Determinants of Cereal Diversity in Communities and on Household Farms of the Northern Ethiopian Highlands

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Abstract

On farm conservation of crop diversity poses obvious policy challenges in terms of the design of appropriate incentive mechanisms and possible trade-offs between conservation and productivity. This paper compares factors explaining the inter-specific diversity (diversity among species) and infra-specific diversity (diversity among varieties within a species) of cereal crops grown in communities and on individual farms in the northern Ethiopian highlands.

Using named varieties and ecological indices of spatial diversity (richness, evenness, and inverse dominance), we find that a combination of factors related to the agro-ecology of a community, its access to markets, and the characteristics of its households and farms significantly affect both the inter- and infra-specific diversity of cereal crops. Factors that explain variation among communities in either the inter- or the infra-specific diversity of cereal crops differ markedly between Amhara and Tigray, underscoring the location-specific nature of any policies designed to support conservation. Policies appear neutral to the type of diversity maintained. That is, there are no apparent trade-offs between policies seeking to enhance the richness or the equitability among cereal crops or within any single crop grown in communities. Trade-offs may occur among crops, however. Policies that shape the access of communities and individual households to critical production assets such as land, labor, oxen and livestock will have significant implications for both the inter- and infra-specific diversity among the cereal crops they grow, differentially among crops. Education is usually positively related to both inter- and infra-specific diversity. As adult male labor is drawn out of farm production into non-farm activities, the diversity among cereal crops will decline, though households headed by women or with more adult women appear to have higher levels of infra-specific diversity. Growing modern varieties has no apparent effect on diversity of maize and wheat, supporting the conclusion that in the northern Ethiopian highlands there may be no trade-off between seeking to enhance productivity through the use of modern varieties and the spatial diversity among named varieties of these cereal crops. 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. Landlessness and farm physical factors have differential impacts at the community and household levels. The role of markets in introducing or reducing cereal crop diversity is revealed to be ambiguous when we examine different geographical scales of analysis and inter- vs. infra-specific dimensions.

If agrobiodiversity conservation is to be seriously considered as a policy option in these communities, applied economics researchers will need to 1) establish the relationship of cereal diversity conservation to private and social welfare, and 2) articulate the relationship between the names of varieties managed by farmers and infra-specific, genetic diversity measured through agro-morphological or molecular analysis. Methodological advance may be required to relate policies to diversity outcomes measured at various geographical scales or levels of aggregation in the same farming system. Specific issues for further social science research include the relationship of seed management practices, seed markets, tenure and soil conservation practices to diversity conservation, and the possible application of bio-economic models to the analysis of species and genetic diversity interactions with farming systems. For policy purposes, it will be important to better understand the particular institutional and social elements that cause communities to behave differently in terms of conservation than the individual household farms of which they are composed, and for some communities to conserve more than others.

Key Words:

JEL: Q2, Q12, O0, O13

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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 and crop varieties for the food and fodder they use. In culturally autonomous, cohesive communities, this diversity is also respected in culinary and other traditions.

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 genebanks has re-emerged as a scientific question in recent years (Maxted *et al*. 1997; Brush 2000; Bretting and Duvick 1997). 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. The diversity of crops maintained on farms[1] has both inter-specific and infra-specific components. Inter-specific diversity is the diversity among crop species, while infra-specific diversity is the repertoire of varieties of a crop that farmers grow simultaneously (Bellon 1996).

Crop diversity can also be viewed at different geographical scales or levels of analysis. Variation manifests itself both among the crops and varieties grown by individual farm families and at a community level (Almekinders and Struik 2000). Seed has both private and public attributes (Smale *et al*. 2001), and for cross-pollinating species especially, the structure of genetic variation may most closely reflect the combined practices of farmers in a community rather than that of any single household farm (Berthaud *et al*. 2002; vom Brocke 2002). The combination of private seed choices made by individual farmers each cropping season generates the spatial distribution of distinct types and genetic diversity across the community and higher levels of aggregation. A community is the smallest social unit that has the capacity to govern the utilization and conservation of genetic resources. Since genetic diversity is a public good, and in locations where it is clearly a "good" or a positive (as

[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).

opposed to negative) externality, the community would be the focus of any policy incentives designed to bring private objectives more in line with social objectives.

On farm conservation of crop diversity poses obvious policy challenges in the design of appropriate incentive mechanisms and in terms of possible trade-offs between conservation and productivity or other social objectives. Progress has also been hampered both by ideological debates that are based on limited information, and by the high cost involved in assembling the sort of large-scale scientific databases that would be necessary to improve the quality of that information. Furthermore, biological diversity has many components that are interrelated within a continually evolving agro-ecosystem, and analyzing causal relationships in any component over a brief time horizon obviously leads to partial, static conclusions.

This paper identifies and compares the determinants of inter- and infra-specific diversity in major cereals in communities and on household farms of the highlands of northern Ethiopia, including modern varieties. The analysis is motivated by the theory of the household farm applied to crop and variety choice, which is the approach previously employed in the applied economics literature on this subject.

In detailed case studies conducted in Peru (potato), Turkey (wheat), and Mexico (maize), applied economists have focused so far on identifying the factors that positively and negatively affect the prospects that infra-specific diversity is maintained on farms and characterizing those farmers most likely to continue conserving it (Brush *et al*. 1992; Meng 1997; Van Dusen 2000; Smale *et al*. 2001). As a tool for targeting conservation efforts, Meng (1997) profiled those farmers most likely to continue growing wheat landraces. Van Dusen explored both inter-specific and infra-specific diversity in the Mexican *milpa* system. None of these studies sought to identify the determinants of variation in infra- or inter-specific diversity among communities. Aguirre Gómez *et al*. (2000) compared levels of diversity indices constructed for maize types (mostly maize landraces) grown in regions of southeast Guanajuato, but not in the context of economic theory. Smale *et al*. (2002) analyzed the variation in diversity indices constructed at the district or province level for modern wheat varieties grown in Australia and China, at a higher level of aggregation defined administratively but not in terms of social units. Neither addressed the relationship of modern varieties to infra-specific diversity when both modern and landrace types are cultivated, since each case represented a "corner" situation where only either one or the other (but not both) were found. Though modern varieties have long been equated with a loss of infra-specific diversity (Frankel 1970), like any new or exotic type that is introduced, a modern variety can add to the set of distinct agro-morphological types grown in a community precisely because it has been bred with the ideal type of other farmer-breeders or professional breeders in mind (vom Brocke 2002; Bellon and Risopoulos 2001; Louette *et al*. 1997).

It is hoped that this paper and related analyses will contribute to advancing the economics methods used to analyze the prospects for on farm conservation, where evidence demonstrates that the expected social benefit-cost ratio of on farm conservation is high. The relationship between the diversity maintained by individual household farms and the diversity maintained from the perspective of the community as a whole will be essential for the design of policy instruments. A factor may not be relevant for policy if it contributes significantly to diversity on individual farms but has no importance at the community level, where efforts to conserve genetic resources would need to be undertaken. To the extent that the determinants of diversity differ among crops, policies designed to enhance the diversity in one crop may have adverse consequences for the diversity of another crop. Through the use of several diversity indices that represent different diversity concepts, we can also compare policy trade-offs among conservation objectives, such as maintaining numbers of distinct types versus the evenness in the distribution of those types. Finally, if modern varieties enhance diversity rather than detract from it, trade-offs between diversity and productivity may not be a concern.

The highlands of northern Ethiopia are a suitable empirical context for testing hypotheses about the determinants of cereal crop diversity. Ethiopia is a center of diversity for barley, wheat, faba bean and some forage crops, among others, and is often referred to as one of the eight Vavilovian gene centers of the world. In recognition of this importance, national activities to conserve genetic resources on farms and in genebanks have been undertaken systematically in Ethiopia 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 determine the extent of diversity maintained on farms. The detailed dataset employed in the analysis is ideal for analyzing differences in diversity among households because of the relatively large number of communities sampled.

The conceptual framework for the analysis is summarized next, with references to relevant literature. The diversity indices that compose the dependent variables and explanatory variables are defined in the third section. Hypotheses are developed with reference to the literature. The econometric structure and approach are then summarized. Findings are presented in the fourth section, followed by a discussion of implications in the fifth section.

2. Conceptual approach

Farmers in the Ethiopian highlands both produce and consume their cereal harvests, and they grow modern varieties of wheat, maize, and teff simultaneously with their own traditional varieties (or landraces), as well as barley, sorghum, millet, and finger millet. Our conceptual approach is based on the theory of the household farm (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). Economic models of crop biodiversity that are based on either or both of these theoretical approaches and applied with econometric analysis of survey data are found in Meng (1997), Brush *et al*. (1992), and Smale *et al*. (2001). Van Dusen (2000) developed an estimable model of household farm decision-making to analyze on farm conservation of both inter-specific and infra-specific diversity, to which the approach used here is similar.

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 (6) 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. Reduced form equations estimated econometrically take the following conceptual form, as in Van Dusen (2000):

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

The same factors are the hypothesized determinants of diversity at both the household-farm and community levels, though the measurement of the variables that represent these economic concepts, and their interpretation, differs between levels of analysis. 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 then summarized.

3. Econometric approach

3.1. Survey and sample design

The variables used in this analysis were constructed from data collected in a sample survey conducted among 198 villages (communities) and 934 households in Tigray and Amhara regions of northern Ethiopia between 1998 and 2001. A stratified random sample of 99 Peasant Associations (PAs, usually consisting of 4 or 5 villages)[2] was selected from highland areas (above 1500 m.a.s.l.) of the two regions. Strata were defined according to variables associated with moisture availability (one major factor affecting agricultural productivity), market access and population density.

In Amhara region, secondary data was used to classify the *weredas* (districts) according to access to an all-weather road, the 1994 rural population density (greater or less than 100 persons/km^2), and whether the area is drought-prone (following the definition of the Ethiopian Disaster Prevention and Preparedness Committee). Two additional strata were defined for PAs where irrigation projects are found. In each of the 10 strata, 4-5 PAs were randomly selected. From each sample PA, 2 villages were randomly selected, for a total of 98 villages. In each village, 4-5 households were randomly selected, for a total of 434 households.

In Tigray region, PAs were stratified by whether an irrigation project was present or not, and for those without irrigation, by distance to the *wereda* town (greater or less than 10

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

km.). A total of three strata were defined in Tigray, with 54 PAs randomly selected per strata. PAs closer to towns and in irrigated areas were selected with a higher sampling fraction to assure adequate representation. Four PAs in the northern part of Tigray could not be studied due to the war with Eritrea. From each of the remaining PAs, 2 villages were randomly selected, and from each village, 5 households were randomly selected. A total of 50 PAs, 100 villages, and 500 households were then surveyed.

Information collected at the PA, village and household levels includes agricultural and natural resource conditions, household composition and assets, access to markets and infrastructure, and agricultural practices (crops and varieties, area allocation, output, etc.) in 1991 and 1998/99. The data were supplemented by secondary geographic information.

3.2. Dependent variables

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

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.

Generally, the relationship between variety names and genetic variation is 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 distinct observable plant types rather than the genes themselves, and they observe them in the presence of environmental interactions. The more sophisticated the scalar index that represents diversity in terms of measurement and mathematical construction, the farther removed it is from the unit over which the farmer makes a choice and, therefore, the more indirect the relationship between the index and the factors that explain the choice. To the extent that genetic structure is determined at the community level, names that are reported at that level are likely to coincide with genetic distinctions.

Many indices are available to represent diversity based on crop and variety units. The three indices used here are adapted from ecological indices of spatial diversity in species (Magurran 1988) to represent either inter- or infra-specific diversity (Table 1). Each represents a unique diversity concept. Richness, or the number of species or varieties encountered, is measured by a Margalef index at the household level or a count at the community level. Relative abundance, or the distribution of individuals associated with each of the species or varieties, is represented by the Berger-Parker index (Berger and Parker 1970). An index that combines both richness and relative abundance concepts is the Shannon index.[4] 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 sometimes an evenness index, it embodies no particular assumptions about the shape of the underlying distribution in species abundance.

The proportion of crop area planted to a variety (or area share) is used as a proxy for the number of individual plants encountered in a physical unit of area. Though area shares are not distributed spatially in the same way as plants (since they combine plants of the same crop or variety from several different locations on a farm or in a community), using area

[3] Named varieties can subsequently be related to the structure of genetic diversity in the community that is identified through agro-morphological or molecular analysis of seed samples grown under controlled conditions. Such work is outside the budget or timeframe of this study but could be contemplated for further research.

[4] Magurran (1988) reported that Shannon and Wiener independently derived the function that is most well known as the Shannon index.

shares emphasizes the choice variable that is central to economic analysis. Summary statistics for cereal crop and variety diversity indices are shown in Table 2.

3.3. Independent variables

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 relationship with the diversity indices at either the community or the household level. Hypothesized effects on the biodiversity of cereal crops are discussed next, in terms of *community and regional characteristics* (those that are fixed to households but vary among communities and regions),[5] *household characteristics*, and *farm physical characteristics*. While similar conceptual factors are the hypothesized predictors of the cereal diversity maintained by either communities or household farms, the variables that represent these economic concepts, their interpretation, and the way they are measured differ. Definitions, hypothesis and summary statistics for explanatory variables are presented in Tables 3 and 4.

3.3.1. Regional and community characteristics

Case studies have consistently identified two major generic or conceptual factors that characterize regions and predict variation in the levels of crop diversity maintained by communities and households located within their boundaries. The measurement of the factor and the direction of the hypothesized effect depend on the empirical context. The first concerns agro-ecological conditions (soils, elevation and climate). Several studies conducted in the Peruvian Andes, Turkey, and Mexico demonstrated a positive relation between marginal growing conditions for the crop and the choice to continue growing landraces (Brush 1995). However, a regional analysis by Aguirre Gómez *et al*. (2000) did not support the hypothesis that households farming in environments with lower productivity potential cultivated more diverse maize landraces.

The relationship of environmental heterogeneity to crop infra-specific diversity has perhaps a stronger basis in the genetics and ecology literature than does the relative

[5] With respect to the community level analysis, household and farm physical factors represent aggregate characteristics of households and their farms within study communities.

marginality of the production environment. According to Marshall and Brown (1975), the most important ecological factor in deciding sample size for collection is the degree of environmental heterogeneity for such variables as soil type, aspect, slope, moisture regime and associated flora. Thus, the more heterogeneous the conditions in which farms cultivate the crop, the higher the expected levels of infra-specific diversity. Van Dusen (2000) also found that across a series of villages with differing agro-climatic conditions, heterogeneity in agro-ecological conditions increased not only the infra-specific but also inter-specific diversity in the *milpa* system (maize, beans, squash) of the state of Puebla, Mexico.

The second generic factor that operates at a regional or community scale and is hypothesized to explain variation in levels of crop inter- and infra-specific diversity is opportunities for trade on markets. This factor operates in several ways that may not be dissociable in a given geographical setting at one point in time. For example, the more removed a 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. Applying the micro-economic 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.

Invoking the Lancaster theory that consumers choose levels of attributes provided by bundles of goods rather than the goods themselves provides one explanation for the differences in these results. 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. Smale *et al*. (2001) found that variety attributes such as suitability for food preparation (tortillas) far outweighed the importance of household characteristics in explaining the number of maize landraces grown by individual farmers and the average share of maize area planted to each. 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). With cross-pollinating species, farmer seed management or deliberate introgression may mean that the introduction of modern varieties generates new types that are attractive to farmers (Berthaud *et al*. 2002; Vom Brocke 2002; Bellon and Risopoulos 2001).

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. In Turkey, concern for bread quality in wheat, in addition to high household transaction costs such as transportation and uncertain prices, were associated with the choice to grow landraces rather than modern varieties (Brush and Meng 1998). Recently, however, Dyer (2002) has challenged the assumption that the opportunity costs of growing landraces rises with development and market integration, based on the case of the North American Free Trade Agreement (NAFTA) and Mexican maize in the state of Puebla. Less access to market infrastructure could also imply reduced access to distinct landrace seed types found in other communities. 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).

A third factor, the ratio of labor to land, 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, though it is not clear that in such environments as the highlands of Ethiopia, their introduction diminishes crop biodiversity. Nor is it clear whether the use of modern varieties has resulted from market demand or subsidized promotion, as demonstrated in the recent maize crisis. Intensification may also occur in terms of larger numbers of farm production activities undertaken, including more cereal crops.

A fourth regional factor in this analysis is a dummy variable representing the administrative region in which peasant associations are located (Tigray or Amhara). Though they represent two distinct regions with respect to farming systems, cultures, and physical endowments, they have been combined in some of the estimations in order to increase the degrees of freedom for the statistical analysis. 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).

About 85% of the population in both Tigray and Amhara depends on subsistence mixed crop-livestock agriculture, where cereal crop production dominates. In Tigray, cereals cover an estimated 84% of cultivated land. Practices of cultivating and grazing on steep slopes are widespread in both regions. Perennial crop production is limited in both regions, though farmers in the Amhara highlands engage in some. Oxen power supplies the only draft power for plowing and threshing in both regions.

Community analysis. Regional factors are represented in the community analysis by the range in altitude, mean rainfall levels, road and market access, and population density. The range in altitude is expected to contribute positively to the numbers of cereal crops and varieties grown. A reliable indicator of rainfall variability in the communities was not available. Mean rainfall levels might contribute either positively or negatively to either aspect of cereal diversity. As argued above, access to infrastructure and population density variables may have ambiguous relationships to inter- and infra-specific diversity.

Household-farm analysis. Market access is measured by the extent to which communities trade their crop on markets, captured by the distance from the peasant association to the district town. The hypothesized effect of this variable is ambiguous. The ratio of labor to land or population density may have either a positive or negative effect on either inter- or infra-specific diversity. A dummy variable is included to capture the effects of regional fixed factors for Tigray, as compared to Amhara. In the household farm analysis, agro-ecological conditions are measured at the scale of the household, as farm physical characteristics.

3.3.2. Farm physical characteristics

Community analysis. Farm physical characteristics represented at the community level include the quality of land in the peasant association and agricultural practices related to soil fertility. Land quality is measured in terms of the extent of erosion and the extent of land with soils classified by community members as "good."[6] The proportion of land that is eroded is hypothesized to be positively associated with the effort by community's farmers to diversify

[6] Classification of cultivated land into categories of "good", "medium" and "poor" quality soils is common and relatively well accepted throughout northern Ethiopia, because such categories were used in the frequent land redistributions that took place during the Derg period. During redistributions, eligible households were generally provided land from each category, to ensure an equitable distribution.

their cereal crops. When more land is of better quality, farmers may specialize in production of fewer cereals or varieties with higher net returns to their efforts.

Household-farm analysis. When markets are perfect and farm production decisions are therefore made separately from household consumption decisions, theory predicts that only the farm physical characteristics and regional factors that are parameters of the production technology will affect cereal crop diversity.

Irrigation, which can affect agricultural potential by improving moisture availability, generally is believed to enable specialization by making the production process more uniform. Having some land (but not all) in irrigated plots may increase the incidence (but not necessarily the dominance) of improved crop varieties, whose yield response is greater to chemical fertilizers, especially under controlled moisture conditions. In general, greater heterogeneity in farm conditions will tend to increase diversity.

Ethno-botanical research has suggested that farmers choose varieties based on the varieties' adaptation to soils and other environmental factors (Zimmerer and Douches 1991). Thus, greater heterogeneity in the conditions in which farms cultivate the crop imply higher expected levels of infra-specific diversity. Bellon and Taylor (1993) explained the partial adoption of modern maize types in Chiapas (a farmer's choice to grow both modern types and maize landraces at the same time) through differential variety response to soil quality on farms. To the extent that the performance of crops and varieties is specific to soil types, a farm with heterogeneous types (in terms of fertility, erosion, and slope) would display a greater mix of crops and varieties in which no single entity tends to dominate.

Greater numbers of plots and farm fragmentation have also been associated with crop and variety specificity. In rice production in the uplands of Nepal (Rana *et al*. 2000), in maize production in Mexico (Bellon and Brush 1994; Van Dusen 2000), these variables have been positively related to infra-specific diversity. Farmers may seek temporal smoothing in crop and variety requirements through growing combinations with different planting, weeding and harvesting dates. Brush (1995) reported that land fragmentation promoted conservation by enabling farmers to conserve landraces in one plot, while planting modern varieties in the majority of cultivated area. Larger cultivated areas both enable more crops and varieties to be produced but also require more labor to produce them. Greater distance from the household to the farm clearly implies more labor time to accomplish the same set of tasks.

3.3.3. Household characteristics

Community analysis. The relationship of household characteristics such as asset ownership to the infra-specific diversity or crops appears to depend on the empirical context and how the variables are measured. In the community analysis, characteristics of interest are those that vary among communities in the highlands of northern Ethiopia. Oxen are one critical capital asset whose level varies among communities in the highlands of northern Ethiopia. On one hand, a larger proportion of households owning oxen is expected to enhance diversity since oxen power supplies the only draft power for cultivation and threshing, increasing the capacity of farmers to grow more crops. Having more draught power may enables farmers to prepare land on time and plant more complex combinations of crops and varieties. On the other, a larger proportion of households owning oxen may be associated with greater specialization in one cereal crop or another. Farmers with more draught power (oxen) are able to engage in more intensive farming practices, such as cultivation of teff that requires multiple, timely plowing of the plot prior to sowing. Those with less oxen may engage in less intensive farming practices, such as maize production.

Land is the other critical asset among the communities studied. Knowing the soil characteristics of their land enables farmers to better match varieties and crops to specific niches where each performs best. The higher the proportion of landless, the less likely there are to be diverse combinations of cereals and crops. Literacy has been used as a proxy for education and human capital in study communities. The effect of greater literacy in communities on the diversity of the cereals they grow is ambiguous, since access to information may lead either to specialization or to diversification. By raising the opportunity cost of farm labor, education may lead people from farm production, reducing the time available for labor-intensive and diverse cropping activities.

The higher the proportion of households using formal credit in a community, the greater their access to new crops or varieties that complement those already grown, increasing their numbers and the evenness of their distribution across farms. On the other hand, credit programs have in the past been associated with a certain "lumpiness" or fixity in the type and amounts of modern seed extended through promotional campaigns. These factors may lead to reduced numbers of varieties and less evenness in their distribution, depending on the size of the package relative to the amounts that farmers would find optimal. If the packages are small, for example, they might enhance rather than detract from infra-specific diversity.

Household-farm analysis. When farm production decisions are affected by consumption choices, theory suggests that household characteristics will also affect cereal crop diversity both through preferences and the household-specific costs of market transactions, as well as through labor stocks and opportunity costs.

In addition to education, the age and gender composition of households can affect preferences, and are related to human capital. Age may have a positive or negative effect on the complexity of cereal production. While experience and knowledge of traditional varieties may lead to a positive association of infra-specific diversity with farmer age, to the extent that more diversity implies greater time commitments we would expect it to decline with the life-cycle stage of the farm household. If younger farmers are more likely to experiment with new crops or varieties and these add new traits to the set they grow, then age could also be negatively associated with diversity.[7] Sex of household head and the gender composition of the household (proportion of males) are also thought to affect variety choices either indirectly, through the effects of wealth and access to inputs, or directly, through variety preferences for consumption attributes, or both. Women are custodians of seed for some crops, which may be positively related to variety diversity.

[7] Though a quadratic relationship was expected (Van Dusen, 2000), including the square of age as an explanatory variable introduced multicollinearity (the variance inflation factors were more than 20 for age or its square), and it was dropped from the final regression. A variance inflation factor greater than 10 indicates collinearity problems (Kennedy, 1985).

Households with more labor will be able to engage in a more complex set of activities, but families with larger sizes may also have higher dependency ratios. Van Dusen (2000) found no significant effect of the pool of family labor on the infra- or inter-specific diversity of the Mexican *milpa* (maize, beans, squash) system. More varieties of a crop may require more time in selecting, storing and managing the seed. On the other hand, planting varieties and crops that mature at different points in time is a way of coping with seasonal labor shortages.

Wealth affects both preferences and household-specific transactions costs. In three sites in Nepal, based on a composite variable for wealth rank, Rana *et al*. (2000) found that poor households cultivate more coarse-grained, drought-tolerant varieties of rice, while wealthier households grew high-quality varieties for premium market prices and special food preparations. In the state of Puebla, Mexico, Van Dusen (2000) found that 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 maize, beans, and squash varieties. In the state of Chiapas, Mexico, Bellon and Brush (1994) found more maize diversity among poorer households. Livestock wealth may facilitate specialization in fewer activities and ensure against crop production risk; on the other hand, livestock also generates income to enable farmers to engage in more diverse crop production activities. We would expect both oxen ownership and total livestock holdings (including oxen, measured in tropical livestock units)[8] to have mixed effects on the cereal crop diversity maintained by household farms.

Previous empirical studies are also inconclusive about the effect of income on the crop diversity maintained on household farms. Brush *et al*. (1992) found that off-farm employment was negatively associated with maintenance of potato diversity in the Andes, and Van Dusen found that overall diversity in the *milpa* system decreased as local labor markets develop and as more migration to the U.S. occurred, though these effects were not as pronounced when each crop was considered singly. Off-farm income can also release the cash income constraint faced by some farmers, enabling them to shift their focus from growing varieties for sale to growing the varieties they may prefer to consume; the converse

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

is also true, since off-farm income may enable them to specialize in the most profitable crops and varieties. In Chiapas, Mexico, Bellon and Taylor (1993) found that off-farm employment was associated with higher levels of maize diversity. Meng (1997) found the existence of off-farm labor opportunities to have no statistically significant effect on the likelihood of growing wheat landraces in Turkey.

In the highlands of northern Ethiopia, labor migration is not a major source of income. For this reason and because decisions about labor are also made concurrently with decisions about labor allocation in the household, we have not included this variable. Exogenous income of the household has been included, and is measured as the sum of (the value of) remittances, food aid, gifts, and pension. Exogenous income can be used to hire labor and purchase other inputs (e.g., improved seed) to increase the capacity to engage in more diverse crop production activities, thereby increasing crop biodiversity. It may also signal that the household allocates more labor to non-farm activities, specializing in fewer activities on the farm.

The distance of the household farm to the nearest road, which is a major component of the cost of engaging in market transactions related to seed, labor, other inputs, and farm produce, is also hypothesized to affect crop diversity. To capture variation among households within communities, this variable has been measured as the average walking time to the nearest all weather road[9], with a hypothesized effect on inter- and infra-species diversity that is either positive or negative in sign, similar to the hypothesized effect at the community level.

3.4. Regression structure

The simplified, general structure of the regression equations to be estimated is given by

$$(8)\ D_i = a_i + b_i x + c_i z + e_i\ .$$

D represents the count or Margalef index of richness, the Shannon index of evenness, or the Berger-Parker index of inverse dominance (Table 1), *x* is a vector of explanatory variables, *z*

[9] Walking is by far the most common means of transportation to roads and market in northern Ethiopia.

represents adoption of improved varieties, *e* is unobserved factors; and *a*, *b* and *c* are the parameters to be estimated. Due to differences in the nature of the data at the community and household-farm levels, different econometric methods were employed in estimating the equations. At the community level, the count, Shannon and Berger-Parker indices were estimated, while at the household-farm level, the Margalef, Shannon and Berger-Parker indices were estimated.[10]

At the community level, Poisson regression models were estimated for inter-specific (crop) and infra-specific (variety) counts of richness across the seven cereals (barley, wheat, sorghum, finger millet, pear millet, maize and teff), assigning zero values to villages that do not grow a particular crop. Poisson regression models are appropriate for count data that take on non-negative integer values and where the outcome is zero for at least some members of the population (Wooldridge 2002). The Poisson model assumes equality between the conditional mean and variance. To check for over or under-dispersion, the estimated Poisson model was tested against the Negative Binomial regression models, resulting in failure to reject the Poisson model. Since all villages grow more than one cereal, the inter-specific Shannon and Berger-Parker diversity indices were computed for all villages at values greater than the lower limit (0 and 1, respectively), and regressions run with Ordinary Least Squares (OLS).

Several estimation problems were encountered in estimating the equations with respect to the infra-specific Shannon and Berger-Parker diversity indices at the community level and all the diversity indices (both inter- and infra-specific) at the household-farm level. First, when a community or household does not cultivate a cereal, a sample selection problem occurs in the variety diversity index for that cereal. Second, even when the cereal is cultivated, if a large proportion of the sample grow only one variety, the diversity index is censored because many of its values cluster at the limit (i.e., 0 for Margalef and Shannon indices and 1 for the Berger-Parker index).[11] A standard ordinary least squares (OLS) or seemingly unrelated regression (SUR) of the diversity indices will yield biased and

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[10] The Margalef index of richness used in the household analysis could not be constructed at the community level because, though proportions of area allocated to crop and variety were reported, total area was not.

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

inconsistent estimates in this situation. In principle, a maximum likelihood approach may be employed to address the censoring (e.g., tobit model) and account for correlations in error terms across equations by specifying a multivariate density function for the error terms. This approach is difficult to implement with more than two equations. Consequently, though a systems approach was originally envisaged, we have estimated single regression equations.

The general approach most often used to address selectivity bias is to employ a technique similar to Heckman's. The probability that the cereal is grown and inverse mills ratio (IMR) are predicted in the first stage, and the IMR is then used to estimate a second-stage censored regression. However, since the second stage is a censored regression, the IMR correction introduces heteroskedasticity (Maddala 1983). The errors in the predicted IMR depend on values of the explanatory variables, which, unlike in a linear model, causes the estimator to be inconsistent (Maddala and Nelson 1975; Maddala 1983). In addition, there is the problem in obtaining the correct standard errors, since the predicted rather than the actual IMR is used. Therefore, we use in the second stage the censored least absolute deviations (CLAD) estimator, which is robust to heteroskedasticity (Deaton 1997). With CLAD, bootstrapping is used to compute the standard errors. However, due to relatively small number of observations with the community level data, the CLAD regression failed to converge. An interval regression, with probability weights to correct for the standard errors, was used to estimate the infra-specific Shannon and Shannon indices at the community level.

Third, a problem with an endogenous explanatory variable also occurs in investigating the effects of choosing to grow modern varieties on infra-specific variety. Problems of this type are typically addressed through regressions with treatment effects or self-selectivity. Including as an explanatory variable a dummy variable expressing whether or not the household adopted an improved variety will give inconsistent estimates (Barnow *et al*. 1981; Greene 1983; Maddala 1983). Instead, predicted probabilities from a probit regression of whether or not an improved variety is cultivated have been included in the second-stage regression (Barnow *et al*. 1981).

As in many two-stage estimation approaches, identification of the second-stage regression is an important issue here. In general, it is difficult to find variables that are correlated with the decision to grow a cereal crop or an improved variety, but not correlated with the associated diversity index (which is constructed from area shares). At the community level, mean altitude in a village was a strong predictor of whether or not a crop was grown. At the household-farm level, altitude and walking times to the nearest grain mill, input supply shop and bus service were used as instruments.[12]

4. Results

4.1. Predicting the cereal diversity maintained by communities

Seven cereal crops (sorghum, barley, wheat, maize, teff, pearl millet and finger millet) are grown in the communities in the highlands of Tigray and Amhara. An average of 4 cereals are grown per community. Barley, maize, wheat, and teff and grown by the largest numbers of communities, as compared to sorghum, pearl and finger millet Mean numbers of varieties grown per cereal are also lower for sorghum, pearl and finger millet. The range in numbers of varieties per cereal is from three to ten (Tables 5 and 6).

4.1.1. Inter-specific diversity of cereal crops

Regression results for the determinants of inter-specific cereal diversity at the community level are shown in Table 7. Separate regressions reveal important differences in factors related to the inter-specific diversity of cereal crops between communities located in the highlands of Amhara and those found in the highlands of Tigray, though the results for Amhara are relatively weaker statistically. Aside from regional distinctions, however, the signs of statistically significant factors are consistent across indices.

Regional and community characteristics. Range in altitude generally is not significant in explaining variation among communities in the inter-specific diversity of cereals grown, except for the richness of cereals grown in Amhara. Level of rainfall has no significant effect on cereal diversity in either Tigray or Amhara. Communities in Amhara may concentrate

[12] Note that even if the explanatory variables in the first and second stage regressions are identical, because the predicted IMRs or probabilities from the first-stage regressions are non-linear functions of the explanatory variables, the second-stage regressions are identified under normality of the probit models.

more on fewer crops to take advantage of higher yield potential as well as commercial benefits, given their relative proximity to markets.

Controlling for region, however, the relationship of market access to inter-specific diversity of cereals remains ambiguous, as hypothesized. The larger the average distance of households in the community to all-weather roads, the greater the inter-specific diversity of cereals they grow, by any of the three indicators. The further the community is from the district market the less diverse the mix of cereals grown in the more remote Tigray, but the more diverse the cereals grown in Amhara. Longer distances to the all-weather road, however, are positively related to inter-specific diversity. Population density is positively associated with the richness, evenness and inverse dominance of cereals in Tigray, and is of no significance in Amhara.

Household characteristics. Education is positively associated with the diversity of cereals grown in both Tigray and Amhara, suggesting that human capital and access to information are favorable for growing a wider range of cereal crops. In both Tigray and Amhara, the greater the proportion of households owning oxen within the community, the higher the inter-specific diversity of cereals they grow. The statistical significance, positive direction of the effects, and large magnitude of the effects of human capital and assets are consistent and evident across diversity indices and regions. The higher the proportion of households with access to formal credit in the communities of Amhara, the greater the inter-specific diversity of the cereals they grow, though this same factor has a negative effect or is of no significance in Tigray. The proportion of landless households has no affect on variation in levels of cereal crop diversity among communities in either region.

Farm characteristics. While higher proportions of land in good soils have no effect on lower cereal diversity in Tigray, the proportion of land that is eroded is positively related. Neither of these factors is significant among communities in the highlands of Amhara. Soil-related factors appear more important in explaining patterns of cereal crop cultivation in the more environmentally-degraded region of Tigray than in Amhara.

4.1.2. Infra-specific diversity of cereal crops

Regressions explaining the infra-specific diversity of all cereal crops except teff are shown in Tables 8 and 9. The factors explaining variation in infra-specific diversity clearly differ from those explaining variation in inter-specific diversity, and they also differ among cereal crops. Findings for teff were not statistically significant. Though richness (variety count) regressions could be estimated for both Tigray and Amhara, inverse dominance and evenness regressions could be estimated only for Tigray, due to absence of area share information at the community level in the Amhara survey. The Berger-Parker index of inverse dominance was not statistically significant in the regression explaining sorghum diversity, while the evenness regression was not significant for finger millet.

Regional and community characteristics. A wider range in altitudes is generally positively associated with less dominance in any single variety and more evenness among wheat and maize varieties, though it is negatively associated with richness in pearl and finger millet. Pearl and finger millet are crops grown at lower altitude and farmers may diversify to other crops (as suggested by the findings for inter-specific diversity) and their varieties with increasing altitudes. Specific wheat or maize varieties may grow better in some altitude niches. Higher mean rainfall implies greater barley richness, but fewer numbers of maize and sorghum varieties.

As is the case for inter-specific diversity in cereals, market and road access have mixed impacts on patterns of variety cultivation across cereal crops. More densely populated communities grow more varieties of maize, but this factor is not related to variation in patterns of infra-specific diversity for other cereals. When controlling for other factors, communities located in Tigray grow more varieties of barley and finger millet, and fewer varieties of maize and sorghum, but there are no significant differences for wheat and pearl millet.

Household characteristics. Access to credit in communities is positively associated only with infra-specific diversity in maize. In Tigray, the higher the proportion of landless households in the community, the more diverse are its wheat varieties. Though this result appears to contradict the negative relationship of population density to wheat diversity, landlessness is higher in low population density areas perhaps due to less cultivable land (Gebremedhin *et al*. 2002). Education is positively associated with the richness of pearl millet varieties, though negatively associated with the richness of barley varieties. The greater the proportion of households that owns oxen, the more diverse their maize and finger millet varieties, but the fewer the number of barley varieties grown in the community.

Farm characteristics. In the Tigray region, communities with better quality of land grow more diverse barley, perhaps because barley is grown on relatively better soils in the region. The higher the proportion of good quality land, the lower the diversity of wheat and maize varieties. It may be that households concentrate on fewer wheat or maize varieties on good soils in order to take advantage of higher yields. Maize richness is associated negatively with both the extent of eroded land and the extent of good quality soils. Maize may be grown on soils with intermediate quality that are less eroded.

Modern varieties. Adoption of modern varieties of maize[13] is associated with greater evenness in the distribution of varieties across communities and less dominance of any single variety. This finding is consistent with the notion that in environments that are less favored with respect to either market infrastructure or productivity potential, modern varieties that are suited to some production niches can provide traits that complement (rather than substitute for) local varieties.

4.2. Predicting the cereal diversity maintained by household farms

Data consistency was sought between the household-farm and community analyses through omitting observations with missing data on relevant variables or where households reported growing a particular crop that was not recognized in the corresponding survey conducted at the community level. A total of 739 observations (households) were used for the analysis.

[13] The Inverse Mills Ratio (IMR) for growing or not growing maize was not included as the probit regression predicting maize growing was not significant. Maize was grown in 83 of the 100 villages surveyed in Tigray.

Households cultivate between one and five cereals. Roughly one-quarter cultivate a single cereal crop, and the percentage growing more than one declines rapidly as the numbers increase. Teff is cultivated by the greatest number of households, followed by barley, maize, wheat, sorghum, finger millet and pearl millet. The maximum number of varieties of any cereal cultivated by any household was three. With respect to pearl millet, however, households growing this crop cultivate only one variety. Only 52 and 46 sample households plant an improved variety of wheat and maize, respectively, while a mere 12 households plant an improved variety of teff and only a single household reported an improved variety of barley. None of the sample households plant an improved variety of sorghum, millet, or finger mille (Tables 5 and 6).

The relationship of adoption of improved varieties to infra-specific diversity was tested only for wheat and maize because the number of observations was insufficient to estimate the first-stage probit regression for other crops. Regressions were estimated to explain the inter-specific (cereal crop) diversity of the seven cereals (barley, maize, wheat, teff, sorghum, millet and finger millet). Regressions explaining infra-specific diversity were estimated for the first four of these crops because the values of the indices for sorghum, millet and finger millet were mostly zeros (for the richness and evenness indices) or ones (for the dominance index).

The value of these indices reflects the fact that individual households generally plant only one variety each of sorghum, pearl millet, and finger millet. This finding may appear surprising 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, 1991). While an individual household may grow relatively few varieties, many varieties of each crop may be found among the households in a community, however. 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. By comparison 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. Moreover, it is important to recall that 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.

4.2.1. Inter-specific diversity of cereal crops

Censored regression results for inter-specific diversity are presented in Table 10. Socio-demographic characteristics of the household such as the age and sex of the household head, the education of its members, or its size appear to bear no relationship to the numbers of cereal crops they grow, the evenness in their area shares, or specialization in any single cereal. However, endowments of land, labor and livestock are significant factors explaining variation in cereal crop diversity among households. Larger stocks of male labor in the household, larger farm size, and a greater capacity to prepare land with oxen are clearly associated with more diverse cereal combinations, as hypothesized. The coefficients on the proportion of males are also greatest in relative magnitude among those factors that are statistically significant, followed by ownership of oxen. On the other hand, the total number of livestock assets (including oxen) owned by the household is associated with less evenness in cereal crop shares, or greater specialization. In the Ethiopian highlands, livestock is a form of wealth and can ensure against crop production risk, which arises from growing a few crops.

Greater farm fragmentation and a larger number of different plots are also associated with cultivation of richer and more evenly distributed cereal combinations. Households living relatively far from their farms are associated with less cereal diversity according to any of the indices, perhaps reflecting labor constraints.

Among the community and regional characteristics, only location in Tigray influences variation in the inter-specific diversity of cereals grown by farm households, and by a relatively large magnitude. Households located in Tigray region have higher levels of cereal crop diversity according to any of the three indices. As hypothesized, the effects of population density and market access factors may be ambiguous and they are of no statistical significance in explaining the diversity of cereals grown on household farms.

4.2.2. Infra-specific diversity of cereal crops

Results of the CLAD regressions predicting the infra-specific diversity in barley, maize, wheat and teff are shown in Tables 11 and 12. Barley and teff are "old crops" to this area, while maize and (bread) wheat are relatively new.[14] Generally, the models of inverse dominance have the least statistical significance, with relatively few variables being statistically significant (none in the case of barley). This is not surprising given that the unit of observation is the household farm, and many households reported few varieties. The discussion below therefore refers to indices of richness (number of varieties grown) and evenness (area shares of varieties).

Regional and community characteristics. Findings for the effects of community and regional characteristics on the infra-specific diversity of cereals grown by households are ambiguous, as expected. Households far away from an all weather road have greater diversity in barley and maize, but lower diversity in teff—a cash crop. However, households in communities located farther away from the district town have less diversity in maize. More densely populated communities have greater diversity in maize and wheat, but less in teff. More densely populated communities are likely to have higher food and feed demands and so farmers will choose higher yielding and more biomass-producing crops such as maize and wheat over teff. Location in Tigray region is associated with greater diversity in teff, but lower diversity in maize and barley, probably because teff is more adaptable to conditions under which many other crops fail to grow (Worede, 1988). Compared to the Amhara region, Tigray is of lower agricultural potential, characterized by less and more variable rainfall.

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

Household characteristics. While socio-demographic or human capital variables are of no significance in determining the diversity of cereal crops (inter-specific diversity) managed by households, they do matter for the diversity among varieties within these crops. Younger farmers and households with more educated members are more likely to grow more diverse wheat, maize or teff. 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 with younger heads may have more labor time to manage teff. Households headed by women grew more diverse wheat. Those with a higher proportion of women grew more diverse wheat, barley and maize varieties—and the magnitudes of these effects are relatively large.

Households with a larger stock of labor in general are associated with greater diversity in maize, probably due to the greater labor demand associated with growing the crop, applying fertilizer and harvesting. As predicted, livestock assets and access to oxen have mixed impacts on variety diversity, depending on the cereal crop. The size of the effects of these variables is often large. Households with more livestock have greater diversity in barley and wheat, but lower diversity in teff. On the contrary, households with more oxen have greater diversity in teff, but lower diversity in barley and wheat. Perhaps households with more livestock holdings are concerned more about 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 greater exogenous income have more diverse barley, but less diverse maize. Households with more exogenous income are also more likely to have older members and more dependents, and therefore are less likely to engage in more labor-intensive activities associated with growing maize (especially for applying fertilizer and harvesting).

Farm characteristics. As was the case for inter-specific diversity, larger farms have greater infra-specific diversity in all cereal crops. Farms with more flat land have greater maize diversity, but lower diversity in barley and teff. Fertilizer is used more often on maize than barley or teff. Hence, applying fertilizer on flatter plots reduces losses from run-off during the rain, and other crops may then be planted on sloped plots. The finding that farms with more evenly distributed soil fertility grow more maize varieties is consistent with this explanation. Evenness in the extent of soil erosion on the farm implies greater diversity in maize and teff. The greater the proportion of the farm that is irrigated, the greater the specialization in maize types, though the opposite is true for wheat and teff. The relationships between farm fragmentation or number of plots and variety diversity are mixed and not always statistically significant. The effects of slope, erosion, fertility, irrigation and farm size on the infra-specific diversity of maize are large in magnitude.

Modern varieties. Adoption of improved varieties of maize and wheat had no statistically significant impact on the diversity in the maize and wheat varieties grown on household farms.

Sample selection. The inverse mills ratio (IMR) was associated with lower diversity in barley, maize, and teff, suggesting that correcting for sample selection is important. This means that using only the observations on households that cultivated barley, maize, or teff in a tobit model, without the correction, would have yielded inconsistent estimates. The IMR for wheat, on the other hand, had a statistically insignificant coefficient.

5. Policy implications

5.1. Scale of policy or program

In the highlands of both Amhara and Tigray, as hypothesized, a combination of agro-ecological variables, market access factors, and the characteristics of the households and farms predicts variation in the inter-specific and infra-specific diversity of cereal crops grown by communities. Factors that are significant in explaining the variation in inter-specific and infra-specific diversity of cereal crops among communities differ markedly between the highlands of Amhara and those of Tigray. Regional effects remain significant in explaining variation in the infra-specific diversity of cereals grown by households even when other household and community characteristics are considered.

These findings reveal the location-specific nature of any policies or programs that are designed to encourage the maintenance of diversity, and the dangers of drawing generalizations from any single case study. They also suggest that the cost is high of assembling the information required to design programs for local conservation of crop diversity.

5.2. Trade-offs between richness and equitability of cereal crops and varieties

The direction of the effect of statistically significant factors is the same for indices of richness, evenness and inverse dominance among cereals. Results therefore suggest indicate that a policy whose goal is to augment the richness of cereals grown would not entail trade-offs in terms of "equitability" or dominance among crops. No trade-offs appear in the household-farm analyses between policies that would enhance one type of inter-specific diversity as compared to another.

The same appears to be true for the infra-specific diversity of any given cereal crop grown by communities. 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.

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. Policies designed to encourage infra-specific diversity in one cereal crop might have the opposite effect on that of another crop. Conserving the richness or equitability among varieties of one cereal crop might lead to less richness or equitability among those of another.

These findings indicate the "partial" nature of most empirical research conducted so far concerning the on farm conservation of crop genetic resources. Crop genetic resources evolve within a farming system and agro-ecosystem. Other tools must be brought to bear on analyses if system interrelationships involved in agro-biodiversity conservation are to be *adequately understood. For example, in these communities, the relationship between animal husbandry and cereal diversity is evident.*

5.3. Trade-offs in conserving inter-specific vs. infra-specific diversity of cereal crops

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. Owning more oxen is generally associated with more diversity among cereals in communities and on individual farms, but less diversity among barley and wheat varieties, and more among varieties of teff. Similarly, farm physical characteristics, agro-ecological conditions, and market access are related in various ways to both inter-specific diversity and infra-specific diversity of cereals. Therefore, the incidence of related policies would be differential and difficult to predict.

While the social and demographic characteristics of the household do not matter for inter-specific diversity of cereal crops they grow, these factors do explain variation in infra-specific diversity, although the direction of effects is not the same for all cereals. As fixed labor stocks of adult male labor are drawn out of farm production for non-farm activities, 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. More educated households also maintain more variety diversity, as more literate communities maintain a greater richness of cereals. 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. Educational campaigns, and recognizing the possible importance of women in variety choice and seed management, as well as educational campaigns, are also relevant.

These findings illustrate that programs designed to influence the infra-specific diversity of cereal crops are not likely to be neutral to their inter-specific diversity, and vice versa. The exception among the factors considered here is education, which has a generally positive impact on inter-specific and infra-specific crop diversity in the study regions. In *general, focusing on women in activities related to the conservation of infra-specific diversity in these communities also seems justified.*

5.4. Trade-offs in targeting communities or households within communities

Policies that serve to build assets will also enhance more cereal crop diversity maintained by the study communities, but will raise equity issues. The wealth of a community, particularly its ownership of oxen, is positively associated with the ability to produce a wider range of cereals because it enables households in communities to handle more complex crop combinations. The effect of oxen ownership is large in size in both community and household-farm analyses and holds for both Tigray and Amhara, regardless of the diversity index. Within communities, households that are richer in land, labor, and oxen are those who maintain more diverse cereal crop combinations. Inter-specific diversity in cereal crops implies heavy investments of assets and management complexity over time and space.

Policies that address physical factors of erosion and fertility matter for the inter-specific diversity maintained by communities in Tigray, but similar factors are unlikely to have implications for inter-specific diversity on individual farms in either region. Slope, erosion, fertility and irrigation are of significance in explaining the variety diversity within cereal crops grown by households, sometimes in positive and sometimes in negative ways.

Tenure does not appear to be important when comparing the inter-specific diversity of cereals among communities, though within these same communities, the degree of land fragmentation and number of plots, which are related to tenure, do explain variation among households. Households with bigger farms not only grow more cereals but they have more variety diversity in each cereal crop. Generally, use of more plots, and more even distribution of landholdings, are negatively related to infra-specific diversity and positively related to inter-specific diversity of cereal crops.

The agro-ecological, population density, and market infrastructure characteristics of the community have effects on inter-specific diversity that vary in significance among indices and between regions, but are generally of smaller magnitude than the impacts of characteristics of the households and farms in the communities. Understanding the distribution of human and physical assets in a community is therefore fundamental to the design of programs to conserve inter-specific diversity of cereal crops. On the other hand, the only community or regional factor that explains differences in inter-specific diversity of cereal crops grown by households within communities is location in Amhara or Tigray. Population density is associated with demands for more varieties of the new crops (maize and wheat) that have higher yield and more biomass. Market access relates significantly to the diversity of maize varieties grown on household farms.

These findings demonstrate the problems associated with designing programs and policies when their incidence will differ across geographical scales of analysis. More research is necessary to understand why the behavior of communities as a whole differs from the behavior of the household farms that compose them with respect to managing crop diversity. Tools of social analysis may prove useful in this regard.

5.5. Development and diversity

Adoption of modern varieties is associated with more diversity among maize varieties, and bears no relationship to the infra-specific diversity maintained by individual household farms. In the northern Ethiopian highlands there appears to be no 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. 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 improved 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 are particularly favorable for specialized, commercial agriculture. This is not to say that the improved varieties introduced in such areas are themselves genetically diverse, but that the traits they add to those of the other varieties grown, enabling farmers to better meet their production and consumption objectives in this difficult and uncertain growing and marketing situation.

In communities of the northern Ethiopian highlands, there seems to be little trade-off at present between the needs of development and maintaining complex combinations of crops and varieties. On the contrary, access to credit and oxen, stability of tenure and education are more likely to have positive than negative relationships with cereal crop diversity. Use of formal credit, like exogenous income in the household analysis, is in general positively related to the infra- and inter-specific diversity of cereals. Currently, in this resource-poor system, modern varieties appear to contribute to rather than threaten wheat and maize diversity. Market infrastructure often appears to have a positive effect on diversity of cereals as well as varieties, though there is apparent ambiguity in the relationship as communities and their households are integrated into markets.

Population density in the community was of no significance in explaining variation in the inter-specific diversity of cereals grown by households, but it is associated with demands for more varieties of the new crops (maize and wheat) that have higher yield and more biomass. Though the market access of the community bore no importance for the inter-specific diversity, it does relate significantly to the diversity of maize varieties grown on household farms.

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.

5.3. Future research

This study has demonstrated that the incidence of explanatory factors differs between cereal diversity maintained by individual households and by the community they compose. Previous empirical applications of economic models in the analysis of prospects for on farm conservation have focused on the household and farm, although the findings presented here reveals that some factors identified as significant for explaining variation in diversity levels among households have no significance for communities. Communities, however, are likely to be smallest social unit for which crop biodiversity programs and policies are designed. This is because crop genetic resources managed by farmers as goods with both private attributes (the physical unit of seed) and public attributes (genetic diversity within and among units of seed). Though some farmers contribute more to the diversity in a reference region than others and may be targeted within communities for specific programs (such as farmer plant breeding and innovation), it is maintaining or expanding the breadth of the pool of genetic resources within a farming, social and economic system that is of policy interest. 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, remains poorly understood.

So far, much of the empirical research about conserving the diversity of cultivated plants on farms has also focused on a single crop species. 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. Measurement problems are inherent in empirical research on this subject. Here, the linkage between named varieties and infra-specific diversity must be more fully articulated in order to better understand the policy implications of the analysis. Other specific issues merit particularly research attention. For example, additional economics research on the relationships of seed systems, tenure, and soil conservation practices to crop diversity would provide insights.

Finally, 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 in these communities, those who are better off in land, labor, and livestock tend to maintain more crops and more varieties. Wealthier communities in the regions of study also maintain more, and it may not make sense to focus on poorer households within these 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. Description of dependent variables used in analysis of cereal diversity in communities and on household farms in the highlands of Amhara and Tigray regions, Ethiopia

Index	Concept	Construction	Explanation
Count	Richness	D=n or m	S = Number of cereal crops or crop varieties grown in community in 1999; n is the number of varieties and m is the number of crops
Margalef	Richness	$D=(S-1)/\ln A_i$ $D \geq 0$	A_i = total area planted to cereal crop or crop variety by household in 1999
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 ith cereal crop or crop variety in community or by household in 1999
Berger-Parker	Inverse dominance (relative abundance)	$D=1/\max(\alpha_i)$ $D \geq 1$	Max (α_i) is the maximum area share planted to any single crop or variety in community or by household in 1999

Notes: The Margalef index of richness used in the household analysis could not be constructed at the community level because, though proportions of area allocated to crop and variety were reported, total area was not.

Table 2. Summary statistics for indices of cereal diversity in communities and on household farms in the highlands of Amhara and Tigray regions, Ethiopia

		Community					Household-farm				
Cereal	Diversity Index	N	Mean	Standard Error	Min	Max	N	Mean	Standard Error	Min	Max
All cereals	Richness (Count index)	198	4.02	0.19	1.0	7.00					
	Richness (Margalef index)						759	0.179	0.008	0.0	0.60
	Evenness (Shannon index)	198	1.19	0.05	0.0	2.88	759	0.597	0.026	0.0	1.56
	Inverse dominance (Berger-Parker index)	198	2.03	0.08	1.0	5.00	759	1.590	0.035	1.0	3.52
Barley	Richness (Count index)	198	1.66	0.28	0.0	9.00					
	Richness (Margalef index)						352	0.017	0.005	0.0	0.23
	Evenness (Shannon index)	198	0.34	0.04	0.0	1.97	352	0.068	0.018	0.0	1.09
	Inverse dominance (Berger-Parker index)	198	1.43	0.06	1.0	3.50	352	1.063	0.020	1.0	2.78
Wheat	Richness (Count index)	198	2.22	0.26	0.0	10.00					
	Richness (Margalef index)						250	0.019	0.049	0.0	0.23
	Evenness (Shannon index)	198	0.66	0.07	0.0	1.42	250	0.083	0.219	0.0	0.98
	Inverse dominance (Berger-Parker index)	198	1.80	0.11	1.0	4.00	250	1.079	0.224	1.0	2.00
Maize	Richness (Count index)	198	1.39	0.13	0.0	6.00					
	Richness (Margalef index)						303	0.017	0.006	0.0	0.303
	Evenness (Shannon index)	198					303	0.047	0.016	0.0	0.822
	Inverse dominance (Berger-Parker index)	198					303	1.027	0.011	1.0	1.970
Teff	Richness (Count index)	198	2.07	0.14	0.0	8.00					
	Richness (Margalef index)						469	0.021	0.005	0.0	0.31
	Evenness (Shannon index)	198					469	0.079	0.018	0.0	0.99
	Inverse dominance (Berger-Parker index)	198					469	1.067	0.018	1.0	2.00
Sorghum	Richness (Count index)	198	0.55	0.10	0.0	8.00					
	Evenness (Shannon index)	198	0.46	0.06	0.0	1.6					
	Inverse dominance (Berger-Parker index)	198	1.50	0.09	1.0	4.14					
Finger millet	Richness (Count index)	198	0.42	0.07	0.0	3.00					
	Evenness (Shannon index)	198	0.59	0.05	0.0	1.10					
	Inverse dominance (Berger-Parker index)	198	1.76	0.08	1.0	2.82					
Pearl Millet	Richness (Count index)	198	0.29	0.06	0.0	3.00					

Notes: Counts were used rather than the Margalef index in the community level analysis because total areas were not measured in the Amhara survey. For the same reason, Berger-Parker and Shannon indices of infra-specific diversity indices were computed for Tigray region only. At the household-farm level, infra-specific diversity indices for sorghum, pearl millet and finger millet were not estimated as there were mostly only one variety of each of these cereals grown. N is number of observations. Means and standard errors are adjusted for stratification, weighting and clustering of sample.

Table 3. Definition of explanatory variables, summary statistics, and hypothesized effects on cereal (inter- and infra-specific) diversity in communities in the highlands of Amhara and Tigray regions, Ethiopia

Variable name	Description	Hypothesized effect Inter-specific	Hypothesized effect Infra-specific	Mean	Standard Error	Min	Max
Household characteristics							
Education	Proportion of literate households in 1998	(+,-)	(+,-)	0.50	0.03	0.03	0.9
Credit	Proportion of households who use formal credit in 1998	(+,-)	(+,-)	0.60	0.25	0.00	9.0
Landlessness	Proportion of landless households in 1998	(-)	(-)	199.40	26.10	0.00	1236.0
Oxen ownership	Proportion of households owning oxen in 1998	(+,-)	(+,-)	0.60	0.02	0.05	1.0
Farm characteristics							
Extent of erosion	Proportion of cultivated land under severe erosion in 1998	(+)	(+)	0.30	0.03	0.00	0.8
Extent of good soils	Proportion of soil considered good by community in 1998	(-)	(-)	0.40	0.03	0.00	0.9
Community and regional characteristics							
Range in altitude	Range of altitude of topography	(+)	(+)	274.20	32.90	3.00	1524.0
Mean rainfall	Average annual rainfall (mm)	(+,-)	(+,-)	1753.00	87.40	501.40	3389.0
Distance to market	Walking time in minutes to nearest market	(+,-)	(+,-)	145.70	13.10	10.00	720.0
Distance to road	Walking distance to nearest all weather road	(+,-)	(+,-)	208.50	33.90	0.00	1236.0
Population density	Population per km^2 in community	(+)	(+,-)	143.10	11.90	15.00	397.0
Location in Tigray	Administrative region of peasant association (Amhara=0; Tigray=1)	(+,-)	(+,-)	0.174	0.01	0.00	1.0

Notes: Means and standard errors are adjusted for stratification, weighting and clustering of sample.

Table 4. 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

Variable name	Description	Hypothesized effect: Inter-specific	Hypothesized effect: 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 male members	(+,-)	(-)	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
Distance to road	Walking time to nearest all weather road (hours)	(+,-)	(+,-)	3.159	0.152	0.00	24.0
Community and regional characteristics							
Distance to town	Distance from peasant association to district town (km)	(+,-)	(+,-)	35.315	1.557	0.00	168.0
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=0; Tigray=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 5. Numbers of cereals grown in communities and on household farms in the highlands of Tigray and Amhara regions of northern Ethiopia

	N	Mean	Standard error	Min	Max
Community	198	4.02	0.19	1	7
Household	739	2.15	0.06	1	5

Notes: Means and standard errors are adjusted for stratification, weighting and clustering of sample. Data on named varieties of finger and pearl millet were not collected in the Amhara region survey.

Table 6. Numbers of cereal varieties grown in communities and on household farms in the highlands of Tigray and Amhara regions of northern Ethiopia

	Barley	Maize	Wheat	Teff	Sorghum	Finger millet	Pearl millet
Community							
Number of varieties planted							
Mean	1.66	1.39	2.22	2.07	0.55	0.42	0.29
Standard error	0.28	0.13	0.26	0.14	0.10	0.07	0.06
Minimum	0	0	0	0	0	0	0
Maximum	9	6	10	8	8	3	3
Number of communities planting	166	149	139	178	75	64	49
Sample size	198	198	198	198	198	198	198
Household-farm							
Number of varieties planted							
Mean	0.61	0.69	0.54	0.78	0.30	0.39	0.10
Standard error	0.04	0.04	0.04	0.04	0.04	0.04	0.03
Minimum	0	0	0	0	0	0	0
Maximum	3	3	3	3	2	2	1
Number of households planting							
Cereal	352	303	250	469	110	101	22
More than one variety	36	30	33	62	7	5	0
Improved variety	1	46	52	12	0	0	0
Effective sample size	638	585	524	683	279	253	190

Notes: The effective sample size with respect to the household-farm refers to the total number of households in those communities/villages in which the cereal is cultivated. Mean and standard errors are adjusted for stratification, weighting and clustering of sample. Data on named varieties of finger and pearl millet were not collected in the Amhara region survey.

Table 7. Regression results, factors affecting the inter-specific diversity of cereals in communities of the highlands of Amhara and Tigray regions, Ethiopia

	Tigray			Amhara		
Explanatory variable	Richness (Poisson regression)	Inverse Dominance (OLS)	Evenness (OLS)	Richness (Poisson regression)	Inverse Dominance (OLS)	Evenness (OLS)
Range in altitude	-0.00008	-0.00071	-0.000058	-0.0005***	-0.000076	-0.00016
Mean rainfall	0.00014	-0.000046	0.00075	-0.0002	-0.0002	-0.00017
Distance to market	-0.0007*	-0.00201**	-0.00135***	0.0005	0.0019	0.00122*
Distance to road	0.00076**	0.001744*	0.001***	0.0001	0.00032*	0.00025**
Population density	0.0015***	0.00321**	0.0015***	0.0002	0.00056	0.00038
Education	0.2606**	0.18098	0.2214	0.3303*	0.6598	0.27174
Credit	-0.0029	-0.40922*	-0.02523	0.03371	0.1672**	0.0746*
Landlessness	-1.11e-07	-0.000368	-0.00003	0.000021	-0.00014	0.00009
Oxen ownership	0.2397**	0.5729	0.19972	0.3285*	0.7692*	0.3154*
Extent of erosion	0.3769***	1.0718**	0.60489***	0.0244	-0.2763	-0.2671
Extent of good soils	0.0608	0.3171	0.14244	-0.2479	-0.2017	-0.1315
Constant	0.9611***	1.3457*	1.2828***	1.4036***	1.4758**	0.9011**
Number of observations	85	85	85	69	69	69
F	7.58	4.72	8.77	3.04	1.56	1.93
Prob>F	0.000	0.000	0.000	0.012	0.017	0.019
R-square		0.3551	0.4395		0.2508	0.2706

Notes: Indices are defined in Table 1. 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.

Table 8. Regression results, factors affecting infra-specific diversity of barley, wheat and maize in communities of the highlands of Amhara and Tigray regions, Ethiopia

	Barley			Wheat			Maize	
	Tigray & Amhara	Tigray		Tigray & Amhara	Tigray		Tigray & Amhara	Tigray
Explanatory variable	Richness (Poisson regression)	Inverse Dominance (Interval regression)	Evenness (Interval regression)	Richness (Poisson regression)	Inverse Dominance (Interval regression)	Evenness (Interval regression)	Richness (Poisson regression)	Evenness (Interval regression)
Range in altitude	-0.00018	0.00004	0.0001	0.0003	0.00067	0.0005**	0.00028*	0.00045**
Mean rainfall	0.00067***	-0.00038	-0.0005	0.0013	0.0022	0.0003	-0.00058***	-0.00118
Distance to market	-0.00096	0.0033**	0.0015	-0.00059	-0.0001	-0.00035	0.00024	0.00017
Distance to road	0.00018	-0.004***	-0.0022**	0.00035***	-0.00034	-0.00006	-0.00069	-0.00011
Population density	0.00148	0.0014	0.0012	-0.00072	-0.0024	-0.0012	0.001222*	-0.00018
Location in Tigray	1.0753***			-0.32183			-0.92876***	
Education	-0.9163**	0.1183	0.0864	-0.30173	1.0534	0.2721	0.4474	-0.0254
Credit	0.00706	0.0313	0.2977	-0.01958	0.2977	0.1591	0.1046**	0.1452
Landlessness	-0.000026	0.0004	0.00026	-0.00005	0.0012	0.0011*	-0.00031	0.00039
Oxen ownership	-0.70953**	0.0553	-0.7859	-0.33622	1.2656	0.5634	1.4691***	0.6286
Extent of erosion	0.33072	0.1269	0.1155	0.07597	0.04915	-0.2305	-0.6792**	0.3605
Extent of good sols	-0.21296	0.0009***	0.0007**	-0.6639	-0.0018***	-0.0019***	-0.6792**	-0.7947**
Inverse Mills Ratio, growing cereal		-0.1295	-0.0688		-0.4894***	-0.3782***		
Probability of growing modern variety					1.2333	0.478		0.5082*
Constant	-0.06865	0.9869	0.06191	1.2263*	-2.11696	-0.6853	0.71415	0.3487
Number of observations	154	71	72	154	56	56	154	75
F	5.57	7.7	5.34	4.12	6.08	6.5	4.12	1.99
Prob>F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.039

Notes: Indices are defined in Table 1. 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.

Table 9. Regression results, factors affecting infra-specific diversity of sorghum, finger millet and pearl millet in communities of the highlands of Amhara and Tigray regions, Ethiopia

	Sorghum	Finger millet		Pearl Millet
	Tigray and Amhara	Tigray and Amhara	Tigray	Tigray and Amhara
	Richness (Poisson regression)	Richness (Poisson regression)	Inverse Dominance (Interval regression)	Richness (Poisson regression)
Explanatory variable				
Range in altitude	-0.00043	-0.00092*	-0.00041	-0.00112**
Mean rainfall	-0.00225***	0.0002	-0.002447**	-0.000312
Distance to market	0.00257**	0.00107	0.001975	0.00088
Distance to road	0.00053*	-0.0012	-0.00167*	0.00042**
Population density	-0.00186	0.00051	-0.00015	0.0021
Location in Tigray	-1.5024**	1.4711**		0.9644
Education	0.34497	0.84854	-0.55735	1.3301*
Credit	-0.5395	0.13126	-0.03787	-0.64834
Landlessness	0.00043	-0.00063	-0.000049	0.00059
Oxen ownership	0.43478	2.16221***	0.58891	-0.1209
Extent of erosion	1.1559	-0.61815	-0.26976	0.8567
Extent of good soil	-0.22947	-0.57056	0.3107	-0.3097
Inverse Mills ratio, growing cereal			-0.61982*	
Constant	2.18422	-2.7673**	3.6071***	-1.8825
Number of observations	154	154	53	154
F	4.13	7.09	2.35	3.54
Prob>F	0.000	0.000	0.022	0.000

Notes: Indices are defined in Table 1. 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.

Table 10. Censored regression results, factors affecting inter-specific diversity of cereals on household farms in the highlands of Amhara and Tigray regions, Ethiopia

Explanatory variable	Richness	Evenness	Inverse Dominance
Age	-0.0003	-0.0023	-0.0038
Male-headed	0.0189	0.0526	-0.0491
Education	-0.0051	-0.0201	-0.0175
Household size	-0.0002	0.0020	0.0041
Proportion of males	0.1322***	0.3682***	0.3437**
Tropical livestock units	-0.0106	-0.0473***	-0.0612***
Oxen ownership	0.0396**	0.1639***	0.2176***
Exogenous income	-0.0000	-0.0001	-0.0001
Slope of farmland	0.0128	0.0691	0.1096
Erosion of farm	-0.0229	-0.0131	0.0406
Fertility of farm	0.0274	0.0213	0.0515
Irrigation	-0.0149	-0.0222	0.0001
Farm size	0.0291**	0.1993***	0.2558***
Farm fragmentation	0.0792	0.4529***	0.6006***
Number of farm plots	0.0213***	0.0427***	0.0481**
Distance from house to farm	-0.0378***	-0.0723*	-0.1049*
Distance to road	-0.0003	-0.0025	0.0023
Distance to town	0.0001	-0.0001	0.0004
Population density	-0.0001	0.0004	0.0003
Location in Tigray	0.1427***	0.1612***	0.1908**
Constant	-0.0763	-0.3176*	0.5398***
Number of observations	739	739	739
Uncensored	577	577	577
Left-censored	162	162	162
F	8.89***	10.25***	8.85***

Notes: Indices are defined in Table 1. 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.

Table 11. Regression (censored least absolute deviation (CLAD)) results, factors affecting the infra-specific diversity of barley and maize on household farms in the highlands of Amhara and Tigray regions, Ethiopia

	Barley			Maize		
Explanatory variable	Richness	Evenness	Inverse Dominance	Richness	Evenness	Inverse Dominance
Age	0.0074***	0.0194***	0.0023	-0.0038***	-0.0232***	-0.0007
Male-headed	0.0001	-0.0981	-0.0061	-0.0364	-0.1259	0.0024
Education	-0.0036	-0.0253	-0.0008	0.0184**	0.0781*	-0.0008
Household size	0.0031	0.0071	-0.0008	0.0095**	0.0663*	0.0035
Proportion of males	-0.1703**	-0.1130	-0.0429	-0.1623***	-0.3186	0.0010
Tropical livestock units	0.0264***	0.0408	0.0244	-0.0070	-0.0743	0.0014
Oxen ownership	-0.0712***	-0.1707*	-0.0448	0.0299	0.2023	-0.0046
Exogenous income	0.0001	0.0003*	0.0001	-0.0004**	-0.0004	0.0000
Slope of farmland	0.0076	-0.3052***	-0.0132	0.1084***	0.6599***	0.0130
Erosion of farm	0.0169	-0.0509	-0.0185	0.1101**	0.6663***	-0.0161
Fertility of farm	0.0044	0.1175	0.0437	-0.0952***	-0.2766	0.0243
Irrigation	0.0213	0.0475	0.0110	-0.1813*	-0.4979	-0.0116
Farm size	0.0183	0.1539*	0.0657	-0.0198	0.1618*	0.0582
Farm fragmentation	0.0118	-0.0276	-0.0780	0.0181	0.4263	-0.0949
Number of farm plots	-0.0411***	-0.0879**	-0.0115	0.0042	-0.0134	0.0229
Distance from house to farm	-0.0277	-0.0549	0.0143	0.0001	-0.1082	0.0029
Distance to road	0.0094*	0.0279	0.0106	0.0192	0.2137**	-0.0042
Distance to town	-0.0008	-0.0032	-0.0003	-0.0025**	-0.0242**	-0.0002
Population density	-0.0001	0.0006	0.0003	0.0006**	0.0025**	-0.0001
Location in Tigray	-0.0615*	0.0596	-0.0242	-0.0815	-0.3009	-0.0832*
Inverse Mills ratio, growing cereal	-0.2304***	-0.6242***	-0.0914	-0.4513***	-2.3201***	0.0380
Probability of growing modern variety				-0.0249	-0.4554	0.2339
Constant	-0.0094	-0.0229	1.030***	0.2862***	0.3581	1.0193***
Number of observations	352	352	352	303	303	303
Pseudo R^2	0.31	0.26	0.04	0.48	0.46	0.27

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

Table 12. Regression (censored least absolute deviation (CLAD)) 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	Evenness	Inverse Dominance	Richness	Evenness	Inverse Dominance
Age	-0.0035*	-0.0175**	-0.0002	-0.0024***	-0.0113***	-0.0013
Male-headed	-0.0651	-0.4856*	-0.0351	0.0337	0.1816	0.0257
Education	0.0196***	0.1057***	0.0528**	0.0110***	0.0373*	0.0088
Household size	0.0051	0.0301	-0.0065	0.0021	0.0181	-0.0048
Proportion of males	-0.1608**	-0.9071**	-0.1111	0.0716	0.2240	-0.0108
Tropical livestock units	0.0397***	0.1734***	0.0210	-0.0090	-0.0585*	0.0028
Oxen ownership	-0.0829***	-0.3941***	-0.0880	0.0308	0.2104***	0.0396
Exogenous income	-0.0001	-0.0004	0.0001	0.0000	0.0001	0.0001
Slope of farmland	-0.0253	-0.2221	-0.0570	-0.0913***	-0.4924***	-0.0363
Erosion of farm	0.0662	0.5218	0.0177	0.0583*	0.2335	-0.0446
Fertility of farm	0.0134	0.2080	0.0255	0.0405	0.0240	0.0791
Irrigation	0.6104*	2.2710	0.8120	0.1069	0.9719**	0.0036
Farm size	0.0989***	0.2920*	0.1609*	0.0169	0.0926	0.0925**
Farm fragmentation	-0.3028***	-1.7204**	-0.2312	-0.2129*	-0.5731	-0.2224*
Number of farm plots	0.0065	0.0867	0.0277	0.0173**	0.0541	0.0436*
Distance from house to farm	-0.0629	-0.3681	-0.0270	-0.0072	-0.0431	-0.0341
Distance to road	0.0049	0.0213	0.0136	-0.0233***	-0.1548***	-0.0047
Distance to town	-0.0018	-0.0064	-0.0006	0.0007	0.0028	0.0001
Population density	0.0010**	0.0019	0.0009	-0.0007***	-0.0050***	-0.0001
Location in Tigray	-0.0376	-0.1624	-0.1109	0.0179	0.2743**	-0.0248
Inverse Mills Ratio, growing cereal	-0.1304	-0.5118	-0.1812	-0.2723***	-1.0143***	-0.0154
Probability of growing improved variety	-0.1704	-0.0345	-0.0390			
Constant	0.2672*	1.6500**	1.2116***	0.2665***	1.3289***	1.0313***
Number of observations	243	243	243	469	469	469
Pseudo R^2	0.32	0.21	0.27	0.16	0.17	0.10

Notes: Indices are defined in Table 1. * 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	Improved variety	All varieties	Improved 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.

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