The determinants of cereal crop diversity on farms in the Ethiopian highlands

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Abstract

On farm conservation of crop diversity entails policy challenges, especially when the diversity of crops maintained on farms has both inter-specific (among crops) and infra-specific (within a crop) components. Survey data is used to compare the determinants of inter- and infra-specific diversity on household farms in the highlands of northern Ethiopia. Physical features of the farm, and household characteristics such as livestock assets and the proportion of adults that are men, have large and significant effects on both the diversity among and within cereal crops grown, varying among crops. Demographic aspects such as age of household head and adult education levels affect only infra-specific diversity of cereals. Though there are no apparent trade-offs between policies that would enhance one type of diversity (richness) versus another (evenness), those designed to encourage infra-specific diversity in one cereal crop might have the opposite effect on another crop. Trade-offs between development and diversity in this resource-poor system are not evident. Market-related variables and population density have ambiguous effects. Education positively influences cereal crop diversity. Growing modern varieties of maize or wheat does not detract from the richness or evenness of these cereals on household farms.

1. Introduction

In the less-favored areas of the world where crop production is risky and opportunities are limited for insuring against it through working off-farm, many farm families still depend directly on the diversity of their crops for the food and fodder they use. Crop biodiversity on farms[1] has both inter-specific (among crops) and infra-specific (within a crop) components (Bellon 1996). The potential to secure harvests in some difficult growing environments is not the only economic issue motivating interest in crop diversity. Maintaining genetic variation *in situ* as a complementary strategy to conservation in gene banks has re-emerged as a scientific question (Maxted et al. 1997; Brush 2000). For cultivated crops, conservation of genetic resources *in situ* refers to the continued cultivation and management by farmers of crop populations in the open genetically dynamic systems where the crop has evolved.

On farm conservation of crop diversity poses obvious social, economic, and policy challenges. In detailed case studies conducted in Peru (potato), Turkey (wheat), and Mexico (maize), applied economists have so far sought to identify the factors that positively and negatively affect the prospects that diversity is maintained on farms, while characterizing those farmers most likely to continuing conserving it (Brush et al. 1992; Meng 1997; Van Dusen 2000; Smale et al. 2001). As a tool for targeting conservation efforts, Meng profiled those farmers most likely to continue conserving wheat landraces. Van Dusen explored both inter-specific and infra-specific diversity in the Mexican *milpa* system.

Case studies have generally concluded that two major determinants of crop diversity at both the regional and farm level are agroecological heterogeneity and the extent to which villages and households trade their crop on markets. Recently, however, the assumption that the opportunity costs of growing landraces rises with development and market integration has been challenged, based on the case of the North American Free Trade Agreement (NAFTA) and Mexican maize (Dyer 2002). The relationship of household characteristics such as human capital, assets, and off-farm employment also appears to depend on the context. A negative relationship between modern varieties and crop genetic diversity is typically assumed, though empirical examples suggest that the relationship is more complex (Zimmerer 1996; Brush et al. 1992).

We test related hypotheses in this paper. Comparing the determinants of inter- and infra-specific diversity among the cereals commonly grown in the highlands of Ethiopia, we highlight three types of policy trade-offs. First, the same policies may enhance the numbers or "richness" of cereals and varieties grown but detract from their "evenness" of their representation on farms. Second, to the extent that the determinants of diversity differ by among crops, policies designed to enhance the diversity in one crop may have adverse consequences for the diversity of another crop. Finally, if modern varieties enhance diversity rather than detract from it in some environments such as these, trade-offs between diversity and productivity may not be a policy concern.

The highlands of northern Ethiopia are a suitable empirical context for testing such hypotheses. Ethiopia is a center of diversity for cereals such as barley, wheat, sorghum, finger millet, and teff (Harlan 1992). Often referred to as one of the eight Vavilovian gene centers of the world, Ethiopia has made a national commitment to conserve genetic resources on farms and in gene banks over the past two decades (Worede et al. 2000). The highlands of northern Ethiopia are relatively less favored than other areas of the country in terms of both growing environment and market infrastructure, two of the generic factors hypothesized to positively affect crop diversity. The detailed dataset used in the analysis is ideal for analyzing differences in the diversity on household farms because of the relatively large number of communities sampled and range of conditions represented.

The conceptual framework for the analysis is presented next. The econometric approach follows, including the data design and description of variables and related hypotheses. Findings are then presented. The final section draws conclusions and suggests areas for further research.

2. Conceptual framework

The conceptual approach to analyzing on-farm diversity is based on the theory of the farm household model (Singh et al. 1986; de Janvry et al. 1991) and the literature on partial adoption of agricultural innovations (see surveys by Feder et al. 1985; Feder and Umali 1993; Smale et al. 1994). Farmers in the Ethiopia highlands both produce and consume their cereal harvests, and they grow modern varieties of wheat, maize, and teff simultaneously with their own traditional varieties. An estimable version of the farm household model, as applied to the study of on-farm conservation of crop inter-specific (among species) and infra-specific (within species) was developed by Van Dusen (2000). Other applied economic analyses of crop biodiversity based either on the farm household model or a model of variety choice that are applied econometrically are Brush et al. (1992), Meng (1997), and Smale et al. (2001).

Farmers' decisions about which cereal crops and varieties to grow and how extensively can be understood in the context of the theory of the household farm. In this theory, the household farm maximizes utility over a set of consumption items generated by the set of crops and varieties it grows (C_f), a set of purchased consumption goods (C_{nf}), and leisure (l). The utility a household derives from various consumption combinations and levels depends on the preferences of it members. Preferences are in turn shaped by the characteristics of the household, such as the age or education of its members, and wealth. Choices among goods are constrained by the full income of the household, total time (T) allocated to farm production (H) and leisure (l), and a fixed production technology represented by $F(\bullet)$. The production technology combines purchased inputs (X) and labor (L) with the physical characteristics of the farm (Ω_F), which are fixed in a single decision-making period. Expenditures cannot exceed the value of all purchased goods, farm production and leisure. Full income in a single decision-making period is composed of the net farm earnings (profits) from crop production (Q_f), of which some may be consumed on farm and the surplus sold, and income that is "exogenous" to the season's crop and variety choices, such as stocks carried over, remittances, pensions, and other transfers from the previous season (Y).

(1) $$\underset{C_f, C_{nf}}{Max}\, U(C_f, C_{nf}, l; \Omega_{HH})$$

s.t.

(2) $$Q_f = F(X, L | \Omega_F)$$

(3) $$T = H + l$$

(4) $$p_f(Q_f - C_f) - p_x X - wL + Y = p_{nf} C_{nf} + wH$$

When all relevant markets function perfectly, farm production decisions are made separately from consumption decisions. The household maximizes the net farm earnings subject to constraints and then allocates these with other income among consumption goods. Farm production decisions, such as crop and variety choices, are driven by net returns, which are determined only by wage, input and output prices (w, p_f and p_x) and farm physical characteristics (represented by vector Ω_F). When comparing farmers among communities located in a broader geographical area, one can see that their decisions are also affected by factors that vary at a regional level but that they themselves cannot influence. These include several fixed factors hypothesized to affect variation in the diversity maintained among regions, such as agro-ecological conditions or infrastructural development, or the ratio of labor to land (represented by vector Ω_R).

The production and consumption decisions of the household cannot be separated when labor markets, markets for other inputs, or product markets are imperfect. Then, prices are endogenous to the farm household and affected by the costs of transacting in the markets. The specific characteristics of farm households (represented by vector Ω_{HH}) and physical access to markets (represented by vector Ω_M) influence the magnitude of transactions costs and hence, the effective price governing the household's choices.

If the land constraint for crop production also binds ($A=A^o$) so that farmers cannot change the total land area they farm in each growing season, the consumption goods produced on farm map into crop and variety area shares through physical input-output relationships between goods, crops, and varieties (Smale et al. 2001). That is, at any point in time, each unit of seed of a crop or variety generates an expected level of output to sell or consume, based on the germplasm it embodies, inputs applied in its production, and physical growing environment. Since the focus of this analysis is cereal crop production, livestock production has not been treated explicitly. The size of the livestock herd is assumed fixed for the cropping season, though there is a derived demand for crops and varieties through feed and fodder requirements. The objective function in (1) can then be expressed as:

$$(5) \qquad \underset{\alpha_{11},\alpha_{ij},\ldots\alpha_{mn}\geq 0}{Max} V(C_f, C_{nf}, l; \Omega_{HH})$$

Where the choice variables are area shares (α) planted to crops i = 1,2,…,m, and varieties j=1,2, …,n. The reduced form equations from (5) express optimal area allocations among crops and varieties as functions of a vector of prices (including wage), farm size, exogenous income, and vectors of farm household, farm physical, market and regional-specific characteristics.

$$(6) \qquad \alpha^* = \alpha^*(p, A^o, Y, \Omega_{HH}, \Omega_F, \Omega_M, \Omega_R)$$

Diversity indices are constructed from these area shares, as described in the next section. Equations estimated econometrically take the following conceptual form, as in Van Dusen (2000):

$$(7) \qquad D = D(\alpha^*(p, A^o, \Omega_{HH}, \Omega_F, \Omega_M, \Omega_R)$$

These factors are the hypothesized determinants of diversity on household farms. In the next section, the data source, dependent and independent variables are described. Individual hypotheses are discussed, as these relate to the literature. The regression structure is summarized.

3. Econometric approach

Data source

A stratified random sample of 99 Peasant Associations[2] (PA's, usually consisting 4 or 5 villages) was selected from highland areas (above 1500 m.a.s.l.) in the Tigray and Amhara regions of northern Ethiopia in 1999. The stratification was based upon indicators of agricultural potential, market access and population density. Data analyzed here were collected in household and plot surveys conducted with 934 households located in these communities. Survey instruments covered household composition and assets, access to markets and infrastructure, and aspects of crop production during the 1999 season. Survey data were supplemented by secondary geographic information.

Dependent variables

The dependent variables are diversity indices. Diversity at the farm level can be measured by any number of indices, depending on the mode of reproduction of the crop, the type of data available to the researcher, and the diversity concept (Meng et al. 1998). Here, each index *D* is a scalar constructed from the choice variable in equation 6, which is a vector of area shares allocated to crops or varieties of crops. Crops are commonly recognized cereals: barley, maize, wheat, teff, sorghum, and millet.

Within these cereal crops, "variety" is simply understood as a crop population recognized by farmers. This definition encompasses landraces that have been grown and selected by farmers for many years, modern varieties that meet the UPOV definition of distinct, uniform, and stable, as well as "rusticated" or "creolized" types that are the product of deliberate or natural mixing of the two (Wood and Lenné 1997; Bellon and Risopoulos 2001). Usually "named" by farmers, varieties have agro-morphological characters that farmers use to distinguish among them and that are an expression of their genetic diversity.

The relationship between variety names and genetic variation is generally not well defined. In an economic model of farmer behavior, however, it is important to establish the relationship between the choice variable itself and the hypothesized explanatory variables.[3] Farmers choose varieties or their observable attributes, rather than alleles. The more sophisticated the diversity index, the more indirect the relationship between the diversity outcome and the farmers' choices and, therefore, between the diversity index and factors that explain the choice.

We employ two indices that have been adapted from the ecological indices of spatial diversity in species (Magurran 1988) to represent either inter- or infra-specific diversity of cereal crops (Table 1). Each represents a unique diversity concept. Richness, or the number of species or varieties encountered, is measured by a Margalef index. Relative abundance refers to the distribution of individuals associated with each of the species or varieties. An index that combines both richness and relative abundance concepts is the Shannon index. The Shannon index, originally used in information theory, has been commonly employed to evaluate species diversity in ecological communities. Also termed a "heterogeneity index" or an evenness index, it embodies no particular assumptions about the shape of the underlying distribution in species abundance.

Independent variables and hypotheses

When the underlying theoretical model of household decision-making is non-separable, the diversity of cereals is affected not only by farm physical characteristics, as would be the case for a commercial producer that maximizes profits, but also by household-specific characteristics and other factors related to the costs of transacting in markets. Independent variables are operational measurements of the vectors shown in equation 7, with the exception of price variables, for which it was difficult to articulate a hypothesized effect in the diversity equations. Each set of operational variables and related hypotheses is described next and summarized in Table 2.

The genetics and ecological literature suggests that greater heterogeneity in farm conditions will tend to increase inter- and infra-specific diversity, while more homogeneity will have the opposite effect (e.g., Marshall and Brown 1975). Here, we hypothesize that greater heterogeneity of plots in terms of erosion or fertility and more farm fragmentation[4] are expected to increase diversity, while greater flatness is expected to reduce diversity. Larger farms will tend to increase diversity, by increasing the capacity of households to allocate land to try out other crops and varieties. Irrigation is expected to reduce diversity, as irrigation tends to make farm technology more uniform. Greater distances from the house to the farm may reduce the opportunities to grow more cereal crops because of requirements in walking time.

Household characteristics include those related to human capital, labor supply and the life-cycle stage of the household. Age of household head is expected to have a quadratic relationship with both inter and intra specific diversity (Van Dusen, 2000), as younger households may be more willing to try out different crops and varieties, while older households may be more set in their production activities and less likely to try new crops and varieties. However, including the square of age as an explanatory variable introduced severe multicollinearity, and it was dropped from the final regressions.[5] The direction of effect of the gender composition of the household is difficult to predict a priori, while household size is expected to have a positive effect on diversity through its effects on preferences and overall labor capacity. Livestock, as a measure of wealth, may act as insurance against crop production risk, bearing a negative relationship with diversity (Rana et al. 2000; Van Dusen 2000). On the other hand, it may have a positive effect on diversity through additional income, enabling farmers to intensify production and engage in multiple activities. Similarly, the effect of income that is exogenous to crop choice, such as remittances, gifts, aid, and pensions, is ambiguous. Oxen ownership is expected to contribute positively to diversity among cereals through ensuring draught power for plowing when it is needed.[6]

Market infrastructure operates in several ways that may not be dissociable in a given location at one point in time. For example, the more removed a household or community is from a major market center, the higher the costs of buying and selling on the market and the more likely that it relies primarily on its own production for subsistence. This implies that the more physically isolated a community or household, the less specialized its production activities. On the other hand, as market infrastructure reaches a village, new trade possibilities may emerge, adding crops and production activities to the portfolio of economic activities undertaken by its members. The theory of the household farm predicts that the higher the transactions costs faced by individual households within communities as a function of their specific social and economic characteristics, the more we would expect them to rely on the diversity of their crop and variety choice to provide the goods they consume. Consistent with this hypothesis, Van Dusen (2000) found that the more distant the market, the greater the number of maize, beans, and squash varieties grown by farmers. Meng (1997) also found that cultivation of wheat landraces was positively associated with their relative isolation from markets in Turkey. In Andean potato agriculture, Brush et al. (1992) found proximity to markets to be positively associated with the adoption of modern varieties, but this adoption did not necessarily decrease the numbers of potato types grown. In southeast Guajanuato, Mexico, the better the market infrastructure in a region the greater the area households allocated to any single maize landrace (Smale et al. 2001) but the greater the evenness in the distribution of landraces across the region (Aguirre Gómez et al. 2000).

Varieties differ in the extent to which they provide agronomic (adaptation to soils, maturity, disease resistance, fodder and grain yield) and consumption (taste, appearance) attributes. When farmers cannot rely on the market to provide them with the seed that meets their demand for attributes, they may grow a more diverse set of varieties to ensure their needs. At the same time, access to seed markets also enables farmers to combine the attributes of purchased seed types with those selected and maintained by farmers in their own community. Modern varieties may possess traits not found in local varieties (Louette et al. 1997) or have more uniform grain quality, enabling cash to be earned to satisfy other consumption needs of households (Zimmerer 1996). Hence, while an area's relative isolation from markets would lead us to predict that modern varieties are less likely to be found or are found to a lesser extent, the number of distinct types may be either greater or fewer when these areas have access to modern varieties, especially when the attributes they offer complement but do not substitute for those provided by local materials.

The ratio of labor to land in the community is associated with the hypothesis that rising population densities induce land-saving technical change or higher output per unit of land. Modern varieties are one form of agricultural intensification. Intensification may also occur in terms of larger numbers of farm production activities undertaken, including more cereal crops.

Finally, regional location is hypothesized to affect the cultural and physical environment in which farmers make their decisions. The physical environment in Tigray is more degraded and the area has lower agricultural potential than Amhara. The average annual rainfall in Amhara is estimated at 1189 mm, compared to only 652 mm in Tigray. Soils are also generally deeper and more fertile in Amhara. Since 1991, concerted efforts have been made to rehabilitate the environment, especially in Tigray (Gebremedhin 1998; Gebremedhin et al. 2002). The average size of land holding per household is larger in Amhara (1.72 ha) compared to Tigray (1.05 ha). The average distance from the community to the nearest market is much lower in Amhara (58 walking minutes) than in Tigray (212 walking minutes).

Regression structure

The general structure of the regression equations is expressed in simple form by

$$D_i = a_i + b_i x + c_i z + e_i ,$$

where D represents either the Margalef index of richness or the Shannon index of evenness, x is a vector of household, farm and community factors; z represents adoption of a modern variety, e is unobserved factors; and a, b and c are the parameters to be estimated.

Several estimation problems were encountered in estimating the equations about infra-specific diversity. First, a sample selection problem occurs because the diversity index for cereal i exists only when the household cultivates the cereal. Second, a large proportion of households that cultivate the cereal grow only one variety so that both richness and evenness indices are censored at zero.[3] Application of ordinary least squares (OLS) or seemingly unrelated regression (SUR) in this situation yields biased and inconsistent estimates.

The most common approach to dealing with selectivity problems is a technique similar to Heckman's. Growing the cereal would be predicted in the first stage, a predicted value of the inverse Mills ratio would be obtained, and the ratio included as an explanatory variable in a second-stage regression (Maddala 1983). However, since the second stage is a censored regression, the predicted IMR introduces heteroskedasticity because its errors depend on values of the explanatory variables. Unlike in the linear model, heteroskedasticity causes the estimator to be inconsistent (Maddala 1983). Obtaining the correct standard errors is also complicated by use of the predicted rather than the actual IMR. In the second stage, we have therefore used the censored least absolute deviations (CLAD) estimator, which is robust to heteroskedasticity (Deaton 1997). With CLAD, standard errors are computed with bootstrapping.

The third problem is that predicting the effect of modern varieties on infra-specific diversity involves endogeneity. Similar to selectivity bias or a treatment effect, including am explanatory dummy variable to represent use of a modern variety gives inconsistent estimates (Barnow et al. 1981; Greene 1983; Maddala 1983). Thus, in the second stage of the CLAD regression, we have used predicted probabilities from a first-stage probit regression (Barnow et al. 1981).[4]

Identification of the CLAD regression is an important issue, as in many two-stage approaches. It is difficult to find variables that are correlated with the decision to grow a cereal crop or a modern variety but are not correlated with the diversity index. We use altitude and walking times to the nearest grain mill, input supply shop and bus service as instruments in the probit regressions. Note that, even if the explanatory variables in the first and second stage regressions are identical, because the predicted IMRs and probabilities from the first-stage regressions are non-linear functions of the explanatory variables, the CLAD regression is identified under the normality assumptions of the probit model.

4. Estimation and results

After removing inconsistent observations, 739 remained for the analysis. We estimated the diversity regression equations across common cereals (including barley, maize, wheat, teff, sorghum, finger millet, and pearl millet) and within barley, maize, wheat, and teff.[5] Households cultivated between one and five cereals; 24% cultivated one cereal only, while 40, 27, 8 and 1% cultivated 2, 3, 4 and 5 cereals, respectively. Teff was cultivated by the most number of households (469), followed by barley (352), maize (317), wheat (250), sorghum (110), finger millet (101) and pearl millet (22). The maximum number of varieties of any cereal cultivated by any household was three. Only 52 and 46 households planted a modern variety of wheat and maize, respectively, while a mere 12 households planted a modern variety of teff and only a single household reported a modern variety of barley. The relationship of growing modern varieties to infra-specific diversity was tested only for wheat and maize, since the number of observations was insufficient to estimate the first-stage probit regression for the other crops.

At first glance, the number of varieties of cereals (especially sorghum, finger millet and pearl millet) reported by households appears to be low, given that they are among the crops in the “savanna complex” believed to have originated in a belt that spreads across the Sahelian region in West Africa to the Horn of Africa (Harlan 1992). While an individual household may grow relatively few varieties, many varieties of each crop may be found among the households in a community. The number of varieties grown by any single farmer is likely to be positively associated with the number of different water regimes in which the farmer plants the crop. In Amhara region, for example, teff, barley, wheat and maize are grown during the main rains (*meher*), small rains (*belg*), and under irrigation. Finger millet is grown only in the main season, while sorghum and pearl millet are normally grown only in the main season or under irrigation. For predominantly cross-pollinating crops, the relationship of variety name to infra-specific diversity is not as strong as it is for self-pollinating crops, and diversity is expected to be partitioned more within than among varieties. Pearl millet has very high rates of cross-pollinating relative to sorghum and finger millet, but rates for wheat, barley and teff are lower than any of these. Maize is a highly cross-pollinating species, but modern varieties are also available in the study area.

Inter-specific diversity of cereal crops

Censored regression results of the determinants of inter-specific diversity of cereals are given in Tables 4 and 5. Socio-demographic characteristics of the household such as the age and sex of the household head, the education of its members, and its size bear no significant relationship to the diversity of cereal crops they grow. Households with more male labor, more oxen or larger farms grow more diverse cereal crops because they have the resources to do so. Greater total livestock assets are associated with greater specialization, or less evenness in cereal crops. In the Ethiopian highlands, wealth in livestock can ensure against the crop production risk that might arise when fewer crops are grown.

More fragmented farms with larger numbers of different plots have more cereal crops that are likely to be more evenly distributed. Households living further from their farms manage fewer cereal crops. Access to roads and markets were insignificant factors. Location in Tigray contributes to higher levels of cereal crop diversity. Tigray, it should be remembered, has lower agricultural potential than Amhara.

Infra-specific diversity of cereals

Results of the CLAD regressions about the infra-specific diversity of barley, maize, wheat and teff are shown in Tables 4 and 5.[6] Though socio-demographic were of no significance in determining the diversity of cereal crops (inter-specific diversity), they matter for the diversity among varieties. Younger household heads and more educated household members are associated with greater diversity in maize, wheat and teff, though the opposite is true for barley. To the extent that education enhances the ability to understand and utilize technical information associated with new crops, younger farmers may be more willing to grow various types of maize and wheat. Households headed by women grow more diverse wheat varieties, while households with proportionately more women grow richer varieties of barley, maize and wheat.

Households with a larger stock of labor have greater maize diversity, probably because of the labor demand associated with growing the crop, applying fertilizer and harvesting. Households with more livestock assets (including oxen) had lower diversity in teff, but greater more diverse barley and wheat. On the other hand, households with more oxen had more diverse teff, and less barley and wheat. Perhaps households with more livestock are concerned with biomass (crop residue) to feed their livestock and so prefer to grow barley and wheat varieties that produce more fodder, while those with more oxen are more able to undertake the intensive plowing practices associated with growing teff. Households with outside sources of income grew more diverse barley varieties, but the same was not true for maize. Households with more exogenous income are also more likely to have other non-farm activities, limiting their ability to engage in more labor-intensive activities associated with growing maize.

Larger farms were associated with greater diversity within, as well as among, cereal crops. Fragmentation and numbers of plots have conflicting effects among crops. Farms with more flat land have greater diversity in maize, but lower diversity in barley and teff. Evenness in the extent of soil erosion on the farm is associated with greater diversity in maize and teff. The greater the proportion of the farm that was irrigated, the greater the specialization in maize types, though the opposite is revealed for wheat and teff.

As predicted, market-related factors have effects that depend on both the measurement of the factor and the crop. Households far away from an all weather road grow more diverse barley and maize, but less diverse teff. Households in communities located farther away from the district town had less diverse maize. More densely populated peasant associations have more diverse wheat and maize, but less diverse teff. This result is consistent with the notion that these communities have higher food and feed demands and so farmers will choose higher yielding crops that produce more biomass, such as maize and wheat, over teff. Location in Tigray region is associated with greater diversity in teff, but lower diversity in barley and maize, probably because teff is more adaptable to conditions under which many other crops fail to grow (Worede 1988). Rainfall is lower and more variable in Tigray than in Amhara region.

Adoption of modern varieties

Barley and teff are "old crops" to this area of the world, while maize and (bread) wheat are relatively new. Cultivation of modern varieties of maize and wheat has no statistically significant impact on the diversity in the maize and wheat varieties grown on household farms (Tables 4 and 5). This finding suggests that modern varieties add traits and attributes that augment the set of traditional varieties provided to farmers, complementing rather than replacing them.

5. Conclusions and implications

Trade-offs in diversity goals

No trade-offs are apparent between policies that would enhance the richness, as compared to the equitability, among cereal crops. The direction of the effect of statistically significant factors is the same for both indices. Thus, a policy whose goal is to augment one conservation goal would not conflict with another. The same appears to be true for infra-specific diversity of any given cereal crop. Different factors are significant in explaining the richness and equitability among varieties grown for any single cereal crop but they are consistent in sign. A program designed to conserve the richness of varieties of any single crop is not likely to have a negative impact on the evenness among them.

Trade-offs in diversity among and within crops

However, the set of factors that determines the pattern of infra-specific diversity varies among cereal crops and some are clearly more important for one crop than another. Thus, policies designed to encourage infra-specific diversity in one cereal crop might have the opposite effect on that of another crop.

Policies related to livestock and oxen ownership will affect both the inter-specific diversity and infra-specific diversity of cereals, but in different ways and differentially among cereal crops. Similarly, farm physical characteristics, market access, population pressure, and regional location are related in various ways to both inter-specific diversity and infra-specific diversity of cereals. The incidence of related policies, therefore, would be differential and difficult to predict.

Trade-offs between development and diversity

Policies that affect household labor supply and its composition are therefore likely to have a major impact on the infra-specific diversity of cereals in the highlands of Amhara and Tigray. If non-farm opportunities arise and fixed labor stocks of adult male labor are drawn out of farm production, inter-specific diversity in cereals will probably decline. On the other hand, households with higher proportions of females or female household heads are more likely than others to grow cereal crops with greater infra-specific diversity. Education generally has a positive effect on variety diversity. Educational campaigns, and recognizing the possible importance of women in variety choice and seed management, appear relevant.

At this point, there is no evident trade-off between seeking to enhance productivity through the use of modern varieties and the spatial diversity among named varieties of these two cereal crops in Tigray and Amhara regions of the Ethiopian highlands. So far, introduction of modern varieties has not meant that any single variety dominates or that modern varieties have displaced landraces, most likely because they have limited adaptation and farmers face many economic constraints in this environment. Instead, as hypothesized, it is just as likely that small amounts of seed of modern varieties diversifies the seed set of these farmers by meeting a particular purpose or filling a particular niche, rather than contributing to uniformity. The obvious reason is that neither the physical terrain nor the market infrastructure network is particularly favorable for specialized, commercial agriculture. This is not to say that the modern varieties introduced in such areas are themselves genetically diverse, but that the traits they add to those of the other varieties grown, enable farmers to better meet their production and consumption objectives in this difficult and uncertain growing and marketing situation. These findings confirm that opportunities to pursue development while enhancing cereal crop diversity do occur in areas of the world that are less favored in terms of environmental conditions and economic infrastructure.

Future research

Though the applied economics research in this area is relatively scant, much of it has focused on a single crop species. This study adds to this literature by investigating trade-offs among some related cereal crops. Though the analysis includes households located across a large range of communities in another gene center (Ethiopia), it is similar to most of the other applications in that the social unit analyzed is the household. Since communities are the smallest social unit for which crop biodiversity programs and policies are likely to be designed, better understanding of the relationship between the incidence of explanatory factors at household and community levels is important. This follows directly from the fact that the crop genetic resources managed by farmers are goods with both private attributes (as physical units of seed) and public attributes (the gene combinations and information embodied within and among these units). The relationship between the incidence of explanatory factors at the household and community levels, and the linkages between them as the spatial scale of analysis increases, needs investigation.

Other fields and other tools, such as bio-economic models, might be applied to increase our understanding of the role of crop infra-specific and inter-specific diversity within farming systems. The case of the Ethiopian highlands underscores the need to better understand the interrelationships between crop and livestock systems for agro-biodiversity conservation in some farming systems. Other specific issues may merit research attention, such as a subtler economic understanding of the relationship of seed systems and markets to biodiversity.

Lastly, the relationship of more diverse crop and variety combinations for farmer well-being should be examined. Are there welfare trade-offs for farmers that grow more diverse crop and variety combinations? How do farmers themselves perceive diversity, its costs and benefits? Among households, those who are better off in land, labor, and livestock tend to maintain more crops and more varieties. Wealth and complexity go hand in hand, and it may not make sense to focus on poorer households within communities in a diversity conservation program. On the other hand, findings suggest clear gender-related distinctions among households who maintain more inter-specific cereal diversity as well as those who maintain more infra-specific diversity, suggesting that a gender focus may make sense.

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Table 1. Dependent variables used in analysis of cereal diversity on household farms in the highlands of Amhara and Tigray regions, Ethiopia

Index	Concept	Construction	Explanation
Margalef	Richness	$D=(S-1)/\ln A_i$ $D \geq 0$	A_i = total area planted to the *i*th cereal crop or crop variety by household in 1999, S is the number of varieties or the number of crops
Shannon	Evenness or equitability (Both richness and relative abundance)	$D=-\Sigma\alpha_i \ln\alpha_i$ $D\geq 0$	α_i = area share occupied by *i*th cereal crop or crop variety in community or by household in 1999

Table 2. Definition of explanatory variables, summary statistics, and hypothesized effects on cereal (inter- and infra-specific) diversity on household farms in the highlands Amhara and Tigray regions, Ethiopia

		Hypothesized effect					
Variable name	Description	Inter-specific	Infra-specific	Mean	Standard Error	Min	Max
Household characteristics							
Age	Age of household head (years)	(+,-)	(+,-)	43.405	0.738	16.00	86.0
Male-headed	Sex of household head (0=female; 1=male)	(+,-)	(-)	0.913	0.016	0.00	1.0
Education	Average number of years of formal education of members 15 years and above	(+,-)	(+,-)	1.827	0.119	0.00	19.5
Household size	Number of household members	(+,-)	(+,-)	5.512	0.160	1.00	15.0
Proportion of males	Proportion of household members that are male	(+,-)	(-)	0.432	0.014	0.00	1.0
Tropical livestock units	Number of tropical livestock units owned by household	(+,-)	(+,-)	3.490	0.153	0.00	17.3
Oxen ownership	Number of oxen owned by household	(+,-)	(+,-)	1.431	0.059	0.00	7.5
Exogenous income	Sum of remittances, food aid, gifts, and pension (EB) [1]	(+,-)	(+,-)	111.184	15.745	0.00	1750.0
Farm characteristics							
Slope of farmland	Proportion of farmland that is flat	(-)	(-)	0.433	0.022	0.00	1.0
Erosion of farm	Shannon index of areas shares in eroded land classes on farm	(+)	(+)	0.453	0.019	0.00	1.0
Fertility of farm	Shannon index of area shares in soil fertility classes on farm	(+)	(+)	0.397	0.021	0.00	1.0
Irrigation	Proportion of farmland that is irrigated	(-)	(-)	0.030	0.006	0.00	1.0
Farm size	Amount of farmland operated by household (hectares)	(+,-)	(+,-)	1.176	0.050	0.01	7.9
Farm fragmentation	Simpson index (1- the sum of squared plot area shares)	(+,-)	(+,-)	0.563	0.012	0.00	0.9
Number of farm plots	Number of farm plots operated by household	(+,-)	(+,-)	3.790	0.102	1.00	14.0
Distance from house to farm	Average walking time from house to farm plots (hours)	(-)	(-)	0.589	0.028	0.00	9.0
Market characteristics							
Distance to road	Walking time to nearest all weather road (hours)	(+,-)	(+,-)	3.159	0.152	0.00	24.0
Distance to town	Distance from peasant association to district town (km)	(+,-)	(+,-)	35.315	1.557	0.00	168.0
Regional characteristics							
Population density	Population density of peasant association (number per sq. km)	(+)	(+,-)	128.663	4.102	15.00	379.0
Location in Tigray	Administrative region of peasant association (Amhara region=0; Tigray region=1)	(+,-)	(+,-)	0.174	0.006	0.00	1.0

Notes: At the time of the survey (December 1999-August 2001), US$ 1≈EB (Ethiopian Birr) 8.50 (FAO, 2001). Means and standard errors are adjusted for stratification, weighting and clustering of sample.

Table 3. Censored regression results, factors affecting the inter-specific diversity of cereals on household farms in the highlands of Amhara and Tigray regions, Ethiopia

	All Cereals	
Explanatory variable	Richness index	Evenness index
Age	-0.0003	-0.0023
Male-headed	0.0189	0.0526
Education	-0.0051	-0.0201
Household size	-0.0002	0.0020
Proportion of males	0.1322***	0.3682***
Tropical livestock units	-0.0106	-0.0473***
Oxen ownership	0.0396**	0.1639***
Exogenous income	-0.0000	-0.0001
Slope of farmland	0.0128	0.0691
Erosion of farm	-0.0229	-0.0131
Fertility of farm	0.0274	0.0213
Irrigation	-0.0149	-0.0222
Farm size	0.0291**	0.1993***
Farm fragmentation	0.0792	0.4529***
Number of farm plots	0.0213***	0.0427***
Distance from house to farm	-0.0378***	-0.0723*
Distance to road	-0.0003	-0.0025
Distance to town	0.0001	-0.0001
Population density	-0.0001	0.0004
Location in Tigray	0.1427***	0.1612***
Constant	-0.0763	-0.3176*
Number of observations	739	739
Uncensored	577	577
Left-censored	162	162
F	8.89***	10.25***
Mean (standard error) of index	0.179 (0.008)	0.060 (0.026)

Notes: Indices are defined on page 5. * Statistically significant at the 10% level; ** Statistically significant at the 5% level; *** Statistically significant at the 1% level.

Table 4. Regression (censored least absolute deviation) results, factors affecting the infra-specific diversity of barley and maize on household farms in the highlands of Amhara and Tigray regions, Ethiopia

Explanatory variable	Maize		Barley	
	Richness index	Evenness index	Richness index	Evenness index
Age	-0.0038***	-0.0232***	0.0074***	0.0194***
Male-headed	-0.0364	-0.1259	0.0001	-0.0981
Education	0.0184**	0.0781*	-0.0036	-0.0253
Household size	0.0095**	0.0663*	0.0031	0.0071
Proportion of males	-0.1623***	-0.3186	-0.1703**	-0.1130
Tropical livestock units	-0.0070	-0.0743	0.0264***	0.0408
Oxen ownership	0.0299	0.2023	-0.0712***	-0.1707*
Exogenous income	-0.0004**	-0.0004	0.0001	0.0003*
Slope of farmland	0.1084***	0.6599***	0.0076	-0.3052***
Erosion of farm	0.1101**	0.6663***	0.0169	-0.0509
Fertility of farm	-0.0952***	-0.2766	0.0044	0.1175
Irrigation	-0.1813*	-0.4979	0.0213	0.0475
Farm size	-0.0198	0.1618*	0.0183	0.1539*
Farm fragmentation	0.0181	0.4263	0.0118	-0.0276
Number of farm plots	0.0042	-0.0134	-0.0411***	-0.0879**
Distance from house to farm	0.0001	-0.1082	-0.0277	-0.0549
Distance to road	0.0192	0.2137**	0.0094*	0.0279
Distance to town	-0.0025**	-0.0242**	-0.0008	-0.0032
Population density	0.0006**	0.0025**	-0.0001	0.0006
Location in Tigray	-0.0815	-0.3009	-0.0615*	0.0596
Inverse Mills Ratio, growing cereal	-0.4513***	-2.3201***	-0.2304***	-0.6242***
Probability of growing modern variety	-0.0249	-0.4554		
Constant	0.2862***	0.3581	-0.0094	-0.0229
Number of observations	303	303	352	352
Pseudo R^2	0.48	0.46	0.31	0.26
Mean (standard error) of index	0.017 (0.006)	0.047 (0.017)	0.017 (0.005)	0.068 (0.018)

Notes: Indices are defined on page 5. * Statistically significant at the 10% level; ** Statistically significant at the 5% level; *** Statistically significant at the 1% level.

Table 5. Regression (censored least absolute deviation) results, factors affecting the infra-specific diversity of wheat and teff on household farms in the highlands of Amhara and Tigray regions, Ethiopia

	Wheat		Teff	
Explanatory variable	Richness index	Evenness index	Richness index	Evenness index
Age	-0.0035*	-0.0175**	-0.0024***	-0.0113***
Male-headed	-0.0651	-0.4856*	0.0337	0.1816
Education	0.0196***	0.1057***	0.0110***	0.0373*
Household size	0.0051	0.0301	0.0021	0.0181
Proportion of males	-0.1608**	-0.9071**	0.0716	0.2240
Tropical livestock units	0.0397***	0.1734***	-0.0090	-0.0585*
Oxen ownership	-0.0829***	-0.3941***	0.0308	0.2104***
Exogenous income	-0.0001	-0.0004	0.0000	0.0001
Slope of farmland	-0.0253	-0.2221	-0.0913***	-0.4924***
Erosion of farm	0.0662	0.5218	0.0583*	0.2335
Fertility of farm	0.0134	0.2080	0.0405	0.0240
Irrigation	0.6104*	2.2710	0.1069	0.9719**
Farm size	0.0989***	0.2920*	0.0169	0.0926
Farm fragmentation	-0.3028***	-1.7204**	-0.2129*	-0.5731
Number of farm plots	0.0065	0.0867	0.0173**	0.0541
Distance from house to farm	-0.0629	-0.3681	-0.0072	-0.0431
Distance to road	0.0049	0.0213	-0.0233***	-0.1548***
Distance to town	-0.0018	-0.0064	0.0007	0.0028
Population density	0.0010**	0.0019	-0.0007***	-0.0050***
Location in Tigray	-0.0376	-0.1624	0.0179	0.2743**
Inverse Mills Ratio, growing cereal	-0.1304	-0.5118	-0.2723***	-1.0143***
Probability of growing modern variety	-0.1704	-0.0345		
Constant	0.2672*	1.6500**	0.2665***	1.3289***
Number of observations	243	243	469	469
Pseudo R^2	0.32	0.21	0.16	0.17
Mean (standard error) of index	0.016 (0.003)	0.072 (0.013)	0.021 (0.005)	0.079 (0.018)

Notes: Indices are defined on page 5. * Statistically significant at the 10% level; ** Statistically significant at the 5% level; *** Statistically significant at the 1% level.

Appendix: Regression (probit) results, factors affecting the probability that household farms grow cereals and modern varieties in the highlands of Amhara and Tigray regions, Ethiopia

	Barley	Maize		Wheat		Teff
Explanatory variable	All varieties	All varieties	Modern variety	All varieties	Modern variety	All varieties
Age	-0.0145**	0.0129*	-0.0215	0.0019	-0.0247*	-0.0008
Male-headed	-0.3298	-0.0382	-0.2325	0.3244	0.5807	0.5024
Education	0.0126	-0.0292	0.2643***	-0.0610	0.0545	-0.0079
Household size	0.0862**	-0.0134	0.0063	-0.0579	0.1821***	-0.0639
Proportion of males	1.0114***	0.9240**	2.4827***	0.6004	0.6302	-0.1233
Tropical livestock units	0.1172*	-0.0166	-0.4819***	-0.0511	0.0109	-0.0310
Oxen ownership	-0.0895	0.2376	1.8495***	0.2313	0.1037	0.0199
Exogenous income	0.0002	-0.0000	0.0001	-0.0000	0.0015**	0.0000
Slope of farmland	-0.0615	-0.3487	1.5153*	-0.0334	-0.1374	-0.0160
Erosion of farm	-0.0518	-0.3389	0.9022	0.0132	-1.1044**	-0.1738
Fertility of farm	-0.2134	0.5114*	-0.1364	0.8238***	-0.2381	-0.1315
Irrigation	-0.7357	-0.0502	-4.3956**	-1.1610	5.9645***	-1.2510
Farm size	0.2082	0.2423*	0.7104**	0.0718	0.5328***	0.1526
Farm fragmentation	-0.4965	-0.6338	0.1439	0.8894	1.0584	1.3205**
Number of farm plots	0.2356***	0.1416*	0.0426	0.0475	-0.2432*	0.1099
Distance from house to farm	-0.3215**	-0.1122	-0.8404	-0.1636	0.1963	-0.2028
Distance to road	-0.0488*	-0.0670	1.6646***	0.0177	-0.0019	0.0326
Distance to town	-0.0017	0.0015	-0.0480	-0.0033	-0.0005	0.0017
Population density	0.0030**	-0.0035***	0.0054	-0.0030**	0.0032	0.0013
Region	0.8655***	-0.8854***	-2.7827***	0.4740**	0.0850	-0.6373***
Distance to grain mill	0.0024	-0.0031	-0.0018	-0.0045***	0.0038	0.0009
Distance to input supply shop	0.0008	-0.0024*	-0.0054	0.0004	-0.0015	-0.0009
Distance to bus service	0.0015**	-0.0006	-0.0203***	-0.0002	0.0004	-0.0008
Altitude	0.0014***	-0.0012***		0.0009***		-0.0014***
Inverse Mills ratio, growing cereal			2.4158		-0.4142	
Constant	-5.1313***	3.1158***	-5.1368***	-3.1671***	-2.2631	2.8819***
Number of observations	628	565	303	515	243	552
F	4.16***	3.73***	4.40***	2.55***	2.04***	3.15***

Notes: Coefficients and standard errors are adjusted for stratification, weighting and clustering of sample. * Statistically significant at the 10% level; ** Statistically significant at the 5% level; *** Statistically significant at the 1% level.

[1] Crop biodiversity is only one part of agricultural biodiversity or agrobiodiversity, which refers to the diversity within and among all cultivated plant species and domesticated livestock, as well as interacting species and wild relatives (Wood and Lenné 1999).

[2] The Peasant Association (PA) is the lowest administrative unit in Ethiopia.

[3] Named varieties can subsequently be related to the underlying structure of genetic diversity in the community that is identified through agro-morphological or molecular analysis with seed samples. Such work is outside the budget or timeframe of this study.

[4] We use the farm fragmentation concept of Blarel et al. (1992), measured by three factors: Simpson index ($1-\sum_k \delta^2$; where δ is the share of *k*th plot in total farm size), number of plots and average distance to plots.

[6] The variance inflation factor (VIF) with respect to oxen and total livestock units are 3.81 and 3.73.

[3] According to Amemiya (1985), censoring is when the dependent variable takes a limiting value.

[4] Another way is to include in the CLAD regression a dummy variable for adoption of modern variety in addition to predicted IMR form the probit regression (where IMR is ϕ/Φ if modern variety is cultivated and $-\phi/(1-\Phi)$ otherwise; ϕ and Φ are the probability density and cumulative distribution functions, respectively) (Barnow et al. 1981).

[5] Estimation of diversity within sorghum, pearl millet and finger millet could not be done, as the values of the diversity indices were either mostly zeros (since households cultivated only one variety each of these cereals) or information on specific varieties were not obtained.

[6] Results of the first-stage probit regressions of whether or not households cultivated barley, maize, wheat, or teff, and whether or not households cultivated a modern variety of maize or wheat are shown in the Appendix.