrees of market integration, we can test whether the level of market integration affects the level of milpa diversity that a household maintains.

$$\frac{\partial D}{\partial \Phi_{\text{Market}}} = 0 \qquad \text{(H4)}$$

From the theoretical model we believe that an increase in the level of market integration will decrease the level of diversity maintained by a household. The testing of this hypothesis has important policy implications for in situ conservation of crop genetic resources. Many of the processes of market integration, such as improvements in infrastructure, increased trade in commodities and basic substitutes, and the expansion of regional and national labor markets, are inextricably linked to the process of economic development.

Moreover, different markets can affect the households diversity behavior in different ways. The 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 the distance to markets) on household diversity outcomes. It is possible from the theoretical model that commodity market integration could increase the household's level of diversity, if the household is able 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 through the reliance on family labor for milpa activities in the village, and through the opportunity cost of staying in milpa activities. Finally, risk and portfolio behavior will be tested by estimating the effect on diversity of the level of household wealth, a classic proxy for the level risk aversion and exposure to risk.

Finally, it is necessary to test whether market variables have differential effects on the different crops. To understand the causes and sources of genetic erosion of milpa CGR, it will be crucial to look at the effects on the different crops (as proposed in Equation H1) The hypotheses to test are

$$\frac{\partial D_{Maize}}{\partial \Phi_{Market}} = \frac{\partial D_{Beans}}{\partial \Phi_{Market}} = \frac{\partial D_{Squash}}{\partial \Phi_{Market}} = 0 \qquad \text{(H5)}$$

Maize is the most commercial crop. Although most households do not sell maize, many sell small quantities throughout the year, and maize makes up a large share of consumption expenditures. Maize is more likely to be subject to subsistence behavior, but at the same time there is a high volume of low quality substitutes. Beans are semi-commercial, almost entirely for home consumption, except for seasonal green market for one variety. Squash is completely non-commercial and entirely for home consumption. Furthermore beans and squash are dependent upon the inter-cropping system for their existence in the milpa, and this may make them reliant on the family labor input that is the key input to inter-cropping. Therefore the effects of the economic variables can be different for each crop.

Appendix to Model Chapter - Trait Based Model

When farmers evaluate the costs and benefits of crop varieties and crop species they may actually consider a series of traits or characteristics. Each crop variety can be seen as a bundle of these characteristics; the literature on crop genetic resource conservation has sought to integrate traits and characteristics into a framework for analysis (Bellon, 1998). The household-farm model presented above is modified here to incorporate varietal traits directly into a household's decision framework. The approach is similar to Smale and Bellon (1998), but is different in two ways. First, the exogenous variables that affect diversity outcomes are modeled separately for production and consumption. Second, the market effects are directly integrated into the model and extensions to missing markets for characteristics are explored.

Each crop has a vector of traits, which are divided into consumption and production traits. Consumption traits could include color, texture, or specialty or ritual uses. A simple but very relevant consumption trait could be home-production, as households may favor their own production over seemingly similar market substitutes (Strauss, 1986; de Janvry et al., 1991). Production traits could be related to matching to a specific soil type or other agro-ecological niche, labor requirements, or resistance to drought or pests (biotic and abiotic stresses) (Bellon and Taylor, 1993). An important, but more complicated, set of production traits would be the moments of the yield distribution for each variety (Meng, 1997; Smale et al., 1999).

Traits are separated into two vectors, Z^c, consumption traits, and Z^p, production traits. A matrix of technical coefficients z_{ij} translates the quantity produced Q_i (or quantity consumed X_i) to the Z^c_j consumption traits, Similarly for production there is a matrix of coefficients z_{ik} to translate Q_i to Z_k^p production traits. Each element z_{ij} or z_{ik} of the matrix **z** is a coefficient of the quantity of trait Z_j supplied by each unit of Q_i. The consumption and production coefficient matrices are stacked into overall trait vector **z** composed of technical coefficients with z_{im} where m=1,…j,1,..k and M=J+K.

Households maximize utility by consuming crops X_i, traits of these crops Z^c, and all other goods through income, Y. The production and farm profit function is again reduced to the sale of net farm output less a cost function, which in this case is a function of Q, the quantity produced, and Z^p, the vector of production traits.

$$\max_{X,Z,Q} U\,(X_i, Z^c, Y; \Phi_{HH}) \tag{2.1}$$

$$l : Y = p_q(Q - X) + p_z Z^c - C(Q, Z^p; \Phi_{Farm}) + \overline{Y} \tag{2.2}$$

$$m : z'Q = Z\,(\Phi_{Market}) \tag{2.3}$$

In this model there may be a missing market for the consumption traits. If a market exists, consumption traits receive p_z, a market premium for quality. A missing market for consumption traits is characterized by equation (2.3) and affected by exogenous market variables, Φ_{Market}. As mentioned in the previous section, missing markets may occur for quality traits where there are significant transaction or information costs. Varieties with high quality traits will be absent from the market if their quality characteristics are not recognized and awarded a premium. Conversely the varieties with low quality traits may be principally channeled towards the market, making it difficult to find high quality traits. In the simplified case that the quality trait is home-production, this trait is necessarily not found in the market nor receives a price premium.

Analytically, we can compare two goods, a market good, and a local good that may be close substitutes but differ by some quality trait.

For variety 1 - "market good" $Q_i^{market} \cdot z_i^{market} = Z_i^{market}$ but $Z_i^{market} = 0$

so it is not demanded for quality.

For variety 2 "local good" $Q_j^{local} \cdot z_j^{local} = Z_j^{local}$ but $p_z^{local} = 0$ and thus it is difficult to find the good in the market.

The FOCs for a good with a non-tradable trait are;

$$\frac{\partial L}{\partial Qi} :\rightarrow l\,(p_q - C\,'(Q_i)) = -m \cdot z_{i.} \tag{2.4}$$

$$\frac{\partial L}{\partial Zj} :\rightarrow Uzj\,' = m \tag{2.5}$$

$$\frac{\partial L}{\partial Zk} :\rightarrow -\,l\,(Cz\,'(Q\,, Zp)) = m \tag{2.6}$$

In Equation (2.5) for a consumption trait Z_j the multiplier μ in is equal to the marginal utility derived from consuming one more unit of trait j. In Equation (2.6)for the case of a production trait, μ is equal to the reduction in cost, or benefit to the production technology.

Rewriting Equation (2.4) we can examine the effect on production decisions.

$$C\,'(Q_i; \Phi_{Farm}) = p_q + \frac{m\,(\Phi_{Market})}{l\,(\Phi_{HH})} \cdot z_{i.} \tag{2.7}$$

In the case of the consumption good the household shadow price for crop i is the market price plus a markup for the marginal utility of consuming the traits that crop i supplies. If it is a beneficial trait ($U'_m > 0$) which cannot be found in the market, then the household will produce more of it.

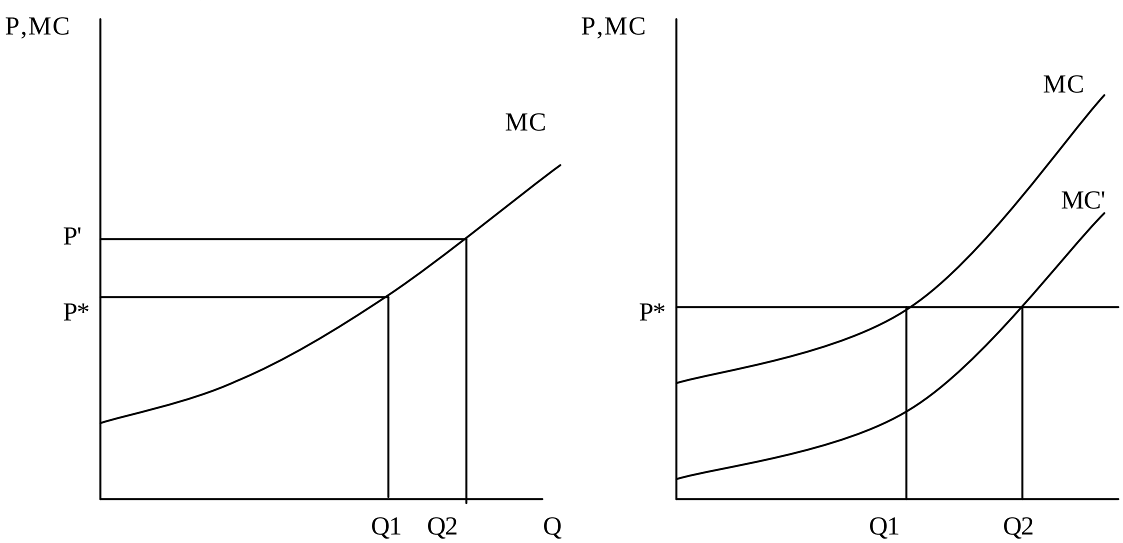
Alternatively,

$$p_q = C_Q'(Q_i;\Phi_{Farm}) - C'_Z(Q_i;\Phi_{Farm})z_{i.} \qquad (2.8)$$

In the case of a production trait the household shadow price for that crop will be the market price minus the per unit cost savings that the crop's set of traits provides. Or in the above formulation the market price is set equal to the marginal cost net of the benefits of the trait. It is important to note that given a functioning market the model is still recursive and the only exogenous variables affecting the crop choice decisions (and thus the diversity outcome) are those describing farm technology and characteristics, Φ_{Farm}. In the case of missing markets for traits, the result is the same as for missing markets for varieties. The diversity outcome is affected by all three vectors of exogenous variables, $D = D(\mathrm{Q}^*(\Phi_{\mathrm{HH}},\Phi_{\mathrm{Farm}},\Phi_{\mathrm{Markets}}))$.

The effects on output levels can be shown in a graphical representation in Figure 6, The effect on profitability can be seen as having effects on which crops will be in the household's activity set and contribute to household level diversity.

Figure 6: Effects of Consumption and Production Traits on Output.



In the above figure, the left diagram is for a consumption trait, and the right diagram is for a production trait. In the consumption case the market price is P*, but the price that the market uses for making output decision is P'. In this case there is a missing market for a consumption trait, and P' is an endogenous household shadow price reflecting the additional marginal utility that the crop adds through its specific traits. The household would set output quantity at Q1 with a functioning market, but given a missing market for a trait, the household increases production to Q2 to supply household demand for the trait.

In the right diagram the market price is again P*, but here the trait is a production trait which lowers the per unit cost of production from MC to MC'. In this case the household increases the production level Q1 to Q2 reflecting the benefit that this crop brings through its production characteristics.

A trait based model is important because it conveys the complexity of the crop choice problem. Household-farms make their primary decision based on the primary trait - yield. From there they go on to make secondary decisions based on other traits, such as variance of yield, taste characteristics, or agro-ecological adaptation. Farmers can rank characteristics on the basis of relative importance and weight the traits in their decisions accordingly. However the trait model can also describe conservation behavior, such as where farmers maintain small amount of minor varieties or crops for reasons other than yield.

It is also important to note that the matrix $\mathbf{Z}$ and each of its coefficients are here treated as fixed. While the coefficients are fixed in any given year for a farmer's crop choice decision, they are all the result of the processes of domestication, crop selection and breeding. In the long term farmers can select crops in relation to the traits that they demand, or the farm technology or agro-ecological constraints that they face. More relevantly any breeding program that seeks to change the Z coefficients will have to take into account the entire vector of consumption and production traits that affects crop decisions. The introduction of new seeds that are the product of a modern breeding program will inherently have a vector of coefficients translating the performance in terms of local production characteristics and acceptability in terms of local consumption preferences.

Chapter 4: Description of Region and Survey Sample

The data for this research were gathered as a part of the McKnight Foundation Collaborative Crop Research MILPA project, composed of a joint Mexico-US research team of botanists, biologists, crop breeders, and social scientists (www.grcp.ucdavis.edu/milpa). Research teams are based around the principal crops of the milpa: maize, beans, squash, and quelites (a broad category of other edible plants found in the milpa). The fifth research group, the socio-economic group (of which I was a member), concentrates on local and regional analysis of the motivations behind farmer behavior.

I surveyed 281 households in 24 villages in the Sierra Norte de Puebla, in a mountainous region roughly delimited (and isolated) by two major river valleys. The survey sample 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. The survey sample was intended to contain enough cross-section variation in the key characteristics affecting household diversity outcomes to allow testing of the hypotheses generated from the theoretical model in Chapter 3. The variation in levels of market integration in the region can also be used to model the processes of development that may be spreading throughout the region and their effects on CGR conservation.

Three surveyors were hired and trained, and helped to pretest the survey. Each surveyor did an average of two surveys per day, and I accompanied a different surveyor each day to ask qualitative and descriptive questions as well as to ensure consistency across surveys. Five of the smallest communities were sampled once ($n \approx 6$) while most communities were sampled twice (n≈12). Within each village, households were selected at random. The focus on the farming systems meant that the commercial centers were not sampled, but some commercial activity was picked up in the sample frame.

The region is characterized by dependence on two major market towns serving as commercial poles, and is served by one major highway with two branch roads. There is also a basic correspondence to an administrative region in the provision of different levels of government services from the commercial poles. Within the sample area the principal regions are dictated by the topography and climate of the region. Tierra Caliente (Hot Lands) are roughly lower than 1200 meters above sea level (masl), and are characterized by sub-tropical vegetation and include a lowland transition zone to the coastal plain of Veracruz state. Tierra Fria (Cold Lands) are those above 1200 masl and are characterized by temperate vegetation and a transition towards the higher altitude zone of the high plateau of Puebla state. The principal agronomic and economic differences are that the Tierra Caliente lands 1) grow coffee, the most important cash crop in the region, and 2) can grow two cycles of maize in a year. The distribution in climate zones is 9 villages with a total of 118 households in Tierra Fria, and 15 villages with 163 households in Tierra Caliente.

The following section discusses and describes the agricultural systems of the SNP and local CGRs. The second section presents summary statistics from the survey sample to describe the management of the CGRs by local farmers.

Milpa in the Sierra Norte de Puebla

Following Louette (1996) the unit for analyzing maize diversity is the farmer's seed lot, defined as a set of seeds selected by the farmer, planted, and used for selection in the next generation and maintained as distinct from other seed lots. A variety refers to a name shared by many farmers and is usually tied to certain characteristics or traits agreed to by these farmers. A race refers to the grouping of maize collections by similar phenotypic, morphological, or genetic characteristics and is often an evolving definition (Wellhausen, 1951; Sanchez and Goodman, 1992). For the other crops studied here, beans, squashes, and quelites, we follow the classification for maize, a seed lot being the basic unit that a farmer uses and maintains as distinct from another, and a variety being a grouping commonly referred to by many farmers. However, for these secondary crops the differentiation between types follows the lines of species directly and thus the infra-species issues are less important.

Maize

My preliminary assessment of maize diversity did not reveal a very high level of diversity within maize in the SNP. There are not a large number of named varieties; the majority of farmers grow only one white maize, called *criollo*, or in nahuatl, *iztac*. Relatively few farmers maintain minor varieties of maize, usually colored variants, yellow, *costic*, and blue, *yahuitl.* Across the region, some villages have only the one dominant white maize, and other villages have a higher percentage of minor varieties and a higher percentage of farmers planting these varieties. This pattern is similar to other studies that have done a stratified sampling of villages is a given region. (Oaxaca, Guanajuato, Chalco/Cuautla)

However, in looking at seed lots and especially post-harvest piles of cobs it often appears that several races of maize are intermixed. Sometimes different local varieties even seem to be mixed within the same cob. The mixing of varieties on the same cob is most likely due to the different flowering times of different varieties. The middle of a cob corresponds to the first silks to develop and may be pollenized by an earlier, (precocious) variety; the base and tip correspond to the later development, pollenized by later-flowering varieties. Indeed, for maize the flowering time of a population indicates the local adaptation of landraces to micro-climates. When farmers select seed, it is common to first select for desirable grain and ear characteristics, and then discard seed from the base and tip and only keep seed from the center third of the cob.

Highland Maize

The higher elevations of the survey region (1400-1800 masl) comprise the more intensive maize growing areas, these are where farmers are more likely to grow multiple varieties of maize. Geographically, the high altitude area that is the center of the survey site is effectively an island, in that there is no direct land connection to even higher elevations with similar maize races. Because of such isolation, the highland area is possibly home to relict populations that have a lower rate of genetic exchange with other highland areas.

The principal race for the highland populations is the *Conico* / *Chalqueno* complex (also known as the *pyramidal* complex). This is the principal racial complex for most of central Mexico for elevations between 1800 to 2500 meters. In the case of the SNP these are the bordering areas of Puebla state as well as the maize belts of the neighboring states of Mexico and Tlaxcala. The high altitude maize varieties have a very long growing cycle: in general they are planted in January, are mature in July, doubled over to dry for two to three more months, and are harvested in September or October.

A smaller race in the area is *arrocillo* (literally "little rice-type"). *Arrocillo* is a very productive local maize, characterize by multiple cobs per plant, that are short cobs, and have small, dense, pointed (rice-like) grains. The population of this variety is delimited within a 100 km area, with fixed lower boundaries that were determined on a brief diagnostic trip. The population was characterized as an older race, a parent of more recent races, according to Wellhausen et al (1951). In this limited area the *arrocillo* competes with *conico*/*chalqueno* type materials and performs favorably with high yields and heavy weight beneficial for selling grain by the kilo. The geographic distribution of *Arrocillo* is almost contiguous with the area surveyed, and the grain does enter the regional market in Zacapoaxtla. In the market, the grain seems to compete well and is considered as a local maize, yellow and smaller grains notwithstanding. This maize is a potential target for conservation or monitoring because of the limited geographical location and because of the fact that the yield is still competitive in the eyes of farmers.

Lower Altitude (Tropical) Maize

In the lower areas of the survey region (250 - 1250 masl), coffee competes with maize for land area, and a few villages grow little or no maize. In the lowest areas surveyed (below 250 masl) farms have flat fields and larger plot sizes and maize again dominates the cropped area. Below around 1000 masl, two cycles of maize are grown, the first cycle is sown in January and harvested in July and the second cycle is sown in August and harvested in December. This is made possible by a combination of more rapidly maturing tropical germplasm and a higher level of precipitation in the January-February winter months compared to higher elevations.

The dominant race of maize in the lower elevations is *Tuxpeño*. In fact, *Tuxpeño* is one of the most productive and widespread maize races in the sub-tropical areas of the world. Historically it is native to the lower elevations of the SNP (unlike other areas where it has been more recently introduced). Some samples collected for seed analysis showed signs of infiltration of the races *Nal-Tel* and *Olotillo*, two other principal lowland races in Mexico.

For the sake of conservation it would be interesting to determine how many of the regional *Tuxpeño* landrace populations are from historical germplasm and how many are the product of modern breeding efforts, which have brought *Tuxpeño* germplasm into many new areas. One possible indicator would be the height of the plant because one of the principal outcomes of modern breeding programs has been to lower plant heights.

Issues for Maize Conservation

There do not appear to be a large number of named varieties grown within any village, nor do farmers mention competition between different varieties of the principal white maize. However the area could be a targeted for conservation because of the genetic diversity and evolutionary potential within the one principal white variety. The intermediate area of the SNP (roughly 1000-1500 masl) is an area of mixing between the *Conico* and *Tuxpeño* racial complexes. Furthermore, some villages span the adaptive range of both races, and some households trade seeds between villages and have other linkages through local and regional markets. Moreover the steep canyon geography creates many microclimates for segregating populations that develop out of the mixtures of different races.

A possible target for conservation is a high altitude Tuxpeño, which is of interest to maize breeders (Castillo, pers. comm. 1999). One such variety, *Xochiteco* (named after the village of Xochitlan) is included in the survey sample. This is a sub-race of *Tuxpeño* that grows at high elevation for this race (1000-1200 masl). There are yellow populations that could be of interest for breeding purposes (S. Taba, pers.comm. 1999)

A few farmers in Zoatecpan (1600m), within the municipality of Xochitlan, reported preferring the lower elevation seed because it matures more rapidly. However, they commented that the seed lots lose precocity over a few generations (1-3) and must be renewed. This loss of a favorable trait, presumably due to cross pollination with highland varieties, points to how some farmer behavior causes constant genetic flow and adaptation. Zoatecpan farmers also sow yellow maize on steeply sloped parcels. This practice was reported in a thesis from Chapingo (Izunza, 1988), and is still borne out in the survey data for Zoatecpan.

Few farmers in the survey had experience with hybrids or mentioned using improved varieties. In the lowest elevation villages a few farmers reported using advanced generation hybrids. In the village of Amatlan, farmers reported that an agronomist had introduced hybrid seed ten years ago; since then the farmers had not purchased new seed and still grow advanced generation seeds that have been recycled since that time. In the town of Nauzontla - in the high elevation zone but with favorable maize conditions - a key informant had tried hybrid seed in the past year. The yield and plant characteristics were favorable, but most of the harvest had been lost due to bad storage qualities. The farmer said that he would not plant it again.

Maize Markets

In monitoring the regional markets, the local varieties often received a price premium, especially when marked by noticeable quality differences to grain imported from outside the region. However, in the largest regional market, Zacapoaxtla, maize prices were more uniform across varieties due to the high level of supply. In smaller, regional markets such as Cuetzalan and Xochitlan, farmers were able to sell local maize at a price premium but in smaller quantities. Moreover, the volume of market sales of local varieties is small compared to overall regional demand, due to the fact that most locally produced maize is consumed domestically. The markets also offer maize imported from outside the region, and the government's food distribution network imports considerable quantities into the region. Historically, however, the region's small farmers did benefit from a complementarity in maize cycles: lower elevation lands harvest in June when maize stocks are depleted in the higher elevations, and higher elevations have a harvest in October when stocks are already depleted in the lower elevations. Furthermore there is a complementarity between maize in highlands and coffee in lowlands, as maize is sold to coffee farmers and maize farmers migrate to work in the coffee harvest.

The Mexican federal government food distribution system, DICONSA, is the single biggest supplier of maize in the region and fundamental to regional food security. The two regional warehouses at Cuetzalan and Zacapoaxtla each import on the order of 700 to 800 tons of maize monthly each. A distribution network supplies a shop in each village with 2-5 tons of maize per week, depending on the size of the village. According to interviews with the shopkeepers the weekly delivery is usually below the village level demand at the subsidized price, and occasionally informal rationing schemes are applied. The government subsidy is principally for infrastructure and transportation, and local shops are supposed to recover their own expenses. However the price of maize is set at a centralized level, and during the study period was slightly below the market price (2$M/kg vs 2.50$M/kg) and was usually of a lower quality. The quality of the DICONSA maize was in general lower than local preferences and often was the less preferred yellow maize, but nonetheless was very popular because of the price. Households often used the DICONSA maize for animal feed and to supplement their own maize stocks.

Private merchants also import substantial amounts of maize into the region, exploiting a gap between the low quality of DICONSA maize and the high price of local maize. One of the largest private traders was interviewed while unloading a tractor trailer of 50 tons of maize that had just arrived from the US border. Assuming one weekly trip this private trader was importing 200 tons per month, which was redistributed to smaller traders and shopkeepers throughout the region. The trader reported using a mix of Mexican domestic and international sources as supplies change throughout the year.

Beans

A similar pattern to that of maize emerged for beans - many villages with low levels of bean diversity and a few villages with high bean diversity. Three main bean types are found in the region, *Phaseolus vulgaris*, *Phaseolus polyanthus* and *Phaseolus coccineus*. Under some conditions all of these are found growing together in a single field, but *P. vulgaris* is the principal bean used for dried consumption and *P. polyanthus* is the principal bean used for fresh consumption. Beans are the most important secondary crop of the milpa inter-cropping system. The decision to plant beans is indicative of the decision to sow inter-cropped plants in general, and seems to be affected by labor constraints and labor allocation decisions. Although beans compete for some nutrients with maize and may decrease maize yields slightly, the decision to plant beans depends more on the extra labor required to weed, cultivate, string up vines, to double over the mature maize without disturbing the beans, and an extra round of harvesting.

Within *P. vulgaris* (frijol negro), there are two main domesticated types, a bush type and a climbing, vine type. There is also a wild type of *P. vulgaris* that grows either in milpa fields or in field margins. The vine type of *P. vulgaris* (negro enrededero) is relatively more scarce in the region and is dependent upon the milpa inter-cropping system for its survival. The bush form of *P. vulgaris* (negro de mata) seems to be a more recent introduction and is often planted from purchased seed. Suprisingly, many farmers at lower elevations purchase seed that has been imported to the region as food from other states (or the USA, one variety was named "frijol michigan"). This imported germplasm is from improved varieties, and although the seeds are not adapted to local conditions, farmers find the yields acceptable.

The most popular bean in the highland areas is *P. polyanthus*, locally called xoyema or "frijol gordo" - fat bean. This bean is appreciated for taste when cooked fresh, and receives a market premium for the fresh beans during the period of maturity from September to November. The market is seasonal, but local sellers show up consistently at regional markets. The production of this bean seems to be mainly driven by labor constraints for harvesting and traveling to the market, as well as transportation costs for the bulky product. Little is sold as a dried bean, perhaps because it cannot compete with market substitutes.

One other species of bean which is common throughout the highland areas is *P. coccineus*, locally called tacahuacet or "frijol duro" - hard bean. This bean is not particularly favored because of the long cooking time due to the hard pericarp. This species was difficult to capture in the survey because of the fact that many have it in their fields without planting it; it exists as semi-weedy or semi-domesticated, but not many people eat it. In the fields, the plants may be confused with other *phaseolus*, but at flowering are obvious because of bright red flowers.

Within the SNP there are certain areas where both the wild and cultivated forms of *P. vulgaris* grow together in the same field. This has been the target of studies by the geneticists within the bean group of the McKnight project. A study of wild and cultivated beans grown in the same field found that the hybrids were fertile and a study of molecular markers found 54% of the samples of wild beans had genes from the domesticated genome (MILPA, 1999). A study of the pollinators that was undertaken by following bees through a field planted with the different bean varieties, and found that the presence of some out-crossing species in the field attracted the pollinator to visit self crossing species and out-crossing species in the same field (MILPA, 1999).

Squash

The SNP is not an area of very high squash production. In fact the squash breeders of the McKnight project could not find any local farmers with favorable conditions to work with, so they worked just outside of the Sierra in an area with higher squash production. Squash production is limited due to the high level of rainfall, especially during the maturation period, which leads to a high incidence of pests and diseases. However, squash is a classic minor crop in the milpa system, and surprisingly high numbers of farmers do maintain a few plants within the milpa. In looking at the population genetics for conservation, while on the one hand farmers may be selecting from very low population numbers to preserve diversity, on the other hand small plots and land fragmentation could lead to cross pollination across different farmers' fields. Thus like maize, the population may need to be considered at a village or regional level given high levels of cross-pollination. As with beans, some of the minor squashes may not be actually sown by the farmers. Many exist in a semi-domesticated state in which they are allowed to seed themselves in the field, and a select few are allowed to survive and spread between the maize stalks. One major threat to squash as a part of a diverse inter-cropping system is the use of herbicide to substitute for hand labor at weeding time. Few farmers use herbicide in the SNP, but those who do are usually at lower elevations, and comment that inter-crops must be grown in a separate plot.

The most common variety of squash (*Cucurbitaciae*) is *Cucurbita moschata*, known as "calabaza pipian". *C. moschata* is used for its seeds, which are high in protein and an ingredient in mole sauce. The flesh of the fruit is prized as a seasonal vegetable, is sweetened for use in a seasonal maize drink, atole, and can be stored for several months in the home. However, only a few plants are grown by each farmer, mostly because they can spread and compete with the maize crop.

Another important squash is *Cucurbita fisificolia*, or chilacayote. In many of the fields a few fruits are allowed to rot and from there the plants seed themselves. The flesh is used at maturity as a vegetable, and *C. fisificolia* is also eaten sweetened in a maize drink, atole, during the fall. Sometimes fruits are stored for use as animal feed.

The other common *cucurbitaciae* species is *Sechium edule*, locally known as "chayote". This climbing vine is not like a classic squash, and is notable for its aggressive growth habit. It is a seasonal vegetable and is eaten fresh for a few weeks each year. In certain fall months every house visited has a pile of steamed chayotes and a visitor is sent home with several. One plant can produce hundreds of fruits and supply a family for several weeks. However many respondents answered that they allowed only a few plants to grow because, one "can't eat it every day forever".

Quelites

There are many other species that grow in the milpa as inter-cropped species or as wild or semi-weedy species that are eaten or tolerated and show different stages of domestication. Quelite means "edible plant" in Nahuatl, but the botanical definition of quelite can vary. A strict definition is a native species that grows without being planted or sown of which some vegetative material is eaten. A broad definition would include any part of the diet where vegetative material (anything but the mature, dried fruit) is eaten and could include squash blossoms, tender tips of bean vines, or non-native brassica vegetable species. Quelites are an unique aspect of the management of inter-cropped minor varieties, because the dominant weeds are edible, so the effort expended to tend the plot doubles as time gathering food for consumption. Quelites are also a temporal separation of land use, since many vegetative species are eaten in the spring, when the maize plants are small and still months from harvest. The labor-intensive nature of such crop management means that quelites are most common in milpas that are close to the house, functioning as something between a garden and maize plot.

The most common quelite is known as "quintoniles", and is comprised of various species of Amaranth (*A. hypochondriachus*, *A. cruentus*, *A. hybridus*). The level of management varies widely; some farmers cultivate quintonil while for others it is simply a useful weed. In the more advanced stages of domestication a few plants are allowed to mature and develop seed heads, some of which are used for decorating altars, and some of which are scattered as seed for the next cycle. Intensive management can also lead to amaranth being the dominant ground cover after sowing, and again, the effort to weed doubles as food collection. Studies by researchers at the UNAM have showed amaranths to be very high in protein and vitamins, being a principal source of protein for some poor farmers during months when tender quintonil is plentiful and other food sources scarce.

Summary Statistics from the Survey

Maize

For the purpose of this study, the milpa begins with the decision to plant maize. The decision is a two-stage process, first whether to plant maize at all, and second whether to plant multiple varieties of maize and whether to inter-crop beans, squash, or other crops. Maize, as the principal crop, the principal staple in the diet, and the focus of the milpa system is the focus of the data summary presented in this section.

The majority of households sow one local white maize as shown in Table 1. A smaller number of households grow yellow maize, and only a few households grow blue or red maize.

Table 1: Maize Types grown by HH

	White	Yellow	Blue	Red
# of HH growing	220	44	18	3
Average Plot Size (ha)	1.23	0.57	0.29	0.2

Furthermore, the average plot sizes also show the minor varieties, blue and red, are planted with very small plot sizes. This creates a possible concern for conservation in that small population sizes are susceptible to genetic bottlenecks and genetic drift (in which rare alleles are lost due to repeated sub-sampling of a small population size, leading to a decrease in overall diversity.

A large number of households (61) reported maintaining the red maize *within* the white variety. Farmers mix the seed from one to three cobs with a ten liter measure of white seed. In the resulting harvest the farmers are able to harvest several pure red ears in order to continue the practice. Some farmers plant the red seeds at the corners of the fields in order to "protect" the field. A wide variety of folk reasons for the practice were recorded, as summarized in Table 2. The possibilities are small that the genetic contribution of a small number of seeds grown within the same population could have an effect, especially an agronomic effect such as lowering stature or increasing pest resistance. However, it is an interesting folk form of maintaining some diversity within a larger population.

Table 2: Reasons for planting red maize

Reason	# HH
Wind - helps to resist lodging	21
Pests - resists fungus and other pests	9
Jealousy - resist the "evil eye"	5
Macho - it is the male	9
Early maturation	1
Tradition	13
Eclipses	3

Calculation of the yields of maize was very problematic in the study sample. One major factor was that there had been a major drought in the previous year and many farmers had had minimal yields. The region is characterized by high rainfall levels, but also a very long growing season. In 1998 there was a lack of rain in the March to June growth part of the crop cycle, and then an excess of rain in the July to September grain filling and drying part of the crop cycle.

Average yields are presented in Table 3 for the two principal maize types. To calculate these means the highest and lowest yields were eliminated as outliers. Farmers were also asked what yield they would expect in a good year as a way to model an average yield.

Table 3:Average yields of principal maize types

	White	Yellow	Good Year
Kg/Ha	1005	1080	1429
St. Dev	581	706	597

The variance on the yield calculations is very high for all three of the averages, even after outliers have been removed, and indicate problems in the data reporting, especially the farmers' reports of total output. However, the means, although low, are consistent with maize yields in other studies throughout the region and the rest of Mexico, especially in studies of maize production in marginal agronomic and economic environments. (Perales, 1998; Louette et al. 1997; Juarez-Varela, 1998; Smale et al., 1999)

Beans

The number of households growing the different types of beans within their milpa is reported in Table 4. The number of households that also harvest the green beans and eat some part of the vegetative part of the plant such as the flowers or tender stems is also noted. Within the *P. vulgaris*, farmers differentiated between the vine and bush types; several farmers also mentioned a third type, basically an improved type grown with purchased seed. In addition, farmers reported using seed not specifically adapted to the region but rather seed from other regions that is sold for consumption.

Table 4: Number of households growing beans (*Phaseolus*) by class

	P. polyanthus	P. coccineus	P. vulgaris (Bush)	P. Vulgaris (Vine)	P. Vulgaris (Other)	Any Bean
	Frijol Gordo / Xoyema	Frijol Pinto / Tacahuacet	Negro de Mata	Negro Enredadero	Michigan / Nayarit	(% all HH)
# of HH	113	7	44	21	10	151 (53%)
Cut Green Beans	74	6	20	14	8	112 (39%)
Eat Flower/ Stalks	51	4	6	3	2	59 (21%)

Just over half of the households growing maize also grow *Ph. polyanthus*, mainly concentrated in the highland region. *Ph. polyanthus* is favored for the fresh beans, and many highland farmers reported growing it because of the ability to market it when prices and yields were favorable. In the sample 21 households reported selling fresh beans at regional markets, usually in small quantities of 20-50 kilos. In contrast, only 15 households reported selling dried beans, and that was restricted to *Ph. vulgaris*. Of the 44 households growing the bush variety of black beans, a small number, 7, actually grow the beans apart from maize in a separate parcel.

The role of *Ph. coccineus* is distinct in the way that different farmer perceive it. Only a small number of farmers, 7, reported actually sowing and harvesting it. Other farmers reported it growing by itself and considered it a weed; some remove it, and some tolerate it in the field margins. Finally, 38 Households reported knowledge of the existence of wild beans in their fields or nearby.

Squash (Cucurbitaciae)

While the region is not notable for squash production, and the high rainfall can increase squash pests, the survey recorded a large number of farmers growing a few squash plants as summarized in Table 5.

Table 5: Number of Households growing Squash (*Cucurbitaciae*) by species

	Cucurbita moschata	Cucurbita fisificolia	Sechium edule	Any Squash (% all HHs)
	Pipian	Chilacayote	Chayote	
Number of HH growing	95	41	71	137 (48%)
Eat Stalks/Flowers	69	25	70	119 (42%)
Average # of Plants/HH	9.9	7.4	6.2	

The first category, *C. moschata* is the most common. It is favored over others for fruit, seed, and flowers, and is grown by almost half of the farmers. Of the households growing *C. moschata*, 72% reported eating the stalk or flower as a vegetable. A smaller number of farmers reported growing *C. fisificolia*; the fruit was reported to be not as desirable as *C. moschata*, but some farmers reported it growing spontaneously. Finally, about a third of the farmers reported growing *Sechium edule*, but some grew it as a backyard vegetable rather than in the milpa because its aggressive growth habits could topple maize plants. The population sizes were very small for squashes; farmers selected seeds from one or two fruits and grew a small number of plants (5-10 on average). However, the population level for squashes could occur across the small parcel size as pollinators can travel from parcel to parcel in 0.5 and 0.25 ha parcels.

Quelites

The wide variety of species and the fact that the list of species changes across ecological zones made it difficult to generate a consistent, categorical listing across households and villages. For the most common quelite, amaranths, also known as quintoniles, data can be compared across regions. Most farmers, 184, reported quintonil growing in the milpa, of which 181 reported eating it, and 13 reported harvesting for selling in the market.

Seed Systems

Maize Seeds

Seed systems for the milpa crops, principally maize and beans, were recorded. Although these parts of the survey are not directly related to the household model presented in the previous chapter for explaining household activity choice, they are of central importance for understanding the larger picture of CGR conservation. While the focus of this paper is to model crop/activity choice and its consequences for CGRs in the area, it is crucial to look at other patterns of farmer seed management. In designing or analyzing the viability of a conservation program these parameters could be of equal importance to explain and relate to the economic context.

The seed histories were recorded to determine how old a farmer's seed lot was, and to extrapolate how frequently the seed lots change.

Table 6: Years with current Maize seed , by color and total

Years	White		Yellow		Blue		Total	
0-5	42	19%	11	23%	4	21%	57	20%
5-10	32	15%	2	4%	1	5%	35	12%
10-15	17	8%	4	9%	1	5%	22	8%
15-20	12	5%	2	4%	1	5%	15	5%
20-25	2	1%	1	2%	0	0%	3	1%
>25	115	52%	27	57%	12	63%	154	54%
Totals	220		47		19		286	

In Table 6, it is observed that across all maize colors we see that 20% of the farmers have not had their seed for more than 5 years and 32% have not had their seed for more than 10 years. On the other hand 54% of farmers have had the seed for over 25 years, many for their entire lives. This bimodal structure is similar to findings by Perales (1998) and Louette (1997) that seed histories are either brief or long. This seems to be characteristic of landraces, many or most are held for an entire lifetime, but some farmers renew seed or try new types in the process of evolution and adaptation.

The question was later rephrased to get at farmers who may "renew" seed that they see as the same, but actually acquire new seed lots. When asked when the last time they had to get seed from a neighbor was, 58% reported within the last five years, and only 32 % said they had never lost their own seed.

The sources of farmer's maize seed is reported in Table 7. Most farmers had acquired their seed from their fathers, followed by others in the same village. The blue maize is a smaller population and more of the farmers have maintained it their entire lives. This is another indication of the precarious status of the blue maize within the region. Farmers may rely on seeds from the same village because of the adaptation of seeds to local conditions. The steep and varied terrain may create very different climatic conditions in neighboring towns. Another reason for the predominance of same village seed is because of social networks that allow farmers to know who would be a good seed source.

Table 7: Source of Maize Seed

	White	Yellow	Blue
Father	45%	56%	68%
Same Village	52%	40%	32%
Other	3%	4%	0%

Although the amount of seed coming from outside the village is low, 3-4%, the cumulative combination with the repeated renewal of seed and trade within the village can have a sizable impact on the flow of genes.

Farmers were also asked if they had ever "changed" their maize seed. A large number, 82 farmers or 39%, said yes. Of those who changed, 87.5% reported using seed from the same village and 13.5% reported using seed from another village. This higher rate of looking outside of the village for seed illustrates farmer experimentation with new types. Farmers who reported changing were also asked why they changed seed.

Table 8: Responses to why changed Maize seed.

Doesn't yield well	9	11%
Changed parcels	8	10%
Lost the seed	29	36%
Try other type	27	34%
Other	7	6%

It is interesting to note that 34% of farmers who changed were doing so to experiment with a new type. The farmers who answered that they changed when changing parcels reflect local opinions that seed could be adapted to the conditions of a specific parcel (correlated with slope, exposure, soil type, etc).

Farmers were asked for a basic evaluation of their local maize. Although the quality or "trait" list here is very abbreviated, it provides some indication of farmer perceptions. Because of the fact that most farmers only had one major maize variety, ranking and pairwise comparisons were quite limited. Therefore perceptions of the major maize type are presented here. Concerns about the ability of their crops to withstand weather related shocks were heightened by the recent experience with drought.

Table 9: Percent of farmers rating the characteristics of their maize

	Bad	Fair	Good
Withstands Drought	46%	38%	16%
Withstands Winds	50%	35%	15%
Good Price in Market	7%	22%	70%
Yields Well	8%	35%	57%
Stores Well	21%	52%	27%
Tortilla Quality	5%	3%	92%
Atole/Tamale Quality	4%	1%	95%

Only 16% of farmers reported their varieties were resistant to drought, but this is in an area where it rains an average of 2-3 meters per year! During the period of the survey there were extreme winds that toppled some of the maize plants previous to the grain filling period, and the data reflects farmer concerns in this aspect. However, 57% of farmers felt that their varieties yield well, and 92% and 95% of farmers reported their maize as good for tortilla and other consumptive uses, respectively. Although few farmers sold maize, 70% reported that it would receive a good price in the market, meaning a quality premium. Finally farmers were divided about the quality of the local maize for storage, as storage losses can be very high, but depend largely on climate and management.

Seeds - Beans

The farmers were also asked about the history and sources of their bean seeds and a different pattern emerged. The results are reported in Table 10. The *P. polyanthus* follows a pattern similar to that of the principal maize varieties. However the bush form of *P. vulgaris* appears less stable as a local landrace. As with maize, the age of *P. polyanthus* is basically bimodal with either a recent acquisition or a very long history.

Table 10: Age and Origin of Bean Seed

Years	*P. polyanthus*	*P. vulgaris* (bush)	*P. vulgaris* (vine)	*P. coccineus*	Other
0-5	25%	40%	10%	33%	36%
5to20	14%	19%	10%	33%	18%
>=20	61%	40%	81%	33%	45%
Source of Seed					
Father	40%	33%	43%	33%	27%
Same Village	47%	45%	48%	50%	36%
Other Village	13%	21%	10%	17%	36%
N	104	42	21	6	11

There appears to be a distinction between the vine form of *P. vulgaris* and the bush form. The vine form follows the maize landrace pattern where 80% of farmers' seed is greater than twenty years old, and only 13% of seed comes from outside of the village. The bush form, however, has a higher percentage of new seed lots, 40%, and 21% of the seed comes from outside of the village. The seed lots listed as other are mostly *P. Vulgaris* bush types as well and follow a similar pattern of recent acquisition and high levels of introduction from outside the village.

Across all bean types, 27% of farmers reported having changed bean seed at some time. Of those who reported changing, 50% reported using seed from local, village sources, 25% used seed from another village, and 25% used seed purchased in the market. Again it is possible that the idea of seed adaptation to local conditions is much stronger for maize than for beans. Furthermore the large number of bean seed lots purchased as food seed in the market indicates a large flow of germplasm and the more precarious nature of local *P. vulgaris* diversity.

Farmers who reported changing bean seed were asked why they had changed, and the results are reported in Table 11. The most common reason reported was that they had lost the seed from the previous season.

Table 11: Reasons for changing Bean seed

Doesn't yield well	3	15%
Changed parcels	1	5%
Lost the seed	8	40%
Try other type	6	30%
Other	2	10%
Total	20	

Finally the seed questions were asked to the larger sample in order to see if the estimates of the flow of seeds into the village were robust. The question was asked where farmers would look for seed *if* they needed it.

Table 12: Potential seed source, by crop

	Maize	Beans	Squash
Father/Same Village	94%	82%	86%
Other Village/Store	5%	17%	14%
N	239	230	222

The rate of 5% seed flow of maize into a village is comparable to those reported previously. For the principal variety of the principal crop (maize) the seed networks are mostly closed, with a small but consistent inflow of seed from outside the community. The rate is again higher for beans at 17%, showing a higher level of inflow of germplasm, and possibly a different perception of adaptation. The level for squash is similar to that of beans, as again farmers may view squashes as more widely adaptable than maize.

Historic

Historic questions were asked to gather some background on the importance of the milpa system for each household. The questions were used to try to ask the households directly what the principal threats to the milpa system are. These questions can be combined with the subjective questions in the following section to identify important parameters for the estimation of the household model.

The first question on the survey was whether the household had planted the milpa in the past year. Those households who reported not planting the milpa were asked why they chose not to.

Table 13: Stated Reasons for not planting Milpa:

Limitation:	Land	Labor (migration/ sickness)	Capital	Coffee (Land, Labor)	Low Yields/ Bad Weather	Not Financially viable
No of HHs	13	12	8	2	14	7

The stated reasons were grouped into the categories presented in Table 13. Many reported a shortage of land, either no available land or rent being too high for milpa production. Labor was reported as a constraint both in finding workers (hired labor) and because the head of household was too old or sick to continue farming (family labor). The most common answer however was that weather was unfavorable to production, or that yields were below acceptable levels. Finally, several households reported that the milpa was not viable because it ended up costing more than it benefited the household.

Many households reported that previously they had grown more maize than in the current period as shown in Table 14. This may be an important aspect of in situ conservation is to understand the process of decreasing involvement in the maize sector.

Table 14: How long ago did you sow more maize?

0-5	32
5-10	28
10-15	12
15-20	10
20-25	1
gt 25	5

The dynamic process of the decreasing importance of maize may be illustrated by the data Table 15 which show households decreasing maize land area. However the combination of different plot sizes and different times reported make it difficult to determine the decrease in hectares. Instead, all farmers were asked how many hectares they planted ten years ago as a way to compare current activity levels to historical ones.

Table 15: Ratio of area planted ten years ago to current

Ratio	# of HH	
0	16	8%
0-1	17	9%
1	59	31%
1-2	12	6%
>=2	87	46%

While under 20% reported growing less maize ten years ago, over 50% reported growing more maize ten years ago. This implies that any sort of de facto equilibrium that describes farmers planting maize at this time is unstable as farmers are decreasing maize acreage, with corresponding consequences for number of varieties and effective population sizes. For many of these cases farmers that previously sold some of their harvest are decreasing acreage to infra-subsistence levels. Over the last 10-15 years, the increase in coffee planted in lowland areas and the increase in migration across the region may be bidding up the wage rate and making maize production less economic.

Subjective Questions

To identify some of the factors about the limitations to maize production that farmers face, the households were asked a set of subjective questions. The farmers were asked if they could imagine doubling the size of their current maize production, and then asked which factors would be the limiting constraints on their ability to do so. First they were asked to identify what the primary constraint would be. (Table 16)

Table 16: Stated Constraints for Not Increasing Production

Limitation:	Land	Family Labor	Hired Labor	Capital	Low Yields/ Bad Weather	Not Financially viable
No of HHs	25	14	6	0	11	20

The leading cause is a shortage of land, or rents that are too high to justify maize production. The second principal reason was a more general conception that maize production is not financially viable due to low output and high input prices. Households were then asked about a series of factor constraints and which ones would bind or make it difficult for them to be able to hypothetically double maize production.(Table 17)

Table 17: Number of HH reporting a constraint

Constraint	Family labor	Hired labor	Capital	Land	Market for output
N	153	110	152	85	38

A much larger number of households (153) reported that their own family labor would not be sufficient to increase maize production. This, combined with the high number reporting a lack of hired labor, illustrates that migration and regional coffee labor have bid up the local reservation wage. A high number of households reported a binding capital constraint, which is probably a reflection of the costs of land, hired labor, and inputs combined. Finally, 38 of the households reported that they would find it difficult to market surplus maize, probably reflecting uncertainty about high enough prices for local maize.

Consumption:

The patterns of consumption for the maize are important because of the role of maize as the principal crop and the driving activity behind milpa cropping. The two most important overall patterns in the region are that the majority of maize production is consumed within the home, and that most households produce below their subsistence requirements. In looking at the regional averages a few general tendencies arise.

Table 18 presents the destination of the maize harvest.

Table 18: Uses of Total Maize Production

Percent of Maize Harvested	Consumption		Animals	Gifts/Exchange	Sales
0-25	5	(2%)	123	13	14
25-50	37	(17%)	44	0	7
50-75	67	(31%)	6	0	0
75-100	107	(50%)	0	0	0
Total	216		173	13	21

In the first column we see that half of households dedicate at least 3/4 of their harvest to family consumption, and 80% dedicate over half of the harvest to family consumption. The second most important use of maize is livestock, principally pork and avian production. Of the households allocating maize from their harvest to animals, 71% dedicate a quarter or less of the total harvest, or 57% of the total households responding. Only 6 households, or 3% use at least half of their harvest for raising animals. The last column shows that very few households sell from their maize production. Of those households selling, all sell less than half and most sell less than a quarter of their production. There may have been some underreporting of small seasonal sales outside of the harvest period, but no large, commercial maize producers were encountered in the sample.

Maize is the principal food in the diet of the SNP. Table 19 presents calculations from the sample of average household maize consumption.

Table 19: Average Maize Consumption

	Average HH weekly maize consumption (kg)	Average per capita weekly maize consumption (kg)	Average per capita weekly tortilla consumption (kg)
All HH	20	4.9	
HH w/o tortillas (201)	22	5.3	
HH with tortillas (80)	15	4.0	1.4

The first line presents the average household consumption per week and the average consumption per capita. To look at the effect of consumption of purchased, manufactured tortillas, the households were split into those purchasing tortillas and those with only home production. Out of the whole sample, 201, or 71% of households rely only on home produced tortillas. This alone is a major indication that households may prefer local maize if there is a quality difference. In the last row of the table we see that on average, households consuming manufactured tortillas decrease their maize consumption by 7 kilos or 30%, and in per capita terms consume 1.4 kilos, or 25% of their maize consumption as tortillas. This is because many households purchased small amounts of manufactured tortillas without completely replacing their home production. While purchased tortillas are obviously substitutes for home tortillas, they are consumed occasionally or in addition to home production.

Reconciling the levels of household consumption and production proved difficult and showed some inconsistencies in responses by household. As mentioned above there was a large variance in the quantification of household production, and this carried through to production as well. A series of three different estimates is offered Table 20 in order to look at the overall trends. First households were asked how long would their harvest last, or from the month of harvest until which month would the household still be consuming from own production. While not precise, this was a measurement mentioned by the respondents themselves to describe the level of maize self sufficiency. On average, the households reported that their own production was sufficient for six months (or half of their annual maize needs).

Table 20: Average Production vs. Consumption

	Mean	Median	St Dev
Household estimate of months that own production will last	6.3	6	3.19
Average annual maize Production - (kilos)	935	600	1029
Average annual maize consumption (human) - (kilos)	1034	1040	708

Looking at annual maize production we see a large divergence between the mean and the median, indicating many small farmers and a few larger producers. In the annual consumption, the median and mean are very close, indicating perhaps more consistency in the consumption data, but also that the distribution of total family size is more normally distributed than farm size. The sample median (center column) seems to be the most comparable across the three disparate estimates. Households estimate six months of maize supply, harvest 0.6 tons and estimate consuming just over one ton. Across these estimates it is clear that on average, and certainly in the median, households are producing below their subsistence needs.

Finally, we look at the share of maize expenditures of total food expenditures. Because of the fact that households consume their own production and purchased maize throughout the year, the expenditure is estimated valuing own production at the average market price.

Table 21: Level and Share of Maize Expenditures

	Weekly Expenditure (Mexican Pesos)	Share of Maize in Total (Percent)
Maize	42.7	
Total Food	183.1	23%
Total Expenditure	226.2	19%

The preceding table presents the estimated expenditure for maize averaged across all households. Of those in the survey who had actually purchased maize in the preceding week, expenditure was only slightly higher at 43.3 pesos per week, but close enough to be ascribed to skewness in the distribution of market price. The share of total food expenditure, 23%, is relatively high, and the single largest food expense. However, if beef, pork, and chicken expenditures are combined, the average expenditure on meat is 52.3 pesos, or 29% of total food expenditure, slightly more than the maize expenditure. The third row, total expenditure, is for all purchases at local stores and in the weekly markets and shows that food is the largest component of weekly expenditures, and maize expenditures remain 20% of the total expenditure.

Average number of varieties grown in sample sub-groups.

From the motivation in the theoretical model and the summary data presented in this chapter, there are a variety of factors that may cause the household to plant a greater number of milpa varieties. This section will present summary data from dividing the sample into relevant sub-samples, in order to motivate the need for a more complex statistical model. For select important variables, the sample median was calculated and used to divide the sample into households above and below the median. Table 22 presents three household variables, age, family size, and wealth, that may affect the number of varieties planted by a household. In Table 22, the average number of maize varieties grown is slightly larger for those households with an older household head, with a larger number of adult family members. Both of these categories present results that may be expected, but for neither category are the means significantly different. The mean number of maize varieties is significantly lower for wealthier farmers. This agrees with the hypothesis generated by the household model that households with a higher level of wealth have less of a need to self-insure through a crop portfolio.

Table 22: Mean Number of Varieties for Household sub-samples

	Number of Maize Varieties		Total Milpa Varieties
Age of HH head			
Below Median	1.01		2.36
Above Median	1.05		2.46
Adult Family Size			
Below Median	0.97		2.25
Above Median	1.11		2.61
Wealth			
Below Median	1.13		2.58
Above Median	0.92	**	2.21

** indicates means are significantly different at 5% level (two-tailed, two sample t-test)

The sample was also divided into sub-samples in order to examine the average number of varieties planted by agro-ecological characteristics. Categories representing constraints on farm production are presented in Table 23 and a category for market integration is also included. The first category corresponds to the major ecological zones in the region, Tierra Caliente (Hot Lands - below 1200 masl) and Tierra Fria (Cold Lands - above 1200 masl). The average number of varieties grown is higher at the higher elevations, due to agro-ecological conditions. The second category is the number of plots farmed by the household, and this is used as proxy for whether the households are matching varieties to soil conditions. The average number of plots is significantly higher for households with multiple plots, indicating that the agro-ecological conditions also hold at the household level. The next two categories address the quantity of land, a key constraint to the number of varieties planted. Own hectares is the total hectares owned by the household, and maize hectares is the total hectares planted by a household to maize. For the own hectares the means are not significantly different, while for hectares planted to maize, the average number of varieties planted is higher. This indicates that within the land planted to maize and milpa, land is a constraint to planting a greater number of varieties.

Table 23 - Number of Varieties by Subsamples

	Number of Maize Varieties		Total Milpa Varieties	
Ecological Zone				
Low Elevation	0.93		1.96	
High Elevation	1.17	**	3.03	**
Number of Plots				
0-1	0.68		1.82	
>1	1.37	**	2.98	**
Owned Land (ha)				
Below Median	0.98		2.29	
Above Median	1.09		2.53	
Maize Land (ha)				
Below Median	0.73		1.70	
Above Median	1.45	**	3.38	**
Infrastructure Level				
Small Town	1.29		3.10	
Large Town	0.83	**	1.86	**

** indicates means are significanlty different at 5% level (two-tailed, two sample t-test)

Finally the market integration category is based on small towns compared to larger towns. Large towns are a municipal capital, on a major paved road, or have a significant commercial sector and services. The average number of varieties is significantly higher in the small towns, indicating that when the level of market integration increases, the number of varieties planted by a household decreases.

However, each of these categories is showing a change in household levels of diversity in isolation of other factors. The theoretical model for household activity choice in Chapter 3 presented reasons why household, farm constraints, and market conditions could all influence the number of varieties planted. Furthermore, the effect of each condition could have a different effect, when all other effects are held constant, *ceteris paribus*. For instance, the age of the household head could increase or decrease diversity, if isolated from the effects of the number of plots farmed and the agro-ecological zone that the household is in. Therefore the use of categories or correlation limits the ability to test for all of the effects hypothesized from the household model. A general, nested model is needed to test the effects of individual parameters and groups of parameters on the level of diversity maintained by households.

Chapter 5: Estimation and Econometric Issues

The reduced form of the household model presented in the modeling chapter is the conceptual basis for analyzing how variables from both the consumption and production sides of household model (household characteristics, constraints, market conditions, etc.) affect household decision making. The reduced form of the theoretical model proposed in chapter 3 is for the number of crop varieties grown, not levels of consumption or inputs or outputs that are often the focus of household models. There are many possible measures of diversity and many levels of human interactions with crop populations. However, planting milpa crops is a basic condition for maintaining diversity. Because participation, not level, determines diversity (D=D(I)), the focus of this analysis is on the discrete choice of participation in the J household production activities, or the decision to plant J different crop varieties.

Random Utility Model of Activity Participation

Participation will be modeled following the random utility (R-U) framework proposed by McFadden. The reduced form of the household model from Chapter 3 is $W(\Phi_{HH}, \Phi_{Farm}, \Phi_{Market})$. Let $W_j^C(\Phi)$ denote the household's maximum welfare, given the constraints represented by 3.2 and 3.3, if the household participates in activity j, and let $W_{-j}^C(\Phi)$ denote maximum constrained welfare otherwise. Both $W_j^C(\Phi)$ and $W_{-j}^C(\Phi)$ assume optimal choices of Qj $\forall$ j, I_{-j}, and X.

In the random utility model, $W_j^c(\Phi) = \overline{W}_j^c(\Phi) + e_j$, and $W_{-j}^c(\Phi) = \overline{W}_{-j}^c(\Phi) + e_{-j}$. The household chooses to participate in activity j if $\overline{W}_j^c(\Phi) + e_j > \overline{W}_{-j}^c(\Phi) + e_{-j}$ or $\overline{W}_j^c(\Phi) - \overline{W}_{-j}^c(\Phi) > e_{-j} - e_j$. The solution to this set of J participation decisions yields a set of optimal participation choices I*(Z), where the probability of observing a household's participation in activity j is given by

$$\Pr(j) = \Pr(I_j{*}=1) \qquad (3.1)$$

$$= \Pr(W_j^c(\Phi) > W_{-j}^c(\Phi)) \qquad (3.2)$$

$$= H(\bar{W}_j^c(\Phi) - \bar{W}_{-j}^c(\Phi) > e_{-j} - e_j) \qquad (3.3)$$

If the errors, e_j are each normally distributed with mean zero and constant variance, H(·) is the normal cumulative distribution function, and the model given by (2) can be estimated by a Probit for participation in each activity.

The count data model is linked to a random utility specification.

The R-U model is appropriate for a single choice (e.g., whether or not to participate in a given activity). However, the objectives of this analysis call for modeling the total number of activities in which the households choose to participate (e.g., the number of varieties grown, which is our measure of diversity). The Poisson model is well suited to this kind of modeling.

The probability of choosing k activities given n independent trials is represented by the binomial distribution:

$$P(Y = k) = \binom{n}{k} p^k (1-p)^{n-k}$$

where $\binom{n}{k} = \frac{n!}{k!(n-k)!}$ and p is the probability of choosing k

From statistical theory a repetition of a series of binomial choices (in our case, from the R-U formulation) asymptotically converges to a Poisson distribution as n becomes large and p becomes small.

$$\lim_{n\to\infty}\binom{n}{k}p^k(1-p)^{n-k}=\frac{e^{-l}m^k}{k!} \tag{3.4}$$

where $p = m/n$ and m is the mean of the distribution (in our case, the mean number of activities per household) This formulation allows us to model the probability that a household chooses a number of activities, k, given a parameter m, the sample mean.

Hellerstein and Mendelsohn (1993) proposed two theoretical linkages between utility theory and a Poisson specification. The first is a demand model for an indivisible good where choice is restricted to be a non-negative integer, which is relevant to a wide range of real consumer choices. The second follows the statistical theory outlined above by modeling a series of discrete consumer decisions which would sum across an aggregation of choices to a Poisson distribution. Thus the Poisson specification is used to model the increase in utility from one additional unit consumed. A common application in the environmental economics literature is for recreation demand where the number of site visits is the object of analysis.

The count data specification is utilized because of the way it gives the model flexibility to explain total system diversity aggregated across crops as well as within crops. This flexibility allows the explanatory power of the model to move in a diversity space both across varieties and across species. The linking of the behavioral model with an econometric model is therefore consistent with the overall conservation strategy of conserving minor varieties. The count data model makes it possible to compare parameter estimates in a model of total system diversity as well as diversity within each crop.

Poisson Regression

The Poisson regression model is the development of the Poisson distribution in Eq. (3.4) to a nonlinear regression model of the effect of independent variables x_i on an scalar dependent variable y_i. The density function for the Poisson regression is:

$$f(y_i|x_i) = \frac{e^{-m_i} m_i^{y_i}}{y_i!}$$

where the mean parameter is a function of the regressors **x**, and a parameter vector, b

$$E(y_i|x_i) = m_i = \exp(x_i' b) \text{ and } y = 0,1,2...$$

In the Poisson model the variance is set equal to the mean such that

$$V(y_i|x_i) = m_i(x_i, b) = \exp(x_i' b)$$

Negative Binomial Regression

The fact that the Poisson model restricts the variance to equal the sample mean may be too restrictive an assumption for the sample data. Extensions to the simple Poisson model continue to model the variance as a function of the mean in addition to a further term, α, to characterize the degree of over- or under-dispersion, or the degree to which the variance differs from the mean. Two common specifications are the NB1 model where $V(y_i|x_i) = m_i + a m_i$ and the NB2 model where $V(y_i|x_i) = m_i + a m_i^2$. This thesis utilizes the NB2 distribution, which has the distribution:

$$f(y_i|m,a) = \frac{\Gamma(y + a^{-1})}{\Gamma(y+1)\Gamma(a^{-1})} \left(\frac{a^{-1}}{a^{-1} + m} \right)^{a^{-1}} \left(\frac{m}{a^{-1} + m} \right)^{y}$$

where $m_i = \exp(x_i' b)$, $a \geq 0$, $y = 0,1,2...$

Cameron and Trevedi (1990) have proposed a test for over-dispersion, i.e. that test for the significance of the α parameter as compared to the Poisson model, and the survey data was checked to determine if over-dispersion is a problem.

Sample Selection Issues

In a model of the diversity of the milpa, it may be necessary to model separately the decision whether to plant the milpa from the decision of what level of diversity to plant given the decision to plant milpa. In the survey sample of 281 households there are 60 households who do not plant the milpa at all. If the process which governs whether households participate in planting milpa is different from the process which determines which crop activities within the milpa they will participate in, then inference based on a simple model of overall diversity will be biased (Maddala, 1983).

The issue of selection bias into an activity is very relevant to the questions surrounding CGR conservation. While most studies focus on the level of diversity in farmer's fields, they are missing an important level of genetic erosion that occurs as farmers leave farming entirely and abandon local landraces. Households may reallocate labor to migration or wage labor and stop farming, or land may move into livestock production or cash crop such as coffee with higher returns. Unfortunately in the survey sample for this study it has proven difficult to model the decision of whether or not to plant the milpa, for reasons that will be discussed with the results. However, the specification of a sample selection or a mixture model will be presented because of the improvement in estimation specification.

Hurdle Model for Selectivity

Mixture models are a class of developments on the Poisson model that attempt to take into account a mixture of two or more stochastic processes that may be present in the data. Mixture models are particularly useful to address heterogeneity in the sample data, motivated either by an unobserved heterogeneity in the dependent variables or a secondary stochastic process in the regressors. A model which is used here is the Hurdle model, generalized by Mullahy (1986) and discussed in the context of two part decision-making by Pohlmeier and Ulrich (1995). The two-stage hurdle model is also useful for data characterized by under-dispersion (where the variance is less than the mean).

The first stage is a binary zero-one model of whether the hurdle is crossed, in this case whether milpa is planted. The second stage is a truncated count model, in this case the number of crops within the milpa as modeled above. The likelihood function is specified as a combination of two independent processes over two different domains. The set N1 represents the full sample, and N2 represents the restricted sample of only those who plant the milpa. The variable d represents the binary variable of the first stage zero-one choice.

$$L = \prod_{i=1}^{N1} P(y_i = 0 | x_i' b_1)^{d_i} (1 - P(y_i = 0 | x_i' b_1))^{1-d_i}$$
$$\times \prod_{i=1}^{N2} \frac{P(y_i | x_i' b_2)}{P(y_i \geq 1 | x_i' b_2)}$$

Given that the two processes are independent, the log likelihood functions are additive and the two equations can be estimated separately. The two separate parameter vectors b_1, b_2 can be viewed separately for their effects on the crop diversity, and the likelihood functions can be summed to test if the model is an improvement over the simple Poisson or NB model.

Model Based tests

Before looking at individual coefficients for their sign and significance, there are a series of model based tests to run. From the household model, hypothesis (H2) is to test for the separability of household decisions on activity choice. As developed in Chapter 3, if the households make a separable, recursive decision on crop choices then the reduced form diversity outcomes should be determined only by Φ_{Farm}, the production characteristics and constraints. As shown by Lopez (1984) separability can be tested by seeing if the other household characteristics, Φ_{HH}, and $\Phi_{Markets}$, are significant in household's decision. A general model is estimated with all three sets of variables and this is compared to a restricted model, which is estimated only with the production characteristics. The test used is a Likelihood Ratio test statistic:

$$LR = -2\left\{\ln L(b_{restricted}) - \ln L(b_{unrestricted})\right\}$$

which is distribute chi-squared with the degrees of freedom equal to the number of variables omitted in the restricted model.

In a comprehensive review of empirical work in agricultural economics and econometric relevance, Just (2000) urges that research encompass various competing hypotheses in order to encourage additivity of research findings. Smale, Just and Leathers (1994) look at various competing explanations adoption decisions between local and modern varieties, and conclude that any one explanation or combination of explanations can be found to be true. Therefore, Smale et al., urge the use of a general model to encompass competing explanations. In order to test competing hypotheses, a set of models is estimated and presented for comparison, including the general model, a risk specification, village variables specification, and production constraints specification. In order to compare models we look at the joint test of the significance of each group of variables, which is measured by the value of the log-likelihood function. In addition, because three sets of regressions are presented, it is important to look at consistency of the parameter estimates across models.

Dependent Variables

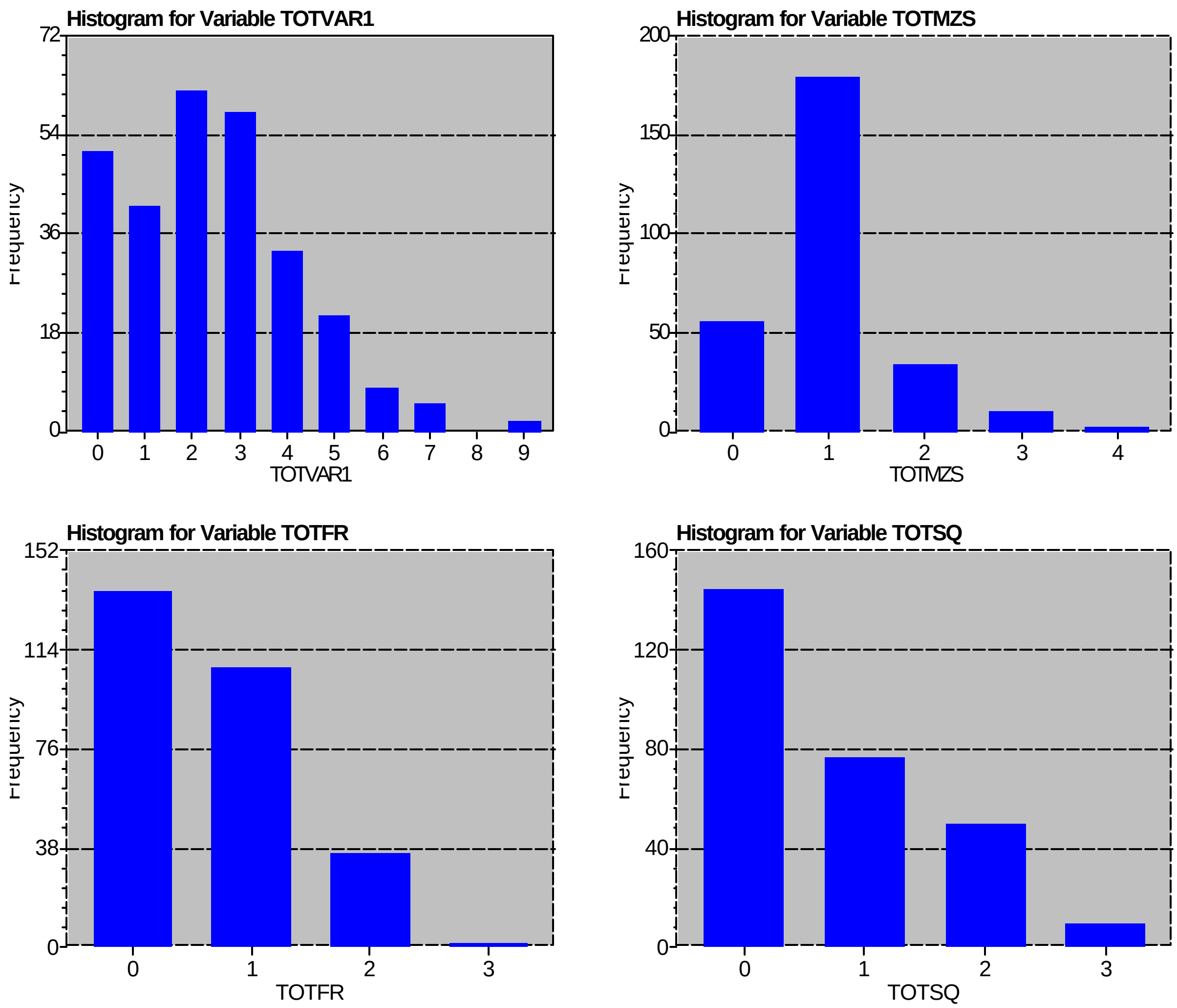
For this thesis the basic measure of CGR diversity at the household level is a simple richness measure, a count of the number of crops that the household plants in the milpa. The count of species is what is used as the dependent variable in the regression model based on the activity choice model in Chapter 3. The summary statistics for the dependent variables are presented in Table 24. As discussed in Chapter 4, most households grow only one maize variety, and around half of the households report growing bean or squash. Furthermore there are 60 households in the full sample with zero varieties.

Table 24 : 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

The first variable in the table, total varieties, is constructed by summing across crops the number of varieties of maize, beans and squash. The total varieties variable is a useful tool for constructing and testing out 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 in order to compare if

Figure 7: Histograms for Dependant Variables



the same factors are driving diversity in each group. Comparing the effects of individual variables on the overall systems and on each crop will serve to test Hypothesis (H1) that the determinants of crop diversity are the same or different for each crop.

The structure of the dependent variables is also shown in the form of histograms in Figure 7. There are a few things to note in this graphical representation. For all of the variables the structure follows a typical Poisson distribution. While variables, Total Bean Varieties (TOTFR) and Total Squash Varieties (TOTSQ), do show a Poisson distribution, they have a large number of zeros which indicates the possibility of an improvement with a mixture model. The variable Total Varieties (TOTVAR1) also has a large number of zeros and the model may be improved by a mixture process. Finally the variable Total Maize Varieties (TOTMZS) seems to be characterized by under-dispersion (where the variance is less than the mean) which can be modeled by the Hurdle model described above (Pohlmeier and Ulrich, 1995).

Explanatory Variables

The variables are divided into three groups, following the model specification in Chapter 3. The groups of variables are Household characteristics, Farm characteristics, and Market Characteristics.

HH characteristics

The first set of variables are those that describe the household, Φ_{HH} , and are presented in Table 25. The first variable, age, is included in order to look at whether older farmers are the ones conserving 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 term is also included in order to look at whether the age effect is increasing or decreasing at advanced ages.

Table 25: 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

The variable on family size is for the number of adults living in the household. This variable represents the pool of family labor available to the household for planting the milpa and other activities. The sign for family size is expected to be positive if minor varieties of crops and the inter-cropping milpa system are intensive in family labor. The wealth variable is a household specific variable that is used to indicate whether risk or missing markets are affecting the crop choice decision. Wealth is often used as a proxy for risk preferences as risk aversion is hypothesized to decrease as wealth increases. The wealth index is built up from a characterization by the surveyor of the size and building materials of the home combined with ownership of major durable goods.

Farm Characteristics

The farm characteristics are used to determine whether household level diversity is caused by agro-ecological constraints, and correspond to the constraints and characteristics of the households-farm, Φ_{Farm} , from the theoretical model. These variables are used to test Hypothesis (H3) that agro-ecological fragmentation leads to higher levels of diversity. The characteristics of each farm are also the variables that are hypothesized to solely determine diversity outcomes in the recursive model, the subject of Hypothesis (H2).

Table 26: Farm 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

The first variable is for the number of plots that the household cultivates. This variable is a proxy for matching varieties to different agro-ecological conditions. The dummy for the high altitude region is included because altitude is an important climate variable, and within this study site can describe the differences in the area's major climate zones. The next two variables reflect input fixity arguments that have been found to affect diversity in other studies. The slope variable is a dummy variable which equals one if the household farms two different parcels, one flat and one on a steep slope. This variable is used to proxy for situations when the household plants multiple varieties because of the adaptation of varieties to different agro-climactic niches. The soil quality index variable is calculated from the percent of total household landholdings that are of a favorable soil quality. There are two possible a priori signs for this variable, either the favorable soil type allows multiple crops to flourish and provides a higher productivity of the milpa across crops and the effect on diversity is positive, or the favorable soil type is land that is more likely used for specialized, market oriented production, and the effect on diversity is negative. Due to the fact that most production is infra-subsistence the former explanation is favored, that favorable soil quality increases the likelihood of diversity.

The last variable, maize hectares, is related to the variable for total farm size that is used throughout studies on the adoption and diffusion of agricultural technologies. In affecting diversity outcomes there are different possible signs for this parameter. Larger farm size could be associated with more diversity as farmers are able to plant more different types on a larger extension of land. On the other hand farmers with small plots may be seeking to produce more different products within the same parcel and thus inter-crop more species. Because of possible endogeneity problems with households choosing the number of varieties at the same time as they are choosing the size of the land area to plant, the variable for maize hectares is an instrument. An regression was run for the number of maize hectares against exogenous household variables, and the predicted values were saved for inclusion as an instrumental variable in the general Poisson regression presented here.

Market and Village Variables

The final set of variables are those representing market constraints, Φ_{Market} , which are motivated by the missing markets models of Chapter 3. The market variables are used to test Hypothesis (H4), that increase in market integration decreases 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. The village level variables are used for a few reasons. First, it is difficult to gather data on exogenous descriptors of endogenous household transactions costs and shadow prices. Many possible variables that reflect household choices become problematic with the simultaneity of household crop choices. Furthermore the village level variables are useful in describing the economic and social contexts that crop choice decisions are being made in. Not only is it likely that households are influenced by what their neighbors are doing, but also the households within a village share many economic factors that are difficult to measure in other ways. The use of village variables is also of interest in order to use outcomes from village-economy modeling for regional analysis as well as to try to capture crop diversity outcomes which are hypothesized to operate on a regional scale.

Table 27: 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

The first variable is for transactions costs which are calculated by the distance to either of the major regional markets at Zacapoaxtla or Cuetzalan. The transactions cost variable measures 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 share of total labor used in the milpa that is hired labor. Almost all households use a combination of own and hired labor, but the quality difference between hired and family labor and the labor intensity of a high diversity milpa indicates that this parameter should be positive. Finally the village level variable for the intensity of migration activities is calculated as the percent of households in the village with migrants. This variable has a direct analysis in the migration networks that affect each household's probability of sending a migrant. The indirect effects include the income smoothing effects that remittances have on the need for a household to balance risks through a crop portfolio. Another important indirect effect is the loss of labor for village agriculture, and the bidding up of the local village wage for labor intensive milpa diversity.

Diversity Regression

A separate set of regressions was run in order to look at the robustness of the Poisson regression model, which relies on a count of the species and is thus limited in its description of system diversity. The diversity variable used for regression analysis is the Shannon index, which provides a combination of richness and evenness. In other studies of crop diversity the Shannon index has been used as a measurement of latent, genetic diversity; molecular genetic information is used to calculate an index in order to describe the diversity of a population (Meng, et al 1998). In this study genetic information was beyond both the budget and capabilities of the project, and the diversity index is constructed on area shares dedicated to each variety. However, just as the count of species and varieties used in Poisson regression above is directly linked to a behavioral model, the area shares index can be linked to a behavioral model of household motivations to diversify a crop portfolio. While the genetic information is useful to describe outcomes for the diversity of crop populations, the area diversity index is more useful for describing farmer behavioral impacts on diversity.

Diversity Index

The Shannon diversity index, which was adapted from the information theory literature for use in ecology and agronomy, is a way to combine a number of qualitative or quantitative traits into a single index. (Magurran, 1998) The formula is:

$$H' = -\sum_{i} p_i \ln p_i \qquad (3.5)$$

For this thesis the p_i are shares of the household's area within a given crop that is planted to each single variety. A separate index was calculated for each crop (maize, beans, squash), and because of the difficulties of combining measures across crops, a credible index for the combined milpa diversity is not tractable. Another commonly used index is the Simpson index, which is related to the Herfindahl index used by economists to measure industry concentration. The formula for the Simpson index is:

$$1-\sum_i p_i^2$$

The Simpson is a dominance index, which is suited for inter-varietal diversity, by combining the of the number of varieties planted with their relative importance (Meng, et al.). While the Shannon index is used for the regression model, both the Simpson and Shannon indices were calculated and are presented in the following table.

Table 28 Means of Diversity Indices

	Maize	Beans	Squash
All Households (n)	281	281	281
Shannon Index	0.13	0.08	0.14
Simpson Index	0.09	0.05	0.09
Households with crop (n)	225	151	137
Shannon Index	0.16	0.14	0.28
Simpson Index	0.11	0.10	0.18
Households with multiple varieties of crop (n)	51	41	60
Shannon Index	0.70	0.65	0.67
Simpson Index	0.47	0.44	0.45

The means of the two diversity indices are presented in Table 28; the two indices are presented for comparison, and three sample sizes are presented to show how the mean changes with sample restrictions. The entire sample contains many households who do not participate in the activity, and the sample of all households within the crop contains a majority of households with a zero diversity value because they only plant a single variety of that crop. Across all sample sizes the Shannon is larger than the Simpson index because the Shannon equally weighs richness and abundance, while the Simpson weighs relative abundance more than richness.

SUR regression with Selectivity Correction

The linear regressions must be corrected for the latent decision of whether or not to participate in that crop activity. Therefore a two-step estimator is used where the first stage corrects for the household's decision to participate, and the second step estimated the level of diversity given household participation in that activity (Heckman, 1979; Lee, 1978; Maddala,1983). In the first stage a Probit regression is run for the household's participation in a given crop activity, and the Inverse Mill Ratio is saved for each crop. In the second step the Inverse Mills Ratio for each crop is included as a right hand side variable in the regression for the level of diversity within that crop. The three crop diversity regressions are estimated as a system of seemingly unrelated regression equations (SUR) in order to exploit the information in cross equation error correlation. Finally the structure of the three equations as a system allows for cross equation restrictions on coefficients. In order to test the hypothesis (H5), that market variables have different effects on different crops, a restricted model is estimated where the coefficients on the market variables are forced to be the same across crops , and this model is compared to the unrestricted model.

Chapter 6 - Results from the Econometric Model

The results from the estimation of the set of four Poisson regressions are reported in Table 6.1. The first regression is for the total number of milpa varieties, the next three are for the total number or maize, beans and squash varieties respectively. These results show that the household decision to plant a number of different crops and varieties of each crop is affected by household, agro-ecological, and market variables. The primary results are for the total number of varieties in the milpa, and these results will be discussed first. The results of the individual regressions for each crop will be discussed next in order to compare the outcomes across crops. It is readily apparent that the null hypothesis from Hypothesis 1 must be rejected, as different variables affect each crop's diversity outcome.

Total Milpa Varieties

In order to test Hypothesis 2 for the separability of the model, a joint test for the significance of each of the groups of variables was calculated. Each group of variables, household, agro-ecological, and market variables is found to be jointly significant. This leads us to reject the null hypothesis for Hypothesis 2 and to conclude that the model is non-separable. Therefore the decisions that lead to diversity outcomes are made simultaneously between consumption and production decisions. The null hypotheses for Hypothesis 3, that agro-ecological variables affect diversity and for Hypothesis 4, that market variables affect diversity are both rejected with the joint significance test. The results for individual variables are discussed below.

Table 29 - 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.

Household Characteristics

The first set of characteristics presented in Table 29 are those that are related to the household. The coefficient for the adjusted age or experience of the household head is positive and significant, indicating that the older farmers are planting a greater number of varieties. The fact that it is an older generation who are conserving a greater amount of diversity presents problems for in situ conservation if CGRs are lost over time as the older generation ages and leaves farming. 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 (or stop farming) at a certain point. This is the expected sign, as some in the survey had mentioned leaving farming at an advanced age due to illness, and it may correspond to evidence presented later that family labor intensity is a key factor in increasing household diversity levels. Finally the coefficient for family size is positive but not significant. This variable is expected to have a positive impact on diversity when the activities entailed in planting a larger number of varieties require inputs of family labor.

Agro-ecological Conditions

The positive and significant coefficient for the number of plots that a household cultivates indicates that a household with a greater number of plots is more likely to cultivate a greater number of varieties. The number of plots is used here as a proxy variable for the fragmentation of the agricultural landscape and reflects the matching of varieties to different 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 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). Another major factor is that the tropical zones may have more intense pest pressures both for weed competition as well as insectivore and microbial predation. The other positive and significant coefficient for an agro-ecological variable is on whether the household cultivates different plots with different slopes. This result is similar to the findings of Bellon and Taylor, that the farmers match varieties to soil types or conditions. Furthermore the different sloped plots could have different exposures to the sun or wind, or levels of soil moisture or drainage. The instrument used for total area in milpa is also positive and significant, indicating that the larger the land area in milpa the greater the number of varieties that the household grows. This makes sense given the fact that the farmer is able physically to plant a larger number of varieties in a larger area. The significance of the agro-ecological variables in explaining diversity outcomes is a test of Hypothesis 3, and we find that the agro-ecological variables jointly and individually affect diversity outcomes in the milpa.

Market Variables

The most interesting results from the estimation are those which show 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 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, measured by distance from a market, is positive and significant. This indicates that the more removed a household is from a major market center, the greater number the number of varieties that will be planted in the milpa. Transaction costs create price bands in the prices faced by the household, increasing prices for purchases and reducing prices for selling. The wider the price band becomes with increased transactions costs the more likely the household valuation of a variety lies within the price band, where the household produces the crop according to an internal subjective valuation instead of buying or selling it in the market.

The coefficient on the village level variable for hired labor intensity is negative and significant. This suggests that diversity in the milpa decreases as local labor markets develop. Conversely, a higher intensity of family labor corresponds to a higher degree of milpa diversity. Cultivation of a diverse milpa cropping system is relatively labor intensive, and family labor is a relatively higher quality of labor input for a variety of specific tasks. In the allocation of family labor the household may seek to fully allocate family labor throughout the cropping cycle and cultivate a greater number of varieties that smooth the use of family labor across the season. The higher intensity of hired labor also corresponds to the development of the local labor market and can decrease milpa diversity by opening the possibility of reallocation of household labor to more remunerative activities.

The positive and significant coefficient for the US migration variable indicates that a household in a village with a high village-wide level of international migration is less likely to plant a diverse milpa system. The village migration variable is a proxy for the opportunity cost of household time on the farm. Because village networks are a key indicator of the costs and probabilities of migration (Taylor and Martin, 2000), a strong migration network increases the shadow wage for family labor within the household. Migration directly competes with labor, because migrants cannot be in the village to work in agriculture. Migration can also provide an income smoothing and income insurance mechanism, which decreases the household's need to self-insure through crop diversification.

Finally, the coefficient for the household's wealth is negative and significant. The greater the wealth of the household, as measured 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, given decreasing risk aversion and greater ability of wealthy households to self insure or secure access to insurance where risk markets are incomplete. The wealth effect is not limited necessarily to risk. Wealth may be a proxy for networks, information, and access to outside market opportunities where the village faces various kinds of market imperfections. A wealthier household has less of a need to use a portfolio of crop varieties in order to insure against low crop yields.

Individual Crop Regressions

In the total milpa varieties regression, the hypotheses were confirmed that household, agro-ecological, and market variables shape milpa diversity. In Chapter 3, Hypothesis 1 was that market context and other variables have differential impacts across crops. This section reports findings from Poisson regressions for diversity in the crops that make up the milpa system, with the goal of testing for differences across crops.

The regression results for the number of maize varieties are dominated by the agro-ecological characteristics. The markets for maize as a commodity, and for inputs like hired labor, may be more developed as maize is the principal staple food in the region. The number of maize varieties is higher for households in the higher altitude zone, for households planting parcels with different slopes, and for households with greater total land area planted in milpa (represented in this regression by an instrumental variable). 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.

By contrast, agro-ecological and market variables are all important in explaining diversity in beans and squash. The effect of transactions costs are positive and significant, meaning that the closer to a market center that the household lives, the more likely that the household grows only one bean variety or leaves bean cultivation altogether. This indicates that minor crops such as beans are relatively quickly replaced by market substitutes. The intensity of the use of hired labor, or the degree of development of a local agricultural labor market, decreases the number of bean varieties grown. Family labor may be the crucial input in the production of inter-cropped beans. Finally, the level of wealth decreases the probability of growing beans, because the household has a decreased need to expand a crop portfolio in to the minor crops. Like maize, the number of bean varieties increases with location in the high altitude region, and with planting parcels with different slopes.

Household variables, agro-ecological variables and market variables also significantly explain the number of squash varieties grown. The high altitude zone and the different sloped parcels both indicate the adaptation of cropping systems to the agro-ecological heterogeneity. The hired labor intensity is again negative and significant, showing that a greater degree of family labor used in the milpa corresponds to a larger number of squash varieties grown. The labor intensive nature of a diverse inter-cropping system is highlighted as a principal explanation for the simplification or abandonment of both beans and squash in the milpa.

Hurdle Model

A market, agro-ecological, or household variable may affect diversity either by influencing the probability of cultivating the milpa or by influencing the number of varieties grown given that the milpa is cultivated. The hurdle model makes it possible to separate these two effects.

The results from the estimation of a Poisson hurdle model for the total number of varieties is presented in Table 30. The first regression is for the normal Poisson regression that is reported in Table 29, and is offered for comparison and as a point of

Table 30 - Poisson Hurdle Model for Total Varieties

	Normal Poisson		Hurdle Model - Total Varieties: Binary Poisson		Truncated Poisson	
	Coeff.	t-ratio	Coeff.	t-ratio	Coeff.	t-ratio
Constant	-0.1580	-0.3859	0.0127	0.0144	-0.2057	-0.4336
Age of HH head	0.0370	2.6508 ***	0.0448	1.4985	0.0352	2.1590 **
Age Squared	-0.0003	-2.0756 **	-0.0004	-1.0924	-0.0003	-1.7212 *
Yrs School HH head	0.0621	2.8548 ***	0.0968	1.9009 *	0.0458	1.9002 *
Family Size	0.0274	1.4907	0.1070	1.9965 **	0.0136	0.6730
Plots	0.1133	2.1700 **	0.4260	2.6628 ***	0.0435	0.7490
High Altitude Dummy	0.4572	5.3920 ***	0.2697	1.2222	0.4117	4.2768 ***
Multiple Slopes	0.4891	3.9497 ***	4.2528	0.0001	0.4123	3.1340 ***
Soil Quality Index	0.0453	0.4922	0.0731	0.3261	0.0126	0.1217
Maize Hectares	0.1294	1.8737 *	0.2963	1.3945	0.0880	1.0701
Transactions Costs	0.0239	2.0262 **	0.0061	0.2240	0.0269	2.0076 **
Hired Labor Intensity	-1.3166	-3.9699 ***	-3.2639	-3.6072 ***	-0.5601	-1.4787
Village US migration	-1.2824	-2.3639 **	0.0273	0.0207	-1.6895	-2.7157 ***
Wealth	-0.0241	-2.0340 **	-0.0611	-2.1253 **	-0.0114	-0.8377

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

reference for the following two regressions. The second regression is a binary regression for the zero-one decision by the household on whether or not to plant milpa at all. The third regression is a truncated regression for the number of varieties planted given that the household has decided to plant the milpa. It is important to remember that the majority of households in the sample do plant milpa, but here we are testing whether the discrete choice for whether to plant milpa is governed by a different process than that determining the level of diversity within the milpa.

At least one household, agro-ecological, and market variable is significant in explaining milpa cultivation. Years of schooling of the household head have a small positive effect on the probability of milpa cultivation, while the larger the size of the family the more likely the household is to plant a milpa. Environmental heterogeneity, proxied by the number of plots that the family has, also increases the probability that the household plants a milpa. However, the most interesting results are the segmentation of the market-based effects in the two stages of the hurdle model. In the binary regression it is the intensity of hired labor that is significant in determining whether the household plants a milpa at all. A more developed local labor market is associated with decreased probability of a household planting milpa. Furthermore the level of household wealth decreases the household's probability of planting a milpa. While the majority of the households in the sample continue to plant milpa despite its low profitability, *ceteris paribus*, a wealthier household is more likely to leave milpa altogether.

In the truncated regression, the age of the household head is positive and significant in explaining the number of varieties grown. While the age of the household head does not explain whether the household will plant milpa or not, it does appear that it is the older generation of farmers who conserve a greater number of varieties. As mentioned in the previous section, it appears that an older generation conserves varieties but this practice is not continued by the younger generation. This is a troubling conclusion for the long-term sustainability of in situ conservation. As in the original Poisson regression, the quadratic term shows that the oldest farmers conserve less diversity, as their ability to contribute the family labor inputs required by a diverse milpa decreases at an advanced age. The agro-ecological characteristics of being in the temperate zone or planting multiple sloped parcels indicate that the adaptation to agro-ecological heterogeneity is important to explain the level of diversity within the milpa. Finally the market variables are again of interest, specifically in this case because of the way in which they diverge from the results of the binary regression. The level of transactions costs affects the level of diversity within the milpa, where it did not affect the decision of whether or not to plant a milpa at all. Households across the sample plant milpa, but those more removed from markets are more likely to produce a greater number of varieties for home consumption and not purchase those varieties or their substitutes in the market. The village international migration coefficient is also significant in explaining the number of varieties grown where it had not been significant in whether the household planted a milpa. The possibilities for a household to migrate decrease the number of varieties that a household is likely to grow, because the opportunity cost for family labor input increases, and because remittances decrease the household's need to smooth consumption shocks through a crop portfolio.

Shannon Diversity Equations

The Poisson regressions presented above use a count of crop varieties as a measure of diversity. As mentioned in Chapters 2 and 3, there are many ways to measure diversity and it may be necessary to use other measures of diversity to tell a more complete story for conservation of CGR. The results of the area diversity regression equations are presented in Table 31. The dependent variable is a Shannon index of area diversity, a widely used index in the ecology literature that takes into account both the richness and evenness of the varieties planted. The Shannon diversity regression is presented in order to explore the robustness of the model specification for the primary regressions presented in Table 29. This comparison of specifications is also useful to see if the diversity (in richness and evenness) corresponding to area planted is different than the diversity as measured by number of varieties (richness only). The results presented in this table are from a SUR regression with each individual equation corrected for the sample selection by a Probit for whether the household participates in that activity.

In the maize regression presented in the first columns of Table 6.3, many more variables are significant than in the Poisson regression model presented earlier. The age and age-squared variable coefficients have the same signs as in the simple Poisson regressions, but now become significant. Among the agro-ecological variables, the number of plots farmed by the household is now significant, and the high altitude region and multiple slopes variables are positive and significant, indicating the robustness of these variables in explaining the matching of minor varieties to agro-ecological conditions. Whereas in the Poisson regression the milpa size (predicted maize hectares) was significant, in the diversity regression the number of plots is significant, but the two

Table 31 - Diversity Regressions

Shannon area diversity	Maize Varieties		Bean Varieties		Squash Varieties	
	Coeff.	t-ratio	Coeff.	t-ratio	Coeff.	t-ratio
Constant	-0.1717	-1.169	0.0144	0.123	0.0102	0.074
Age of HH head	0.0112	2.346 **	0.0020	0.528	0.0058	1.289
Age Squared	-0.0001	-2.636 ***	0.0000	0.064	0.0000	-0.761
Yrs School HH head	-0.0057	-0.714	0.0093	1.457	0.0119	1.572
Family Size	0.0032	0.438	0.0022	0.378	0.0119	1.701 *
Plots	0.0369	1.819 *	0.0019	0.115	0.0061	0.32
High Altitude Dummy	0.0566	1.68 *	0.0299	1.115	0.0869	2.729 ***
Multiple Slopes	0.3024	5.076 ***	0.1157	2.444 **	0.1281	2.282 **
Soil Quality Index	-0.0272	-0.783	0.0005	0.019	-0.0185	-0.563
Maize Hectares	0.0197	0.68	-0.0036	-0.156	-0.0111	-0.406
Transactions Costs	0.0102	2.339 **	0.0072	2.071 **	0.0025	0.594
Hired Labor Intensity	-0.0144	-0.117	-0.1233	-1.252	-0.3498	-2.995 ***
Village US migration	-0.6201	-2.968 ***	-0.3708	-2.228 **	-0.1766	-0.894
Wealth	0.0005	0.105	-0.0060	-1.757 *	0.0018	0.454
Inverse Mills Ratio	0.0545	2.143 **	0.0639	3.869 ***	0.1537	8.406 ***
Adj R-squared	0.17		0.11		0.26	

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

regressions may tell a similar story of adaptation to plots or extensive margins with minor varieties.

The most striking difference between the Shannon and variety-count regressions is that in the Shannon regression, two market variables, transactions costs and wealth, are significant. Households that are more isolated or more removed from the major market centers have a greater diversity of maize. The Shannon index, unlike variety counts, is sensitive to the allocation of area among varieties. One possible reason for the difference between the Shannon and Poisson models is that households in isolated villages tend to allocate land more evenly among chosen varieties. Those who conserve minor varieties in a more market-integrated village may conserve only a small plot. The wealth variable is negative and significant. Wealthier households, while growing the same number of maize varieties as less wealthy households, may allocate land more unevenly among chosen varieties - a finding consistent with weaker risk motives for diversifying.

In the beans regression the variables are less consistent when compared to the Poisson regression. The household variables are not significant, and the agro-ecological variables are robust for multiple sloped plots but not for the high altitude dummy. Among market variables, the transactions costs, village US migration, and wealth are all robust between the two specifications. The hired labor intensity, which is significant in the Poisson regression, is not significant in the Shannon regression. However, the general implications that market development decreases diversity, while reliance on family labor increases it, hold across the different specifications. In the squash regression, the same household and agro-ecological variables are significant as in the Poisson regression, indicating a general robustness across models. The market variable for hired labor intensity is again negative and very significant, indicating that family labor is a key input for the diversity of squash varieties in the inter-cropping system.

In order to test Hypothesis 5, whether the market effects are different across crops, a restricted version of the Shannon diversity system was run. The SUR system was restricted by forcing the coefficients on the market variables to be the same across crops. A likelihood ratio test was calculated using the log-likelihood from the restricted and unrestricted models. The test was unable to reject the null hypothesis that the coefficients are equal across crops. The coefficients appear different in the regression results presented in Table 31, but the differences are small enough to not be captured by the model restriction.

Chapter 7 – Discussion and Conclusions

A summary of the findings with respect to each of the central hypotheses presented in Chapter 3 follows:

Review of Hypothesis Tests

H1 – The conclusion from the test of Hypothesis 1 is that different factors affect the diversity outcome for each crop, and affect the cropping system as a whole differently than for each crop. Planning for in situ conservation will need to move beyond focus on a single crop to a broader understanding of cropping systems and all of the possible CGRs. Previous studies that have found de facto conservation of the principal staple crop may have missed other important instances of genetic erosion.

H2 – The test of Hypothesis test 2 demonstrated the non-separability of household behavior concerning crop diversity outcomes. This indicates that household decisions leading to diversity outcomes are affected by more than just constraints to farm production. While this conclusion may seem primarily theoretical, the non-separability finding means that conservation programs must take into account overall household economic and social contexts and not just the endurance of a single crop.

H3 – The conclusion from Hypothesis 3 is that heterogeneity of agro-ecological conditions increases the diversity of CGRs conserved by farmers. This is a result that has been shown in previous studies on in situ conservation and partial adoption of Green Revolution agricultural technologies. However in this study the conclusion holds across a series of villages with differing agro-climatic conditions. Furthermore this finding is holds constant household characteristics and levels of market integration that vary across the region. Conservation planning should utilize information on geography, soil conditions, climatic conditions, and levels of landholding fragmentation when targeting regions and cropping systems.

H4 – The conclusion from testing Hypothesis 4 is that market integration decreases the diversity that farmers maintain. The markets affected are not only those for the crop, but also for key inputs like land and labor. This result highlights broader possible causes of genetic erosion. Current de facto conservation of CGRs may seem to be in equilibrium despite economic pressures, but dynamic development processes may undermine this equilibrium. Influential aspects of regional integration such as road improvements, increased regional trade and increased out-migration will have indirect effects on the conservation of CGRs.

H5 – The conclusion from Hypothesis 5 is that market factors affect different crops in different ways. A fundamental finding for the milpa system is that the secondary crops of maize and beans are linked to the use of family labor in milpa production. Conservation planning that seeks to mitigate the effects of market transformations on local diversity outcomes will need to measure which crops are more resilient or more susceptible to market forces.

Village and Region as units of analysis

A useful methodological and empirical finding from this study is the importance of village and regional variables to describe household diversity outcomes. Many important factors affecting the context for CGR conservation cannot be found within each household or in government statistics. The compilation of village level averages from household statistics proved to be a useful tool to understand economic contexts, especially for levels of market integration. While previous studies have focused on a single village or a series of villages, it was a goal for this study to expand the focus to a large number of villages within a given region. In situ conservation may involve targeting communities with a combination of conditions that will make conservation programs successful and sustainable. Each context and story of CGR conservation is unique, but the ability to move from household motivations to village contexts to regional processes will be fundamental for planning conservation programs.

Policy Implications

Market Integration

One of the most important findings from this thesis is that process of market development and the integration into regional markets negatively impacts the conservation of CGR. Within village cross-section studies have shown the possible equilibria of de facto conservation, where households conserve CGR despite contradictory market forces. In this study, a cross-section of villages shows that along a continuum of levels of market integration, the market development causes genetic erosion. Because the equilibria of local economic contexts are not stable, the long-term sustainability fundamental to in situ conservation is not guaranteed.

In the overall development of the SNP region, increased market integration has the effect of moving people out of low productivity milpa production into other activities. Some of the alternatives in the region are cash crops such as coffee, which is a source of foreign exchange for Mexico and a way to channel capital through a vertical chain of purchasing. In many areas labor-scarce and land-extensive cattle production is replacing land- and labor-intensive milpa production; a few wealthy families controlling extensions of land that once fed many families. Finally, similar to the experience throughout rural Mexico, migration out of the region leads to the reallocation of household labor away from farm activities. Within the region, household labor in farm production is substituted by wage labor, which in turn is influenced by opportunity costs in national and international markets. Many farmers continue to conserve the traditional cropping system and the CGR contained within it by making milpa production a part of a diversified income portfolio. However, the longer-term forces driving the simplification of maize production are operating on several different market levels simultaneously.

Supply intervention by the government

Within this survey it was difficult to determine whether the price of maize marketed by the government maize program, DICONSA, is actually subsidized. The household survey covered household consumption directly the maize market was only covered through informal and descriptive interviews. The price that maize is sold at from the government stores is close to the prices recorded for private traders and inter-village trade in maize. The official government policy is not to subsidize the maize below its market price, but to subsidize the infrastructure and transportation of grains into the region. While the price of maize is only slightly subsidized, another service of DICONSA is to guarantee a base supply of maize in each village. The weekly delivery of 2-3 tons in a small village is a major component of the local food security. For farm households deciding whether to reduce planting maize and depend on meeting subsistence needs in the market, the reliability of supply is as important as the price. Beyond the subsidy of the price, there is a subsidy through reducing a households risk premium, by ensuring the availability of a minimum quantity of maize, year- round, at a constant price.

NAFTA and biodiversity

In the lengthy negotiations over NAFTA, a 15-year phase-out of maize price and import controls was established. However the Mexican government has never applied the tariff-rate quota that is allowed over a certain import threshold (2.5 million tons). This has forced local farmers to face low world prices for maize and increasing imports of low-quality maize from the United States. The Mexican government prefers to keep inflationary pressures down, and faces a growing urban population dependent upon cheap food. The maize price is an element of the consumption bundle used to calculate inflation indices, and psychologically it is an important indicator of rising prices. The policy favors the welfare of poor Mexicans, for whom maize remains an important share of calories, over the welfare of Mexican maize producers, who remain producing at or above the market price.

The low maize price policy of the Mexican government highlights the contradictions of rural development. Allowing prices to rise, through applying the import controls approved under NAFTA or reducing the subsidies to regional maize from the DICONSA distribution network could make maize production profitable and increase the planting of local landraces. More importantly, reducing imports and favoring local production for local consumption could favor the price-quality interactions that would allow market forces to support the continued planting of higher quality local landraces. However, the demands of poverty seem to dominate the demands of conservation. The poor farmers of the villages in this study who are the potential guardians and stewards of crop genetic resources are also the beneficiaries and consumers of cheap, imported maize. The fact that most households are producing below subsistence, and that over time they seem to plant less and purchase more maize, means that the negative welfare impact of increased maize prices would be a cost of using the market to foster conservation.

Directions for future work

There is room for future work to expand from the conclusions presented in this paper. One obvious extension is to integrate the behavioral model with key aspects of farmer seed management. The practices of farmers with respect to seeds have important consequences for crop populations and the possible interactions of conservation programs on population characteristics. There is a need to use a similar behavioral model to link econometric results to seed selection behavior, or other behavior that can show the effects of economic contexts on crop population outcomes.

Another useful and interesting area of study is the impact of ethnicity on conservation behavior. This is an area that was covered in the household survey and was included in early versions of the econometric model. In this study, the role of ethnicity was dropped as the village contexts and level of market integration seemed to describe key factors related to ethnicity. The goal of future study should be to test whether ethnicity can explain diversity separately from the impacts of marginalization that are correlated with it.

Finally, it would be useful to apply the methodology developed in this study to directly integrate biological data on crop genetics into the econometric analysis. An original goal for this thesis was to collect crop varieties and use genetic analysis to develop a household specific measure of crop diversity. The monetary cost of such a study and coordination costs made such information impractical. There are many areas where information from molecular measures of crop diversity would be useful to understand which dimensions of diversity should be the focus of socio-economic research. For example, genetic information is needed to provide an understanding of the extent of diversity within a seed lot and between farmers, villages, or regions. Future studies could use crop genetics to frame what questions to model for conservation programs.

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