Production Risk, Food Security and Crop Biodiversity: Evidence from Barley Production in the Tigray Region, Ethiopia•

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Abstract:
This paper investigates the effects of crop biodiversity on farm productivity and risk management in the Tigray region of Ethiopia. Using a moment-based approach, the analysis relies on a flexible stochastic production function approach (Antle, 1983). Data are from 205 farms producing barley. Econometric results show that maintaining a larger number of barley varieties in the fields supports productivity and reduces the risk of crop failure. To study the welfare implications of diversity, a simulation exercise is presented. The analysis provides evidence that diversity helps reduce the risk of crop failure and the cost of risk (as measured by a risk premium). In general, the skewness effect can differ from the variance effect. In the context of biodiversity effects evaluated at sample means, we find that the skewness effect dominates the variance effect. Thus, under such circumstances, reducing the odds of crop failure can be more relevant that reducing yield variance.

Keywords: Genetic Diversity, Landraces, Risk, Land degradation, Ethiopia, Tigray.

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1. Introduction

Risk exposure is one of the quintessential features of farming in developing countries. Variety of risks exposes farm households to very serious hardship. Harsh climatic conditions can result in harvest failure and famine. The highlands of Ethiopia are a prime example of such environment. During the last millennia, at least 25 severe drought periods were recorded, and crop production in most areas “never topped subsistence levels” (REST and NORAGRIC, 1995 P. 137). Severe drought clearly affects farm household consumption and welfare (Dercon, 2004). In Ethiopia, harvest failure caused by environmental conditions (i.e. drought) is the most important cause of risk-related hardship by rural household. Indeed, Dercon (2005) has reported that 78 percent of rural households were seriously affected by harvest failure. Land degradation exacerbates risk exposure and low productivity. Ethiopia has one of the highest rates of soil nutrient depletion in Sub-Saharan Africa (Stoorvogel and Smaling, 1990; Grepperud, 1996; FAO, 2001). Hurni (1993) estimated that 42 t/ha of soil were lost on the sloped cropland of Ethiopia each year.

Managing risk exposure and avoiding consumption shortfall is an important preoccupation of agricultural households, particularly in such environments (Bromley and Chavas, 1989, Paxson, 1992, Fafchamps, 1992, Deaton, 1992, Fafchamps et al., 1998, Fafchamps and Pender, 1997). Farming strategies can be restricted and technology adoption limited or partial. Indeed, agroecological conditions and land heterogeneity can reduce the potential benefits of High Yielding Varieties (Bellon and Taylor, 1993). The use of fertilizers can be uneconomic, either because moisture cannot be controlled through irrigation, or transport and transactions costs are prohibitive.

Insurance mechanisms, whether formal or informal, often function poorly, due to credit constraints, information asymmetries and commitment failures (Deaton, 1990, Fafchamps, 1992, Kurosaki and Fafchamps, 2002). And even when present, safety nets may provide only limited support (Jayre et al., 2000; Dercon and Krishnan, 2003; Dercon 2004). Off-farm, non-covariant income may be restricted. Therefore, the capability to implement income or activity diversification can be minimal. Although farmers can accumulate grain and livestock as buffer stocks, drawing down farm assets to meet consumption needs has long-term consequences. Therefore, *ex ante* crop production decisions remain an important part of risk-management strategies for farm households (Just and Candler, 1985, Fafchamps, 1992, Chavas and Holt, 1996, Dercon, 1996; Benin et al., 2004).

Tigray is the northernmost of the nine ethnic regions of Ethiopia. Rainfall is sparse and unpredictable in this region, both over space and over time. It has an estimated area of 50078 square kilometers. Mean annual rainfall has been estimated at 650 mm or less over the past few decades (REST and NORAGRIC, 1995; Pender and Gebremedhin, 2004). And rainfall varies remarkably over relatively small distances. For instance, agricultural land located in the central part of the region would have a rainfall level of 950 mm per year while land located in the eastern part of the region would have around 400 mm per year. The coefficient of variation for yield in Tigray is four times the national level (REST and NORAGRIC, 1995). Farms and the operated plots by households are, thus, characterized by highly varied micro-environments that differ in rainfall, topography, soil type, temperature and soil fertility (Bekele, 1984; Hagos et al., 1999).

The paper examines the role of crop biodiversity[1] in risk management. In this context, it investigates two questions. First, how does risk exposure affect the incentive to use inputs (including crop biodiversity) as a means of reducing the cost of risk bearing? Second, what is the relative importance of crop failure in the valuation of the cost of private risk bearing? This paper aims to contribute to the existing literature by tackling both questions. In isolated dry environment where ex ante risk management strategies are restricted, farmers' reliance on crop biodiversity can be essential (Benin et al., 2004). Indeed, crop genetic resources embedded in crop seeds can help support productivity and manage risk. Ethiopia is a recognized global center of genetic diversity for several crops, including barley (Harlan, 1992; Vavilov, 1949; Pecetti et al., 1992). The majority of varieties grown in Ethiopia are farmers' varieties, or 'landraces' characterized by high morphogenetic variation. The genetic structure of landraces has been shaped by natural processes and selection practices implemented by farmers' generation after generation (Smale et al., 2001). The importance of crop biodiversity can also be documented by the low level of adoption of improved varieties (Bellon and Taylor, 1996). Local germplasm is often preferred to improved varieties because of its greater tolerance to severe biotic and abiotic stresses[2] (Byerlee and Husain, 1993; Byerlee and Morris, 1993; Eyzaguirre and Iwanaga, 1996; Tesemma and Bechere, 1998; Almekinders et al., 1994). Having crop varieties that respond differently to weather randomness ensures that "whatever the environmental conditions, there will be plants of given functional types that thrive under those conditions" (Heal, 2000, p.4). To investigate the potential role of crop biodiversity on risk management we rely on a moment-based specification of the stochastic production function (Antle, 1987). Data are from a survey,

1 In this paper, we will use the terms crop biodiversity, diversity and crop genetic diversity interchangeably.

2 It should be noted that besides its "private" value, genetic diversity has an important social value specially for plant breeding programs (Benin, et al., 2004; Smale et al., 2001; Evenson and Gollin,1997; Bellon, 1996).

undertaken in 1999-2000, of 205 barley-producing farms in Tigray region Ethiopia. To our knowledge, this is the only available database recording Ethiopian farm-level information on grown crop varieties and thus crop biodiversity.[3] Diverse landraces of barley can adapt to specific sets of agroecological and microclimatic regimes throughout the region. Therefore, productivity and food security depends upon the utilization of this diversity. This dataset will be used to investigate the role of genetic diversity on productivity and risk management under harsh agro-climatic conditions. Our analysis involves a refined econometric estimation of the production process, with a focus on the role of biodiversity in risk management. Special attention is given to the effects of local environmental conditions (i.e., slope of the plot, soil fertility, farm altitude etc.) and managerial decisions. Controlling for such effects is important to reduce the potential biases arising from omitted variables (Sherlund et al., 2002). This provides a framework to study the influence on productivity of soil quality, crop biodiversity, and their interaction (Bellon and Taylor, 1996), with implications for risk management.

The paper investigates the welfare effects of production risk. This seems particularly relevant in the context of the current literature. Farm households are typically risk averse (Dercon, 2004). They suffer a welfare loss when they experience a fluctuation or variability (e.g., as measured by variance) in their production or consumption pattern. However variability (as measured by variance) may not capture completely the extent of risk exposure. Indeed, the variance does not distinguish between an unexpected bad event compared to an unexpected good one. On that basis, it seems important to go beyond variance and to introduce skewness in risk analysis. In general, the skewness of yield can capture the probability of crop failure (where

3 The survey generated cross section data. Note that the cross section nature of the data does not allow an analysis of the dynamic aspects of farm-level management decisions. Panel data would be required to explore such issues. Unfortunately, while farm-level panel data exist in Ethiopia (e.g., from the Ethiopia Rural Household Survey, conducted by IFPRI, Addis Ababa University and the University of Oxford), such data do not include information on farm household crop varieties.

negative skewness reflects a greater exposure to "downside risk"). Under risk aversion, any increase in variance tends to make the decision maker worse off. Empirical evidence suggests that most decision makers exhibit decreasing absolute risk aversion (e.g. Binswanger, 1981; Chavas and Holt, 1996; Chavas, 2004), which implies "downside risk aversion" (Menezes et al., 1980; Antle, 1987). Therefore, risk averse farmers exhibiting downside risk aversion have an incentive to grow crop cultivars or varieties that affect positively the skewness of the distribution of returns, thus reducing their exposure to downside risk (e.g. severe drought leading to crop failure). Our analysis investigates these issues. Applied to the Tigray region on Ethiopia, it provides evidence on how crop biodiversity can affect farm productivity and risk exposure (including downside risk exposure), and how such effects can vary with soil fertility.

The paper is organized as follows. Next section presents the conceptual framework. Section three presents the data sources and the variables used in the empirical analysis. The estimation method and results are discussed in sections four and five, respectively. Section six reports a simulation exercise illustrating the effects of risk (and downside risk) exposure on farmers' welfare, with implications for the role of biodiversity and soil quality in management decisions. Section eight concludes the paper offering some remarks and direction for future research.

2. Conceptual framework

Consider a farm producing output y using inputs x under risk. The production technology is represented by the stochastic production function $y = g(x, v)$, where v is a vector of random variables reflecting uncontrollable factors affecting output (e.g., rainfall). The farm output y can either be consumed by the household or marketed: $y = c_1 + m$, where c_1 is the part of farm output consumed by the household, and m is the marketed surplus that can be marketed at price p_1. In general, m is unrestricted in sign. The marketed surplus can be positive ($m > 0$) when the farm household produces more than it consumes, or negative ($m < 0$) when the household produces less than it consumes. The household also consumes another good c_2 that it can purchase at price p_2. For simplicity, assume that all prices are normalized such that $p_2 = 1$. The household income is: $p_1\, m + N(x)$, where $p_1\, m$ is the income generated from the marketed surplus, and $N(x)$ denotes the net income from other activities (net of the cost of inputs x). Given $p_2 = 1$, the household budget constraint is: $c_2 \leq p_1\, m + N(x)$. With $m = y - c_1 = g(x, v) - c_1$, and assuming that the budget constraint is binding, solving the budget constraint for c_2 yields: $c_2 = N(x) + p_1\, [g(x, v) - c_1]$. Let $U(c_1, c_2)$ be a von Neumann Morgenstern utility function representing household preferences under risk. Under the expected utility model, the household makes decisions so as to solve the optimization problem

$$\text{Max } \{EU(c_1, N(x) + p_1\, [g(x, v) - c_1])\}, \tag{1}$$

where E is the expectation operator based on the subjective probability distribution of the uncertain variables facing the decision maker. Under non-satiation in c_2 (where $\partial U/\partial c_2 > 0$), the choice of x in (1) can be alternatively written in terms of the "certainty equivalent" CE which satisfies

$$U(c_1, CE(x) - p_1\, c_1) = EU(c_1, N(x) + p_1\, [g(x, v) - c_1]). \tag{2}$$

Letting $\pi = N(x) + p_1\, [g(x, v) - c_1]$ and following Pratt, equation (2) can be alternatively expressed as

$$U(c_1, E(\pi) - R) = EU(c_1, \pi). \tag{2'}$$

where $E(\pi)$ is expected income and R is a risk premium measuring the cost of private risk bearing. The risk premium R in (2') measures the decision maker's willingness to pay for an insurance scheme that would replace the random variable π by its mean. Combining equations (2) and (2') implies that certainty equivalent can be decomposed into two additive parts:

$$CE = E(\pi) - R. \tag{3}$$

Under risk aversion, the risk premium is positive ($R > 0$) and equation (3) implies that risk preferences matter. In general, under risk aversion, risk exposure tends to lower the certainty equivalent and make the decision maker worse off. As shown by Pratt, risk aversion can be assessed "locally" using the Arrow-Pratt risk aversion coefficient $r_2 \equiv -(\partial^2U/\partial\pi^2)/(\partial U/\partial\pi)$. With $(\partial U/\partial\pi) > 0$, risk aversion corresponds to $R > 0$, $\partial^2U/\partial\pi^2 < 0$, and $r_2 > 0$. Pratt also defined decreasing absolute risk aversion (DARA) as situations where increasing mean income tends to reduce the risk premium R. Thus DARA implies that increasing expected income behaves as a substitute for "insurance motives". Pratt showed that $\partial r_2/\partial\pi < 0$ under DARA. There is empirical evidence that most decision makers exhibit risk aversion and DARA risk preferences (e.g., Binswanger; Chavas and Holt; Chavas).

Risk-averse decision makers have an incentive to reduce their risk exposure. This suggests a need to investigate how crop genetic diversity and risk (e.g., as measured by variance and skewness) interact in the evaluation of crop genetic diversity (e.g., Heisey *et al*., 1997; Smale *et al*., 1998). In addition, since $\partial r_2/\partial\pi = -(\partial^3U/\partial\pi^3)/(\partial U/\partial\pi) + r_2^2$, note that DARA implies $\partial^3U/\partial\pi^3 > 0$, corresponding to aversion to unfavorable "downside" risk" (see Menezes *et al*.). Under "downside risk aversion",4 decision makers are adversely affected by downside risk (e.g., the risk of crop failure) and try to implement strategies that reduce exposure to such risk (Anderson *et al*., 1977; Menezes *et al*., 1980; Antle, 1983). This raises the question of how

4 Increasing downside risk means increasing the asymmetry (or skewness) of the risk distribution toward low outcomes, holding both mean and variance constant (Menezes *et al*.). By definition, a downside risk averse decision maker is made worse off by such a change.

maintaining biodiversity affects the third central moment (skewness) of the distribution of revenue. In general, farmers exhibiting downside risk aversion have incentives to develop management strategies that affect positively the skewness of the distribution of yields (e.g., by reducing the probability of crop failure). This indicates the need to go beyond a mean-variance analysis in the investigation of the effects of crop genetic diversity.

Below, we investigate the role of production uncertainty v as represented by the stochastic production function $y = g(x, v)$. This indicates a need to assess the probability distribution of $g(x, v)$. Following Antle (1983), we explore the moment-based approach to this assessment. Consider the following econometric specification for $g(x, v)$:

$$g(x, v) = f_1(x, \beta_1) + [f_2(x, \beta_2) - (f_3(x, \beta_3)/k)^{2/3}]^{1/2}\, e_2(v) + [f_3(x, \beta_3)/k]^{1/3}\, e_3(v), \tag{4}$$

where $f_2(x, \beta_2) > 0$, and the random variables $e_2(v)$ and $e_3(v)$ are independently distributed and satisfy $E[e_2(v)] = E[e_3(v)] = 0$, $E[e_2(v)^2] = E[e_3(v)^2] = 1$, $E[e_2(v)^3] = 0$, and $E[e_3(v)^3] = k > 0$. This means that the random variables $e_2(v)$ and $e_3(v)$ are normalized (i.e., they are each distributed with mean zero and variance 1). In addition, $e_2(v)$ has zero skewness ($E[e_2(v)^3] = 0$) while the random variable $e_3(v)$ is asymmetrically distributed and has positive skewness ($E[e_3(v)^3] = k > 0$). It follows from (4) that

$$E[g(x, v)] = f_1(x, \beta_1), \tag{5a}$$

$$E[(g(x, v) - f_1(x, \beta_1))^2] = f_2(x, \beta_2), \tag{5b}$$

and

$$E[(g(x, v) - f_1(x, \beta_1))^3] = f_3(x, \beta_3). \tag{5c}$$

The specification (4) provides a convenient representation of the first three central moments of the distribution of g(x, v).5 Indeed, from (5a), the first moment (the mean) is given by $f_1(x, \beta_1)$. From (5b), the second central moment (the variance) is given by $f_2(x, \beta_2) > 0$, and from (5c), the third central moment (measuring skewness) is given by $f_3(x, \beta_3)$. This provides a flexible representation of the impacts of inputs x on the distribution of output under production uncertainty. In addition, if we treat the distribution of $e_2(v)$ and $e_3(v)$ as given, then the three moments $f_1(x, \beta_1)$, $f_2(x, \beta_2)$ and $f_3(x, \beta_3)$ are sufficient statistics for the distribution of g(x, v) in the specification (4). It provides a flexible representation of mean effects $f_1(x, \beta_1)$ and variance effects $f_2(x, \beta_2)$. By going beyond mean-variance and considering the effects of skewness and downside risk exposure, such a specification expands on previous studies of crop genetic diversity (Smale *et al.*, 1998; Widawsky and Rozelle, 1998; Di Falco and Perrings, 2005).

In general, one expects expected output $f_1(x, \beta_1)$ in (5a) to exhibit positive and decreasing marginal productivity with respect inputs x: $\partial f_1/\partial x > 0$ and $\partial^2 f_1/\partial x^2$ being a negative definite matrix. However, the effects of inputs x on the variance and skewness of output is largely an empirical issue. For example, from (5b), the i-th input can be variance increasing, variance neutral, or variance decreasing as $\partial f_2/\partial x_i > 0$, $= 0$, or < 0, respectively. Similarly, from (5c), the i-th input can affect downside risk exposure through its effect on skewness $f_3(x, \beta_3)$. In particular, the i-th input would contribute to decreasing (increasing) downside risk exposure when $\partial f_3/\partial x_i > 0$ (< 0). Of special interest here are the effects of genetic diversity on the variance as well as skewness of production.

5 Recently, the stochastic production function approach has been criticized by Chambers and Quiggin (2000) who suggested the adoption of the "state- contingent" approach to model production uncertainty.

To help motivate the importance of these effects on the cost of private risk bearing, consider the definition of the risk premium R in (2'). Under risk aversion, the risk premium R depends on all the relevant moments of the profit distribution. In general, given $\pi = N(x) + p_1 [g(x, v) - c_1]$, we expect to find a close relationship between the moments of income π and the corresponding moments of production g(x, v). Below, we will focus our attention on the simple case where output price is known, i.e., where each moment of profit π is a linear function of the corresponding moment of output g(x, v). Then the linkages between the cost of private risk bearing and the moments of outputs can be assessed using (5a)-(5c).

As shown by Pratt, the risk premium R in (2') can be approximated as follows. Taking a Taylor series approximation on both sides of equation (2') at point $E(\pi)$ gives

$$U(c_1, E(\pi)) - (\partial U/\partial \pi)\, R \approx U(c_1, E(\pi)) + ½\, (\partial^2 U/\partial \pi^2)\, E[\pi - E(\pi)]^2$$
$$+\ 1/6\, (\partial^3 U/\partial \pi^3)\, E[\pi - E(\pi)]^3.$$

This yields the following approximation to the risk premium

$$R_a = 1/2\ r_2\, M_2 + 1/6\ r_3\, M_3, \tag{6}$$

where $M_i = E[\pi - E(\pi)]^i$ is the i-th central moment of the distribution of profit, $r_2 = -(\partial^2 U/\partial \pi^2)/(\partial U/\partial \pi)$ is the Arrow-Pratt coefficient of absolute risk aversion, and $r_3 = -(\partial^3 U/\partial \pi^3)/(\partial U/\partial \pi)$, all evaluated at $E(\pi)$. Equation (6) can be alternatively written as

$$R_a = R_{a2} + R_{a3}, \tag{6'}$$

where $R_{a2} \equiv 1/2\ r_2\, M_2$ and $R_{a3} \equiv 1/6\ r_3\, M_3$. Equations (6) and (6') decompose the risk premium R_a into two additive parts: $R_{a2} \equiv 1/2\ r_2\, M_2$ reflecting the effect of the variance M_2, and $R_{a3} \equiv 1/6\ r_3\, M_3$ reflecting the effect of skewness M_3 on the cost of risk. When $M_3 = 0$, equation (6) reduces to the standard Arrow-Pratt approximation establishing that the approximate risk premium R_a is (locally) proportional to the variance of profit M_2, with $r_2/2$ as the coefficient of proportionality (Pratt). It gives the intuitive result that, under risk aversion (when $\partial^2 U/\partial\pi^2 < 0$ and $r_2 > 0$), any increase in the variance of profit tends to increase the private cost of risk bearing. Equation (6) extends this result to show how the third central moment M_3 (the skewness) affects the risk premium. It indicates that $\partial R_a/\partial M_3 \approx 1/6\ r_3$, i.e. that the risk premium tends to decrease with a rise in skewness under downside risk aversion (when $\partial^3 U/\partial\pi^3 > 0$ and $r_3 < 0$). In this case, a rise in skewness associated with a decrease in downside-risk exposure (e.g., a reduction in the probability of crop failure) would reduce the private cost of risk bearing.

This raises two questions related to risk management. How does risk exposure affect the incentive to use inputs (e.g., crop biodiversity) as a means of reducing the cost of risk bearing? And what is the relative importance of the variance effect versus skewness effect in the valuation of the cost of private risk bearing? Answering these questions requires evaluating the risk premium R. As just discussed, this can be done using the risk premium R_a given in equations (6)-(6').

We will also be interested in exploring the farmer's certainty equivalent given in (3). This can help assess the relative importance of the cost of private risk bearing R compared to expected net revenue $E(\pi)$. Substituting the measure of the risk premium given in (6) in to the certainty equivalent (3) gives

$$CE_a = E(\pi) - R_a = E(\pi) - ½\ r_2\ M_2 - 1/6\ r_3\ M_3. \quad (7)$$

This decomposes the certainty equivalent into three additive parts: expected return $E(\pi)$, the variance component of the risk premium $R_{a2} \equiv ½\ r_2\ M_2$, and the skewness component of the risk premium $R_{a3} \equiv 1/6\ r_3\ M_3$ (with $R_a = R_{a2} + R_{a3}$ from (6')). We explore the empirical assessment of these three components below, with a focus on the effects of diversity.

There are at least two common hypotheses in the literature about on-farm crop genetic resources that relate the diversity of crop varieties to the mean and variance of yields. The first is that farmers match the different varieties to the micro-environments on their farms, enhancing overall yield levels and possibly, reduce yield variability. A second is that planting more varieties diversifies risk, spreading risk spatially or temporally as in an investment portfolio solution. In the first, variety richness leads more optimal resource use. In the second, variety richness substitutes to some extent for other offsetting sources of income or insurance. For example, in the study by Smale et al. (1998), various indicators of genetic, spatial, or temporal diversity in modern barley varieties had mixed effects in high potential and low potential environments of Pakistan's Punjab. The variability effect was more evident in the low potential environments, also the subsample sizes too small for reliable estimates. That analysis did not encompass farmers' materials, as is the case here; nor was land quality explicitly taken into account. Equation (7) provides a convenient way to investigate hypotheses concerning the effects of crop diversity and land degradation on expected income and on the cost of risk bearing (including both variance and skewness effects). This is explored below in the context of barley production in the Tigray region of Ethiopia.

3. Background and data information

Barley is a staple food grain in the highlands of Ethiopia. Along with teff and wheat, barley is the most widely grown and consumed in the Tigray region. Indeed, barley production represents about the 20% of the total national cereal production. Remarkably, over 90% of the Barley produced by subsistence farmers is landraces (Alemayehu, 1997) with no or very little external inputs. In almost every household, barley is used to make different types of bread, dough, porridge, beer and gruel (Asfaw, 1990). Thanks to its ecological plasticity, barley is cultivated from 1500 to over 3000 meters above the sea level. Ethiopia is an important centre of diversity for barley. This crop was brought to Ethiopia at least 5000 years ago (Harlan, 1968; Frost, 1974). Over the centuries, barley developed a lot of genetic diversity (Engels, 1991). The Ethiopian barley stock is considered as an isolated line that evolved independently from the mainstream of world barley evolution (Harlan 1968).

Genetic variation in Ethiopian barley is remarkable and is reflected by differences in morphogenetic traits among landraces. Genetic characteristics and resistance of Ethiopian barley have been widely studied (Asfaw, 2000). In crop genetic resources conservation, Ethiopian barley has been identified as a priority crop since the 1920s, and extensive germplasm collections have been deposited in gene banks throughout the world (Orlov 1929; Ciferri 1940, 1944; Negassa 1985; Asfaw, 2000). There is variation in barley characteristics such as caryopsis type, spyke density and kernel colour. While some morphotypes are widely distributed, other morphotypes are used in more isolated or remote areas (Asfaw, 2000). Therefore, the barley of Ethiopia is an important source of genes for resistance, protein quality and many lines have been used as donors of resistance to commercial varieties in North America and Europe (Qualset and Moseman, 1966; Qualset, 1974; Alemayehu, 1995; Asfaw, 1989; Asfaw 2000; Negassa, 1985). In the 205 barley farms surveyed and analyzed below, ten different landraces were grown. Among these ten, the landraces called white, karkaera, sasera and kuntsbe were found to be widely used.

The dataset used in the analysis is from a farm survey conducted in 1999 and 2000 in the highlands (more than 1500 meters above sea level (masl)) of Tigray region of Ethiopia by researchers from Mekelle University, the International Food Policy Research Institute (IFPRI), and the International Livestock Research Institute (ILRI). The survey involved a stratified sampling of farm households, with the strata being chosen according to agricultural potential, market access, and population density (Pender et al. 2001). In the Tigray region, peasant associations (PAs) were stratified by whether an irrigation project was present or not, and for those without irrigation, by distance to the *woreda* town (greater or less than 10 km). Three strata were defined, with 54 PAs randomly selected across the 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, two villages were randomly selected, and from each village, five households were randomly selected. A total of 50 PAs, 100 villages, and 500 households were then surveyed. Usable data were available for 96 villages, or kushets. Out of 96 villages, 43 were growing barley. These 43 villages are dispersed throughout the region of Tigray. A total of 245 households grew barley on 736 different plots in the survey year analyzed here. After controlling for outliers and observations with missing values for relevant variables, 205 household observations remained. This household-level data provides a basis for estimating a stochastic production function for barley, following equations (4) and (5). Detailed plot level information was used to construct several of the household-level variables.

Table 1 reports the variables list and definitions, and table 2 presents descriptive statistics. Crop diversity is measured by the Margalef index, defined as [(number of barley varieties)/ln(barley area) - 1]. The explanatory variables are grouped as conventional inputs (land, labour, animal, urea, and biodiversity), environmental and soil condition variables (erosion, slope, fertility and altitude), and managerial variables (years of experience in cropping the operated plots, adoption of modern varieties, number of operated barley plots). Land, labour, and animal are the most important conventional inputs. The average input use for labour and animal is respectively 70 person days and 40 oxen days. The fertilizer (urea) is distributed by the agricultural extension and was used by 147 farm households. Regarding the environmental and soil conditions faced by the farms in the sample, we have that on average 5% of the operated plots are affected from severe erosion and water lodging problems and 7% are located on steep slope. The most important problem is the low productivity of the soil. Indeed, on average 37% of operated plots by the household was classified as infertile. On average, more than nine years were spent cropping the plots (with a maximum of 14 years and a minimum of one year). Production is quite fragmented. On average almost 3 plots are operated per household. The adoption of improved seeds seems quite limited with only 25 households over 205 using improved varieties.

4. Estimation Procedure

Equation (4) can be interpreted as a standard regression model where the dependent variable is barley production ($y = g(x, v)$), $f_1(x, \beta_1)$ is the regression line representing mean effects, and $\{[f_2(x, \beta_2) - (f_3(x, \beta_3)/k)^{2/3}]^{1/2}\, e_2(v) + [f_3(x, \beta_3)/k]^{1/3}\, e_3(v)\}$ is an error term with mean zero, variance $f_2(x, \beta_2)$ and skewness $f_3(x, \beta_3)$. The error term exhibits possible heteroscedasticity (given by $f_2(x, \beta_2)$) and skewness (given by $f_3(x, \beta_3)$). Following Antle (1983), the parameters (β_1, β_2, β_3) in (4) can be consistently estimated as follows. First, estimate the regression model

$$y = f_1(x, \beta_1) + u_1, \tag{8a}$$

yielding β_1^e, a consistent estimator of β_1, and the associated error term $u_1^e = y - f(x, \beta_1^e)$. Second, consider the regression models

$$(u_1^e)^i = f_i(x, \beta_i) + u_i, \tag{8b}$$

$i = 2, 3$. Applying feasible generalized least-squares to (8b) generates consistent estimators of the parameters β_i, $i = 2, 3$ (Antle, 1983). However, note that the variance of u_1 in (8a) is $f_2(x, \beta_2)$, and the variance of u_i in (8b) is $[f_{2i}(x, \beta_{2ie}) - f_i(x, \beta_{ie})^2]$, $i = 2, 3$ (see Antle, 1983). It follows that both equations (8a) and (8b) exhibit heteroscedasticity, which needs to be taken into consideration in the estimation of the parameters. Heteroscedasticity suggests using a weighted regression approach to capture efficiency gains, where the optimal weights are given by the inverse of the variance of the error terms. However, this requires positive weights. As noted by Antle (1983), the estimated variances for u_2 or u_3 are not guaranteed to be positive. In situations where the weights are found to be non-positive for some observations, this precludes the use of the weighted regression approach in (8b). As a result, we proceeded as follows. We found the weights to be positive in the estimation of (8a) and proceeded to estimate this equation by weighted least squares. However, we found weights to be negative for some observations in (8b). In this case, we used least squares to obtain consistent parameter estimates for the variance and skewness equations. Knowing that heteroscedasticity affects the estimated standard error of the parameters, we calculated White heteroscedasticity-corrected standard errors. This provides the basis for the hypothesis testing reported below.

5. Results

We examined whether the model may be subject to endogeneity bias. This would occur if some of the explanatory variables are correlated with the error term. For example, if the measure for biodiversity (the margalef index) were correlated with the error term, the least-squares estimate of the effects of variety richness on the mean, the variance and the skewness of output would be biased due to endogeneity. A similar situation may also arise with respect to land or fertilizer use. They can be choice variables. Thus, the potential presence of endogeneity needs to be addressed. We tested for endogeneity is using a Durbin-Wu-Hausman test, which compares least squares estimates with estimates obtained from an instrumental variable estimator. This means that valid instruments must be identified. Finding suitable instruments can be difficult (see Davidson and MacKinnon, 1993; Wooldridge, 2002). We used lagged land value, distance from the market (in Km), and distance from the input supplier as instruments. We failed to find statistical evidence of significant endogeneity related to biodiversity, fertilizer or land.

The econometric results are reported in Table 3 for the mean function, the variance function and the skewness function. A linear-log specification was used for the mean function. Also, the variance and the skewness functions were each assumed to be linear.6 In the mean function (reported in column A, table 3), conventional inputs have positive marginal effects, consistent with theory. Labour and land have statistically significant effects, while oxen use and urea use are not statistically significant. Among the conventional inputs, land is the most effective input. Land displays a production elasticity of 0.52, compared to the one of labour that is 0.22. The effect of biodiversity on production is captured through two terms: a linear term and an interaction term with land degradation. Only the former was found statistically significant in the mean function. Biodiversity is found positively and significantly related with production. Therefore, increasing the number of varieties grown by the farmers affect positively the quantity produced. The potential benefit of biodiversity on production seems very large: the elasticity of production with respect to biodiversity is 0.55.

Altitude positively affects barley productivity, probably due to the relatively cooler temperatures that are associated with higher elevation. Soil erosion and water lodging problems

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6 Alternative functional specifications were estimated for the mean, the variance and the skewness functions. However, these specifications were less robust than the one presented in the paper.

have a significant and negative effect on production. Same effect is found for the variable “steep slope”. Therefore, a larger share of farmland on steep slopes affects negatively the quantity produced. In contrast, a larger amount of fertile land affects positively production. These two effects, however, are not statistically significant. Among the set of managerial variables, only the number of plot is statistically significant. The estimated coefficient for plot is positive and significant.

Regression results for the variance function are shown in Table 3, column B. Biodiversity is found to be statistically significant both in the linear form and in the interaction with land fertility. Biodiversity increases the variance of output. The negative sign of the coefficient of the interaction, however, implies that the effect of variety richness is sensitive to the share of fertile land. The marginal impact of biodiversity is found to be positive for the full range of values represented in the sample when fertility is at the sample mean, but becomes negative when the share of fertile land becomes large (above 80% of the operated plots).

[TABLE 3]

The share of barley production on fertile land contributes positively and significantly to the variability of yield. Increasing land, also, increases the variance of barley production. Among the managerial variables, plot, the amount of land in alternative crops and experience are all statistically significant. It is important to stress that if the variance were taken to be the only measure of risk, Table 3 (column A) suggests that biodiversity and fertility should be considered risk-increasing inputs. As such, they would have a negative effect on the welfare of risk averse farmers. However, as discussed earlier the concept of variance does not distinguish between upside and downside risk. Indeed, under very difficult agro-climatic conditions, farmers may be especially averse to “downside risk” effects, which the variance fails to capture. These issues are investigated in detail below in the simulation section.

Regression results for the skewness function are shown in Table 3, column C. Biodiversity is positively and strongly related with the skewness of the output. This identifies that increasing the number of grown varieties hedges against the risk of crop failure. More varietal diversification, in this type of agriculture, is desirable to reduce the exposure to downside risk and insure that food production would not fall below some threshold level. Households producing barley at higher altitudes are less exposed to risk, perhaps because cooler temperatures reduce yield variability. Labour use has a positive marginal effect on yield variability, and more use of oxen appears to reduce risk. These coefficient are, however, not statistically significant. Production fragmentation across multiple plots has a negative and statistically significant effect on the variance of yields. This may be due to the diversification of production conditions. The steep slope of the plots is found to increase farmers’ exposure to risk.

6. Simulation

To analyze the economic and welfare implications of our econometric results, we present a simulation exercise on the effects of crop biodiversity. The contribution of diversity on mean revenues, risk premium and certainty equivalent is investigated under two different scenarios. The first scenario assumes the values of all the variables included in the model at sample means. The second scenario simulates the role of diversity when land fertility is higher than the sample mean. This will shed some light on the relative beneficial effect of diversity in reducing risk. The simulations are reported assuming that the decision maker's risk preferences exhibit constant relative risk aversion, with a coefficient of relative risk aversion equal to 2.7

Figure 1 reports the results from the first scenario. Diversity increases mean revenues for all the range of values. This indicates that diversity has a very important role in supporting agricultural productivity. To investigate the distinct effect of biodiversity on both variability and crop failure, we use equations (6)-(6') to decompose the total risk premium into a variance component R_{a2} and a skewness component R_{a3}. The skewness component captures the role of crop failure in risk management. The risk premium as a whole, $R_a = R_{a2} + R_{a3}$, becomes smaller when diversity becomes lager. Thus, diversity reduces the cost of uncertainty. The risk premium decomposition clearly identifies the role of skewness and downside risk exposure. The effect of diversity on the variance component R_{a2} is modest and slightly positive. However, this effect is largely dominated by the strong role of diversity in reducing the risk of crop failure. The results show that biodiversity tends to increase risk (variance component) and decrease downside risk (skewness component) when fertility is at or below the sample mean. Diversity could, in a sense, increase fluctuation. But figure 1 shows that the implication of diversity on the cost of risk is dominated by its effect on skewness. This is captured, also, by the certainty equivalent. It does increase throughout the range of diversity values.

Figure 2 presents the simulation when the level of fertility is high (i.e., above the sample mean). While the impact of biodiversity on expected revenue is similar to the one exhibited in figure 1, the contribution of diversity on the variance component is different. Indeed, under a higher level of fertility, diversity is now found to reduce yield variability. Also, the contribution

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7 Following Pratt, under constant relative risk aversion r > 1, the utility function is $U(\pi) = -\pi^{1-r}$, which satisfies (-U"/U') π = r. Empirical estimates of relative risk aversion have typically varied between 1 and 4 (Gollier, p. 31). Therefore, our estimate (r = 2, with corresponding utility function $U(\pi) = -1/\pi$) represents to a case of moderate risk aversion.

of the skewness component of the risk premium is now found to be smaller. This identifies that when the land is more fertile, the contribution of diversity in reducing crop failure is relatively more modest. This suggests that, as far as risk management is concerned, land fertility and diversity behave as substitutes, as that the role of downside risk exposure becomes more important as land fertility decline. While diversity is found to contribute to increased agricultural productivity, its effect on risk (and especially downside risk) becomes of greater value under degraded land. In this context, diversity is found to deliver important payoff by reducing the cost of risk exposure (including the risk of crop failure on more degraded land).

7. Conclusions and future research

This paper presented an assessment of the role of crop of biodiversity in risk management. Using data from a survey conducted in the region of Tigray, Ethiopia, we analyzed the contribution of barley diversity on the mean, variance and skewness of production. The effects on the skewness capture exposure to downside risk (e.g., the probability of crop failure). We found that maintaining a larger number of barley varieties in the fields supports productivity and reduces the risk of crop failure. We found evidence that the role of diversity in reducing the risk of crop failure helps reduce the cost of risk (as measured by a risk premium). In general, the skewness effect can differ from the variance effect. In the context of biodiversity effects evaluated at sample means, we found that the skewness effect dominates the variance effect. Thus, under such circumstances, reducing the odds of crop failure can be more relevant that reducing yield variance. This seems particularly relevant in the context of the current literature. Farm household are usually assumed to be "fluctuations adverse" (Dercon, 2004). Thus, they suffer a welfare loss when they experience variability and risk in their production or consumption pattern. However, the results presented in this paper indicate that the variance may not provide an accurate characterization of risk exposure. Also, land fertility plays an important role in risk management. Growing more fertile land affects positively the skewness of production. We found that, as far as risk management is concerned, land fertility and diversity tend to behave as substitutes. While diversity contributes to increased agricultural productivity, its effect on risk (and especially downside risk) becomes of greater value under degraded land.

The findings of this paper are based upon data drawn from a one-year survey. To our knowledge this is the only Ethiopian survey recording farm household data on crop biodiversity. This prevented us from addressing issues related to the dynamics of management decisions. Future research is needed to address such issues.

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Table 1. Variables list and definitions

Urea	Fertilizer use (1=Yes; 0=No)
Land	Land for barley (in logs)
Labour	Labour in person days (in logs)
Animal	Animal in oxen days (in logs)
Biodiversity	Margalef index for biodiversity [(number of barley varieties)/ln(barley area)-1]
Biodiversity*land fertility	Interaction between biodiversity and fertility
Altitude	Household altitude
Steep slope	Share of land on steep slope
Severe erosion	Share of land affected by severe erosion and water lodging
Fertility	Share of land on medium/ high fertility
Plots	No of operated plots
Land in other crops	Share of land allocated to other crops (in logs)
Experience	Number of years of cropping the plots
Improved seed adoption	Adoption of improved seeds (1=Yes; 0=No)

Table 2. Descriptive statistics

Variables	Mean	Std deviation	Min	Max
Urea	0.6061	0.4897	0	1
Land	7.9391	0.8262	5.5947	9.5742
Labour	4.1690	0.6401	1.7918	5.6768
Animal	3.5688	0.5808	1.0986	5.4161
Biodiversity	0.1655	0.0523	0.1166	0.4074
Biodiversity*land fertility	0.1047	0.0620	0	0.3548
Altitude	2323	302	1500	2988
Steep slope	0.0764	0.2045	0	1
Severe Erosion	0.0550	0.1579	0	1
Fertility	0.6306	0.2925	0	1
Plots	2.9913	1.5180	1	11
Land in other crops	8.2814	1.1972	-1.204	9.815
Experience	9.2124	2.1724	1	14
Improved seed adoption	0.0996	0.3001	0	1

Table 3. Mean, variance and skewness function, estimation results

Variables	Mean Function (A) $f_1(x, \beta_1)$	Variance Function (B) $f_2(x, \beta_2)$	Skewness Function (B) $F_3(x, \beta_3)$
Constant	-1618.92*** (279.9)	2.058 (2.34)	-94.15*** (28.6)
Urea	11.022 (21.8)	0.189 (0.33)	1.12 (3.48)
Land	136.118*** (16.2)	0.521*** (0.18)	4.083* (2.2)
Labour	56.08* (30)	-0.413 (0.4)	-1.046 (4.2)
Animal	16.38 (35.6)	0.48 (0.4)	2.16 (5.32)
Biodiversity	1641.99* (982.7)	17.41*** (5.021)	335.21*** (75.9)
Biodiversity*land fertility	-1210.39 (1109.49)	-21.72** (9.43)	-366.1*** (100)
Altitude	0.128*** (0.00383)	-0.0000035 (0.000059)	0.00659 (0.0058)
Steep slope	-39.068 (57.34)	0.697 (0.79)	-7.407 (8.12)
Severe Erosion	-164.846** (72.67)	-0.468 (0.9)	-13.079 (11.54)
Fertility	162.9855 (183.2)	3.45** (1.64)	55.38*** (19.12)
Plots	19.29345** (9.2)	0.257*** (0.0092)	1.17 (1.25)
Land in other crops	-17.06 (16.48)	-0.242*** (0.0089)	-0.71 (1.5)
Experience	4.53 (4.8)	0.102[a] (0.007)	-0.302 (0.75)
Improved seed adoption	-31.0138 (31.17)	-0.202 (0.39)	-3.577 (5.3)

N = 205; R-squared= 0.47; Breusch - Pagan chi-squared = 91.68; F-test = 12.37;
Diagnostic: Log-L = -1323.3, Restricted Log-L = -1389.7; White standard errors are in parentheses. Estimated mean, variance and skewness, respectively: 260, 23684.47 and 2993784. Significance levels are denoted by one asterisk (*) at the 10 % level, two asterisks (**) at the 5 % level, three asterisks (***) at the 1 percent level and one a ([a]) 10% with two sided test.The estimated coefficients in the skewness equation have been rescaled and divided by one million.

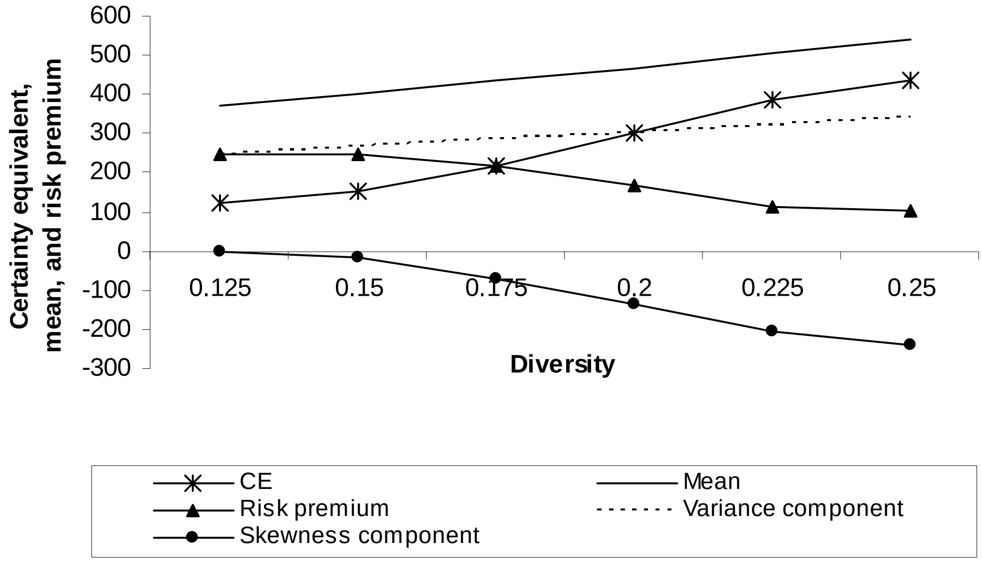

Figure 1. Certainty equivalent, mean revenue and risk premium, simulation results at sample means. Values are in Birr.

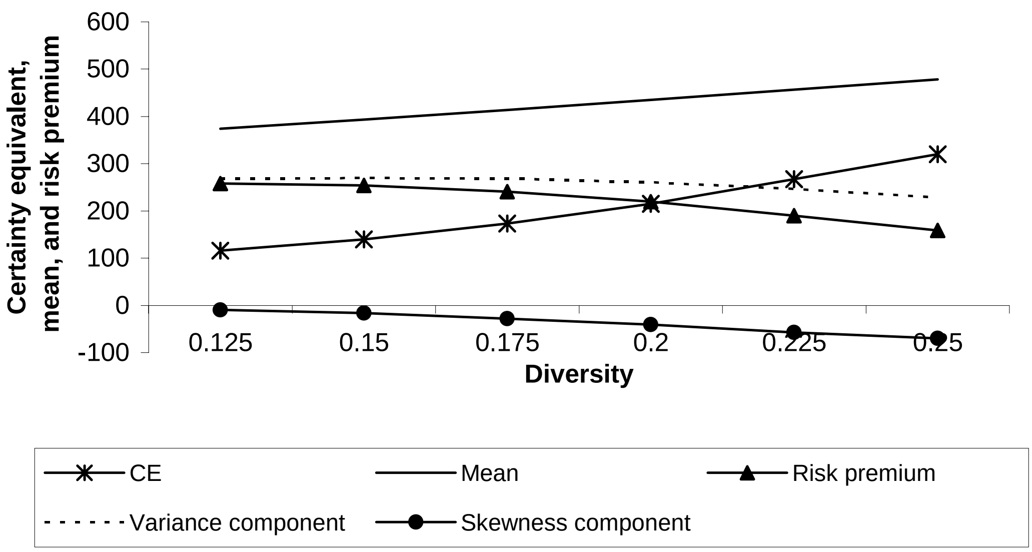

Figure 2. Certainty equivalent, mean revenue and risk premium, simulation results for high levels of fertility. Values are in Birr.