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Modern variety adoption and risk management in drought prone areas: insights from the sorghum farmers of eastern Ethiopia

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Abstract

Adoption rates of improved or modern varieties (MV) of sorghum in eastern Ethiopia are generally low. Although these MV may represent an effective means of coping with droughts, given their early maturing traits, landraces could prove to be more drought-tolerant and better adapted to marginal production conditions. Whether MV adoption is a risk reducing technology is very much an empirical question which this article investigates using a unique dataset from eastern Ethiopia in a year of extreme weather conditions. Results show that risk-factors coupled with access to markets and social capital drive farmers' decisions to adopt MVs. On the one hand, it appears that farmers use MVs to mitigate moderate risks. On the other hand, farmers who have been most vulnerable to extreme weather events are less likely to use MVs suggesting that MV adoption does not necessarily represent an effective means of coping with drought. Finally, findings show that MV growers are more likely to be affected by sorghum failure once controlling for exogenous production factors.

JEL classifications: D81, O12, O13, Q12, Q54

Keywords: Ethiopia; Farm household; Agrobiodiversity; Landraces; Modern varieties; Climatic risks; Food security

1. Introduction

Improving farm level resilience to agricultural production shocks is essential to reducing poverty and improving household food security throughout the developing world, particularly in areas at high risk of climatic shocks and with a high percentage of the population dependent on agriculture as in Ethiopia. One of the primary causes of household food insecurity in Ethiopia is the risk of agricultural production failure due to drought, resulting in reduced harvest and farm incomes (Dercon et al., 2005; Doss et al., 2008). Such shocks, although transient, tend to have a persistent impact on household consumption levels in Ethiopia (Dercon, 2004), worsening chronic problems of low yields and food insecurity rooted in poverty (Sperling and Cooper, 2004). Dercon et al. (2005) found that households in Ethiopian villages that are affected by at least one drought within 5 years face a 20% lower per capita consumption level over the same time period.

The Ethiopian government is pursuing a strategy of improving agricultural productivity primarily through agricultural intensification, involving an increased use of inputs, including seeds of improved crop varieties (Byerlee et al., 2007; McGuire, 2005). Considerable resources have been devoted to the development and dissemination of modern varieties (MV),[1] however adoption rates have been low, and farmers maintain the use of

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Data Appendix Available Online

A data appendix to replicate main results is available in the online version of this article. Please note: Wiley-Blackwell, Inc. is not responsible for the content or functionality of any supporting information supplied by the author. Any queries (other than missing material) should be directed to the corresponding author for the article.

[1] In this article, we use the term modern varieties interchangeably with improved varieties to refer to crop varieties that are the result of a process of scientific breeding programs as opposed to traditional varieties or landraces that are the result of farmer selection. Included in our definition of modern varieties are those developed through the process of pure line selection conducted by scientific breeding programs.

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landraces (LR) for many crops and in many areas of the country (Byerlee et al., 2007).

LRs are the product of centuries of selection by farmers and the natural environment. They are typically adapted to specific agro-ecological conditions and usually grown with very little capital inputs, such as fertilizers, pesticides, or irrigation. Ethiopia is particularly rich in local crop genetic diversity as it is the center of origin and diversity for several crop species, including sorghum, the focus of the present article (McGuire, 2005; Tanto and Demissie, 2000; Vavilov, 1992).

There are several reasons why farmers may prefer LRs over improved varieties. The country's tremendous variation in altitude, temperature, rainfall, soil type, and ecological settings, as well as the diverse "environments" in which Ethiopian farmers cultivate their crops gives rise to the need for a wide range of adapted crop varieties, which the formal plant breeding system is incapable of meeting. In general, research efforts to breed improved varieties have primarily concentrated on more favored and high-potential environments in which the increase in productivity and yield response to complementary inputs is high (Bellon, 2006). In contrast, LRs are generally the product of farmer selection for adaptation to specific environments (FAO, 1998; Mekbib, 2006). High genotype-environment interactions can result in higher performance from LR compared with improved varieties (Bellon, 2006; Ceccarelli et al., 2001). These "crossover" effects (i.e., changes in the rank of genotypes between environments) tend to be more common in marginal environments and in farming systems with low capital inputs where LRs are often found to perform better than improved varieties (Bellon, 2006; Matlon, 1990; McGuire, 2005; Mekbib, 2006). The photoperiodicity of LRs, that is the sensitivity of their biological functions to the duration of light, is another potential factor affecting farmers' choice of varieties, as it provides an important mechanism of environmental adaptation. Photoperiod sensitive varieties can better adjust to changes in rainfall patterns, and avoid problems of mold, insect, and bird damage that affect many early maturing varieties (Traoré et al., 2007). Uncertainty over the length of growing period and the initiation of the rainy season generate high values for photoperiodic varieties that allow the farmer to respond to a range of planting dates (Niangado, 2001; Traoré et al., 2007). Improved varieties are generally not photoperiod sensitive and often reducing or eliminating this factor to broaden the range of adaptation is an objective of breeding programs. These factors might, at least partially, explain the low adoption rates of improved varieties and high levels of sorghum crop genetic diversity persisting in Ethiopian farmers' fields.

Sorghum is a crop essential for food security throughout semi-arid Sub-Saharan Africa. Drought stress impacts on sorghum can occur at seedling, pre-flowering, and post-flowering (Rosenow et al., 1983). Yield impacts depend on the timing and length of drought, as well as the characteristics of the varieties in use and their response to the type of drought stress. Varieties may have characteristics that allow it to "escape" from drought or resist its negative impacts, by either maintaining a more favorable water balance or by protecting cellular functions from dehydration (Tuberosa and Salvi, 2006). Early maturing improved varieties fall into the first category, whereas LRs have traits (including photoperiodicity) related to the second category. Early maturing varieties (early flowering) can be effective in addressing late-season drought stress and have lower total seasonal evapotranspiration (Blum, 2010). Early maturing improved varieties have been shown to be effective in reducing downside production risk in some situations in Sub-Saharan Africa (Ahmed et al., 2000; Matlon, 1990; Mekbib, 2006). However, adoption rates of such varieties in the area have generally been very low (Ahmed et al., 2000; McGuire, 2005).

Understanding the motivations and constraints of farmers in adopting improved sorghum varieties designed to reduce a major source of production risk is thus essential in designing an effective strategy for intensifying agricultural production. The literature shows that risk is a major factor in the decision to adopt modern crop varieties (Antle and Crissman, 1990; Feder, 1980; Just and Zilberman, 1983; Smale et al., 1994). Empirically assessing the risks associated with MV versus LR adoption in the drought prone and highly variable production environment of Ethiopia and its impacts on variety choice is thus an important one to understand in moving ahead with agricultural development strategies for the country.

In this article, we explore how agricultural households in the Hararghe region of eastern Ethiopia manage their diverse set of sorghum varieties to cope with risks of crop failure. We use a unique dataset from an area rich in local sorghum genetic diversity and with high rates of poverty. Sorghum is the most extensively grown crop in the area, cultivated primarily for subsistence needs and critical for food security. Data from a shock year provides us with an opportunity to explore the role of genetic resource utilization in risk management. Although early maturing improved varieties of sorghum, developed as a means of coping with drought, have been disseminated in the area, only 11% of farmers in our sample were found to be MV adopters, consistent with findings from other studies (McGuire, 2005; Mekbib, 2006). The question we explore in this article is the role of sorghum MV adoption in coping with downside risk exposure (i.e., probability of crop failure) in the context of a low productivity agricultural system, subject to frequent climate shocks, where most of the population is poor, but local genetic diversity for the crop is abundant.

The remainder of this article is organized as follows: Section 2 presents the case study background and draws special attention to the forces affecting supply and demand of variety selection in eastern Ethiopia. Considering MV adoption as a technology choice, a conceptual framework is presented in Section 3 that addresses the following two questions: (i) what is the role of downside production risk in the decision to adopt MVs? and (ii) to what extent are improved sorghum varieties effective in reducing downside production risk in the Ethiopian context? Section 4 includes the econometric model and empirical results. Finally, Section 5 concludes by discussing the policy implications for the study region.

2. The case study background

Ethiopia is one of the poorest countries in the world with high rates of food insecurity, and where many people depend on small-scale, low-productivity agriculture (Shiferaw and Holden, 1999). Drought is a major problem hobbling agricultural productivity in the country. In the 2000–2001 and 2002–2003 production seasons major drought affected the food security of over 10 million people (Bramel et al., 2004).

The dataset used in this article was collected during the 2002–2003 drought period in the Hararghe region of eastern Ethiopia. The sampling at household and community level was designed around seed system interventions carried out by the Hararghe Catholic Secretariat (HCS), a nongovernmental organization operating in the area. HCS' small-scale seed intervention comprised seed selection, multiplication, and distribution of both LRs and improved varieties of wheat and haricot beans and to a lesser extent sorghum.[2] The surveys were undertaken in two rounds, the first one at the end of the main crop planting season in August 2002 and the second one after harvest in January/February 2003. The data comprises 720 households from 30 peasant associations (PA) located in the highland and midland regions. The PAs belong to three woredas (i.e., districts) namely Chiro, Meta, and Dire Dawa, representative of the main agro-ecological zones in the region.

Sorghum is the most important staple crop in the study region. It is mainly cultivated for subsistence purposes.[3] It provides over one third of the cereal diet and is almost entirely grown by subsistence farmers to meet needs not only for food and income but also for feeding animals, brewing, and construction purposes (McGuire, 1999, 2005; Mekbib, 2006).

2.1. *Modern variety adoption in Haraghe region*

Given the importance of sorghum for food security in the drought prone areas, the development of early maturing, drought escaping varieties have been a main focus of breeding programs in Ethiopia as well as other areas of Sub-Saharan Africa (Ahmed et al., 2000; Matlon, 1990; McGuire, 2005; Mekbib, 2006).

Table 1 provides an overview of the range of sorghum varieties identified in the study, with a description of the variety traits or characteristics and classified into MVs or LRs. Before moving into describing how varieties were classified as improved or LR, two important points need to be made. First, almost all of the MVs farmers reported using in this study were sourced from the "informal" seed sector. Hence, they are not certified seeds but rather recycled seeds. Second, since sorghum has a low rate of outcrossing for pollination, there is the possibility that LRs and MVs are cross-pollinated in the field, resulting in varieties that combine genetic material from both. However, information from the agro-morphological characterization as well as related studies on sorghum variety management in the area indicate that LRs are fairly stable and distinct (Mekbib, 2006).

Given these premises, our variety categorization is based on variety names, triangulating information from farmers' categorization[4] with information from breeders and secondary sources on variety identity. We categorized a variety as a MV either when the variety name given by the farmer was associated only with a MV (as confirmed by breeders and secondary sources), or in cases where farmers identified a variety as improved, and information from breeders and secondary sources confirmed that indeed an improved version with that variety name existed in the area. The reason this was necessary, is that given the large utilization of farmers' varieties for sorghum in the area (Mekbib, 2006), a number of breeding initiatives have been carried out in the region to improve the performance of the most common and adapted LRs.[5] These breeding efforts were mainly based on pure line selection of some selected farmers' varieties and focused on using mainly early maturing traits. Even though the outcomes of such breeding efforts were given a scientific name, they were often disseminated using the name of the local variety they were derived from. While the intention was apparently to enhance adoption through use of a familiar name, it introduced confusion in terms of variety identity. The same variety may in fact be a MV or a LR depending on whether it is the result of breeding effort or not. Essentially our classification of MV versus LRs is based on verifying information from farmers on variety name and classification, with that from secondary sources and local breeders. Our intention is, to the extent possible, to classify varieties into MV and LR categories based on principles of scientific plant breeding, rather than farmers' taxonomy. While we recognize the latter is very important in understanding varietal choice and utilization decisions, for the question we are concerned with in this article, the plant breeding classification is more relevant.

Table 2 reports the extent of MV adoption and intra-crop (i.e., within crop) diversity amongst sorghum growers. The table also compares the differences in means for MV and LR growers for reported variables using *t*-test statistics, as reported in the last column. Within the sample of 446 sorghum-growers, MV adoption rates are rather low. Nearly 89% of the households (396 households) cultivate solely LRs, and only 11% of the households adopt MVs. Of these, about one third is represented by "partial adopters" in the sense that they grow MVs[6] in addition to LR. Accordingly, the overall land area planted with MVs

[2] Data are based on a random sample of households stratified with regard to participation in the HCS-programs.

[3] Only 1% of the sample households sell part of the sorghum production on the market.

[4] While we acknowledge the limitations of using farmer variety names, attempts to improve varietal identity were made via focus group discussion, key informant interviews as well as agro-morphological characterization.

[5] Mainly muyra, muyra red and muyra white, and wegere.

[6] With 1/2 to 2/3 of their sorghum area dedicated to MV.

Table 1
Classification of sorghum varieties grown in Hararghe region, 2002–2003

Name[1]	Description	Adoption rate (%)	Land area[2]	Frequency of cultivation	
				LR	MV
Muyra Red	It is a type of Muyra characterized by red color grains.	28.70	1.52	126	17
Muyra	It is a very common variety in the area, characterized by goose neck and compact head.	12.40	1.93	54	8
Abdelota 'Alaa'	It means Juicy.	11.00	4.55	55	
Masugi Dima	It is a type of Masugi variety characterized by red color grains.	10.40	3.29	52	
Geldi	Landrace but because it is mainly distributed by HCS or vendors some farmers believe it is an improved variety	6.40	0.99	32	
Itibele	The name of this variety indicates a very red variety, usually characterized by compact head.	6.20	3.32	31	
Chafarae	Is has dispersed/loose panicle.	5.20	3.01	26	
Fendisha	"pops." It is characterized by straight and semi-compact head. It is a variety that makes good injera and it is very easy to store. Disadvantage is that it needs a longer growing season as it needs 10 months. High yielding under good rain conditions but easy to lose if not enough rain.	5.20	1.31	26	
Wegere	It is characterized by white seeds and semi-compact goose neck head. Two varieties of wegere have been released by Alemaya: AL 70 in 1970 and ETS 2752 in 1978. Both have white seeds and similar panicle.	5.20	2.21		26
Chekore	It is characterized by straight head.	3.60	1.58	18	
Masugi Adii	Masugy type of variety of white color.	2.60	2.97	13	
Masugi Dalech	Masugy type of variety of grey color.	2.20	2.85	11	
Dima	It is a very distinct red type of sorghum.	1.80	3.45	9	
Gebabe	It is characterized by very short stalk, which is usually a disadvantage but can be an advantage in steep slopes or in areas susceptible to wind where lodging is a problem and short stalk is preferred. Short stalk is also good for intercropping with chat or coffee.	1.60	2.94	8	
Zengada	It is usually utilized for making local alcohol (beer) and it is not good as food.	1.40	2.45	7	
Amajigta	It means "does not lodge." Distributed by HCS or farmer vendors.	1.20	1.58	6	
Hamdea	It means "thank to God" and indicates a good quality. It is a particular type of Muyra.	1.00	1.24	5	
Jammal Abdala	It is a landrace that indicates the name of the person that first distributed that variety in the area.	1.00	1.38	5	
Bele	It is an early maturing variety.	0.80	3.63	4	
Muyra Aliso	It is a particular type of muyra.	0.80	1.32	4	
Ahmed Isee	Landrace. It indicates the name of a person.	0.60	1.39	3	
Daslee	Landrace. Not very common or easy to find but with very good performances.	0.60	1.86	3	
Filatta	Very rare landrace variety.	0.60	1.62	3	
Muyra White	It is a type of muyra characterized by white color.	0.60	2.50	1	2
Wahelu	No information available.	0.60	1.17	3	
Warabi	It is a term that relates to the variety performance. It means "we have something" and usually indicates resistance to drought.	0.60	0.92	3	
Aliso	It is a particular type of muyra.	0.40	0.75	2	
Cherchero	It is short and early maturing.	0.40	0.63	2	
Katamara	Rare landrace.	0.40	1.00	2	
Mesengo	It is very rare to find. Landrace.	0.40	2.80	2	
Muyra Chekore	Black type of muyra with straight head.	0.40	0.98	2	
Muyra Dini	Red type of muyra.	0.40	0.88	2	
76 T1 #23 (Mv)	It was released in 1979 by Alemaya and Melkasa Research center. Also distributed by HCS.	0.20	1.00		1
Adem Mussa	It is the name of the person that first distributed the variety in the area.	0.20	2.00	1	
Bamiliq	It is a term which means "meets the challenge," "escape the problem," and it indicates a good resistance. It is an early maturing variety.	0.20	4.00	1	
Bishinga Dima	It is a red type of sorghum variety.	0.20	5.10	1	
Feshe	Very rare. Landrace.	0.20	3.00	1	
Qillee	Very rare. Landrace.	0.20	0.50	1	
Sharitae	It is a very rare variety about which no particular information is available.	0.20	0.25	1	
Other		0.20	4.00	1	
Total				527	54

[1]Varieties are in descending order of rate of adoption.
[2]Mean value in timmad conditional on utilization of the respective variety.

Table 2
Extent of modern variety adoption and intra-crop diversity among LR growers and MV adopters

	Total	Only LR growers	MV adopters	*P*-value*
No of households	446	396	50	
Total land area in timmad	4.25	4.36	3.45	0.048
Sorghum land area in timmad	2.55	2.59	2.23	0.241
Area allocated to LRs in timmad	2.35	2.59	0.42	0.000
Area allocated to MVs in timmad	0.20	–	1.82	–
Average number of varieties	1.17	1.13	1.42	0.000
Intra-crop Shannon index	0.11	0.09	0.26	0.000
Intra-crop Simpson index	0.07	0.06	0.18	0.000
Intra-crop Berger index	1.13	1.11	1.29	0.000

Notes: **P*-value computed by a two-sided *t*-test.
Source. Authors' calculation using FAO Netherlands Partnership Programme (FNPP): Seed System Impact on Household Welfare and Agricultural Biodiversity data set.

is rather small, covering only about 8% of the total sorghum land area. No significant differences are reported in the total area planted to sorghum between the two groups, while LR growers seem to have a slightly larger land extension than MV adopters significant at 5% level. On average, MV adopters allocate slightly more than 80% of their land area under sorghum to MVs (1.82 timmad[7]).

As most farmers only use one variety, the extent of on-farm intra-crop diversity in the study area is rather limited. Only 13% of LR growers cultivate more than one sorghum variety, whereas 38% of the MV adopters do so. This implies that the latter manage significantly higher levels of on-farm sorghum diversity, as can be seen from results on various measures of diversity including the variety count, the Shannon and Simpson index for proportional abundance and the Berger index for relative abundance[8] reported in Table 2. Only one of the MV growers that cultivate more than one variety uses more than one improved variety. All the others use a mix of traditional and improved varieties.

According to local experts, LRs are normally preferred to early maturing MVs since the latter generally yield fewer desired traits and lower amounts of straw residues for feed and construction purposes (Lipper et al., 2005; McGuire, 2005). In effect, it appears that improved varieties are likely to supplement, rather than substitute for LRs, similar to the findings of Benin et al. (2006) for wheat and maize in the highland areas of northern Ethiopia and by Ahmed et al. (2000) in other areas of Sub-Saharan Africa. Environmental heterogeneity and experimentation with new varieties have often been found to result in partial adoption (Bellon and Taylor, 1993).

Whether MVs represent a threat to crop genetic diversity, a concern raised in many contexts (see e.g., Brush, 1995; Brush et al., 1992; Frankel, 1970; Harlan et al., 1973; Hawkes, 1983) is thus uncertain and depends on the long term implications of current adoption patterns, as well as on the measures of diversity considered. Smale (1997) argues that MVs displacing LRs does not necessarily imply a reduction of genetic material in the field. She observes that since MVs may be crosses between a number of LRs and other MVs, a new MV might preserve LR genetic material and yet bring new genetic material into the existing population (Smale, 1997).

Our data indicate that MV sorghum growers dedicated a smaller portion of land to LR varieties at the time of the survey. To the degree this represents a trend, LR area could significantly diminish. At the community level however, LR growers are still the vast majority for sorghum and thus MV adoption might in effect be adding to diversity rather than diminishing it.

An understanding of both the demand for, and the supply of, crop genetic resources is needed to understand variety choice (Bellon, 2004). This includes consideration of the types of varieties needed to fit the specific production and consumption requirements of the farm household, as well as the availability of and accessibility to varieties that can meet them (Bellon, 2004). The following sections address these questions.

2.2. *The formal seed sector and seed supply*

Limited seed industry development and barriers to seed marketing, together with poorly targeted crop breeding policies hinder widespread adoption of modern crop varieties in Ethiopia (Ahmed et al., 2000; Byerlee et al., 2007; McGuire, 2005; Mulatu, 2000). Difficulties with seed quality and timely delivery have been identified as a problem for farmers using the seed supplied by the formal sector (Byerlee et al., 2007; Lipper et al., 2006). Access to credit is another potential constraint farmers face in obtaining improved sorghum varieties in Ethiopia, as they commonly obtain the seeds of such varieties, as well as other production inputs, via credit packages from the government extension service (Mulatu, 2005). These problems are mostly related to obtaining formal sector certified seed of improved varieties. Farm-saved and sales in local markets of recycled open-pollinated improved varieties are other widely used means of accessing improved varieties.

Farm-saved seed is the main seed source for most Ethiopian sorghum farmers (Lipper et al., 2006; McGuire, 2005; Mulatu, 2005). Off farm sources of seed range from gift giving and exchanges via social networks to market transactions. Our sample shows that only about 15.5% of the farmers interviewed had ever used external sources to replace or renew seeds of the varieties in use in 2002–2003 production year. Moreover, although MVs are known by farmers to decline in productivity much faster than LRs, the rate of renewal is higher for the LRs in use (15.1%) than for the MVs (11.5%). In addition, while about 49% of the LR seeds are obtained through gifts and other exchange mechanisms, all MVs are purchased through cash payments at local markets.

[7] One timmad corresponds to 1/8 of ha.
[8] For more information on diversity indexes, see Smale (2005) and Baumgärtner (2002).

Surprisingly, in the sampled population, only 18% of the sorghum MV adopters indicate any difficulty in getting seeds, compared to 31% of the sorghum LR producers. Of the farmers that indicated any preferences for alternative seed sources, rates are about the same for LR growers and MV users. Overall, about 37% of the sorghum growers would like to have planted additional or different varieties with rates being about the same for LR growers and MV users. Interestingly, early maturity was the most frequent trait that farmers reported they would want from different or additional varieties (43%)—considerably higher than good yields in grain (29%).

These results suggest that generally, MVs are as accessible as LRs in the study region, albeit through informal seed sector sources, so that supply constraints are not likely to be the driver for the limited extent of MV adoption. Low adoption rates may thus be due to lack of demand. This is the issue explored in the next section.

2.3. *Demand for sorghum varieties and its traits*

There is not one single variety that is able to satisfy both consumption and production needs at the same time. Hence, farmers demand multiple varieties to meet a range of objectives (Bellon, 1996; Smale et al., 2001). Even if there are no supply side constraints, farmers are unlikely to adopt MVs if they do not provide the attributes farmers need. Several studies have indicated high private values of LRs in Ethiopia across a range of crops (Benin et al., 2006; Lipper et al., 2005; McGuire, 2005; Mulatu, 2000). The sorghum farmers surveyed in this study were asked to rank the most desirable attributes of their varieties. They were given a list of 19 variety characteristics identified through open ended questions during the pilot phase and ranging from production to risk management and to consumption-based attributes. The farmers had the options of providing up to three preferred traits ranking from most to second and third preferred attribute associated with the varieties in use. As Table 3 shows, attributes such as yield and risk management potential appear to be more important than consumption characteristics, although the latter are relatively more important for LR growers.

Unsurprisingly, the most important trait was good yield in grain. MVs are more likely to be associated with higher yields than LRs, as more than 50% of MV users ranked this attribute as the most important trait associated with their variety, while only 36% of LR users do so, and was the only significant difference found between the two groups. Good residues (in straw or grain to use for purposes other than food), in addition to good grain quality and good fodder quality were ranked as less important attributes. Risk management characteristics, such as good adaptability, early maturity, and drought resistance are considered the most desirable attributes for more than 30% of the varieties in use.

A key issue affecting the demand for improved and traditional varieties is their adaptability to marginal and variable production conditions without the use of complementary inputs, which is frequently the case for many Ethiopian farms. Early maturity is a variety trait that may provide farmers with an *ex ante* means of coping with drought, by virtue of the short rainy season required for production and by giving the option of planting twice on the same plot over the two production seasons typical of eastern Ethiopia's agriculture. Another trait farmers may demand is drought tolerance, which refers to the capacity of the plant to adjust water use efficiency over a production season, including photoperiodicity (Tuberosa and Salvi, 2006). Table 3 indicates no significant differences between MV and LR growers with regard to demand for these risk attributes, although a higher percentage of LRs are associated with these attributes (40% vs. 30% for MVs). Given that MVs in the study region have been bred specifically with a focus on early maturity, it is surprising that no significant differences are found between LR and MV growers with regard to reported demand for the trait. Instead the trait was found to be one of the most desirable characteristics for all farmers. When asked about attributes of the varieties farmers would have liked to have planted, 43% of these unavailable varieties were associated with short maturity and 29% with good yields in grain.

Table 3
Most desirable sorghum attributes: MVs vs. LRs

	All varieties	LR	MV	*P*-value
High return				
Good yield in grain	37.5%	36.1%	51.9%	0.027
Good yield in residuals	3.4%	3.2%	5.6%	0.419
Good grain quality	1.5%	1.7%	0.0%	1.000
Good fodder quality	3.8%	3.4%	7.4%	0.138
Risk management				
Early maturity	11.9%	12.1%	9.3%	0.662
Resists drought	11.0%	11.2%	9.3%	0.821
Good adaptability	11.9%	12.1%	9.3%	0.662
Other resistance attributes	4.5%	4.7%	1.9%	0.498
Consumption				
Taste of food/cooking quality	4.8%	5.1%	1.9%	0.502
Other				
Other attributes	2.1%	2.3%	0.0%	0.615
No advantage stated	7.4%	7.8%	3.7%	0.413
Total number of varieties	581	527	54	

Notes. *P-value for a two-sided Fisher's exact test.
Source. Authors' calculation using FNPP: Seed System Impact on Household Welfare and Agricultural Biodiversity data set.

2.4. *Drought and sorghum failure*

In addition to understanding the reasons for MV adoption, it is important to assess how these improved varieties perform under extreme weather conditions, which occur frequently in the study site. As with other crops, sorghum LRs are generally considerably lower in grain productivity as compared with improved varieties when grown under optimal moisture conditions with recommended practices (e.g., Byerlee et al., 2007). However, crossover effects, whereby sorghum LRs outperform

Table 4
Sorghum output 2002/03: LR growers vs. MV adopters

	Total	Only LR growers	MV adopters	*P*-value
Households with sorghum failure%	35.20	36.87	22	0.038
Total area under failing sorghum varieties (in timmad)	0.94	1.00	0.44	0.030
Sorghum loss in % of expected harvest	77.2	78.4	68.2	0.007
Sorghum yield in kg per timmad	86.2	82.1	118.2	0.125

Notes. *P-value computed by two-sided t-test for continious variables and by a Fisher's exact test for sorghum failure.
Source. Authors' calculation using FNPP: Seed System Impact on Household Welfare and Agricultural Biodiversity data set.

improved varieties, have been found under the eastern Ethiopia farms (McGuire, 2005; Mekbib, 2006; Mulatu, 2000). Yet the role of improved sorghum varieties in reducing the risk of crop failure due to drought is potentially more important for the study area, given the high level of rainfall variability. Evidence from other parts of Sub-Saharan Africa have indicated that early maturing, improved varieties of sorghum have been effective in decreasing downside risk (Ahmed et al., 2000; Matlon, 1990).

Given the harsh drought conditions of the production year studied, almost every farmer faced harvest shortfalls and nearly a quarter of the planted crops did not produce any output.[9] In what follows we refer to sorghum (crop) failure when planted sorghum varieties yielded no harvest. Table 4 provides a comparison of performance between MVs and LRs for crop failures. MV adopters have a lower percentage of crop failures than LR growers. Similarly, MV adopters experience a lower percentage of harvest loss and report higher sorghum output.[10] These results suggest that MV varieties perform better than LRs under the adverse conditions of the 2002–2003 production season. Yet these results could be misleading, as the same factors that lead to MV adoption could also indicate a reduced vulnerability to drought, for example location in a favorable agro-ecological zone. To control for these confounding factors requires a multivariate analysis of the factors determining sorghum-failure.

3. Conceptual approach linking risk and modern variety adoption

The adoption of MVs may be considered a technology choice (I). When land endowment is limited and adoption rate low as in the area studied, land allocation models might have limited explanatory power. Technology adoption decisions are particularly important in situations of high food insecurity, where the probability of complete crop failure is rather likely and where risk-averse farmers have limited capacity for *ex post* consumption smoothing. In such contexts we can expect that small-scale farmers choose their production technology to minimize the probability of disaster outcomes, such as complete crop failures (e.g., Moscardi and de Janvry, 1977). Given the high incidence of crop failure in Hararghe under the 2002–2003 drought conditions, understanding the impact of production technologies on the exposure to downside production risks is an important research question. This kind of disaster-avoidance behavior is rooted in the standard household model where the farmer maximizes his expected utility from a bundle of consumption goods, given his production and income constraints.

Staple crop production levels are determined by land area (L_S), a vector of other production inputs, like labor and fertilizer, (X_S), the technology parameter, I, and stochastic weather conditions (ε) conditional to agro-ecological production conditions (Φ_{Agro}):

$$Q_S = q(L_S, X_S, I, \varepsilon;\ \Phi_{\text{Agro}}). \tag{1}$$

Assuming that weather conditions, ranging from extreme drought to flood,[11] follow a normal distribution with a mean of zero, production levels can take zero values, if weather conditions are extremely adverse. In these cases the crop fails given the chosen input levels and technologies. Accordingly, farm households allocate their production inputs and chose their production technologies in order to maximize expected outcome subject to keeping the probability of crop failure below an acceptable level of disaster, $\Pr(Q_S = 0) \leq \alpha$, which corresponds to a safety-first criterion by Telser (1955).

The probability of crop failure, *Pr*, can be described by a vector of weather related risk variables Φ_{Weather}, capturing the sensitiveness of staple crop-production to climatic variability. The acceptable level of disaster, α, is determined by the household's level of risk aversion explained by structural household variables, Φ_{HH}, reflecting household risk preferences, and by household specific means Φ_{Assets} for *ex post* consumption-smoothing like ownership of assets and access to insurance mechanisms and credit.

Accordingly, Φ_{HH}, Φ_{Assets}, and Φ_{Weather} enter the household's technology adoption decision through the safety-first behavior of the household. In subsistence-farming contexts, where households are exposed to extreme poverty and/or food insecurity and highly variable production environments and where markets for certain goods are assumed to be missing or imperfect, we can expect that the farm decisions on their staple-crop production (Q_S), including the varieties to use, will be very much driven by such risk management aspects. Given the scarce resources, high dependence on agriculture for food security, and high risk of food insecurity for farmers in this situation,

[9] Each farmer has been asked about the harvest time of the planted crops on the operated plots. If none of the sorghum planted was harvested or to be harvested they could indicate the "crop failed."

[10] The data on sorghum output is not fully in accordance with the information on sorghum failure. For instance, some farmers report no sorghum harvested, but they do not report any sorghum failure, which would have been expected. This may be due to recall biases, as farmers have been asked about sorghum output in the second survey only, i.e., in January 2003, while harvesting occurs over the entire production season. In contrast farmers were asked about sorghum failure in the first (August 2002) as well as in the second round of data collection.

[11] Likely to occur when rainfall finally come on steep and drought soils.

the minimization of the probability of falling below a minimum threshold of agricultural production to meet subsistence food requirements is a key driver of farm production decisions, including variety choice.

However, variety choice is not only driven by risk management objectives, but also by farmers' demand for a range of variety traits (Bellon, 1996; Smale et al., 2001). Factors, such as consumption related traits like cooking quality and taste may also influence variety choice, so that taste-shifters enter the technology-adoption decision via the vector with structural household variables Φ_{HH}.

At the same time farmers face constraints when adopting new technologies. First of all, there is land constraint given by the total land endowments: $L_S \leq L$. Second, MVs may not be cultivable under the agro-ecological conditions found on the farmer's plots: Φ_{Agro}. Third, certain varieties may not be accessible, so that constraints in form of access to markets for inputs Φ_{Market}, and to social capital, for example, intra-community and inter-community networks for seed exchange Φ_{soc}, enter the technology adoption equation.

The general reduced form solution for technology adoption (i.e., MV adoption) can thus be written as follows:

$$I_{MV} = l_{MV}(L, \Phi_{HH}, \Phi_{\mathrm{Agro}}, \Phi_{\mathrm{Market}}, \Phi_{\mathrm{Soc}}, \Phi_{\mathrm{Assets}}, \Phi_{\mathrm{Weather}}), \tag{2}$$

where the adoption of MVs is explained by total land endowments, household demographics, agro-ecological conditions, market access, social capital, household assets, and weather-related risk variables.

We expect that the farmers who are most sensitive to climatic risk and with the least capacity for *ex post* consumption smoothing would be most likely to adopt a technology that reduces risk. However, whether MV adoption increases or reduces risk in subsistence production systems is context-dependent. As pointed out earlier, for sorghum in Ethiopia the relationship is ambiguous. On the one hand, most MVs are bred with early maturing traits in order to escape drought. On the other hand, most of the LRs appear to be better adapted to the marginal and harsh environment like the one under study and are thus more drought tolerant. Therefore, it is very much an empirical question if MV adoption is a risk reducing technology and can thereby contribute to food security in times of drought.

If MVs are less sensitive to rainfall conditions, they would contribute to lower variability in output and thus reduce exposure to downside risks, such as sorghum crop failure in drought periods. As can be derived from the output function in Eq. (1), failure of any variety depends on the land area cropped, input use, and rainfall levels given a vector of agricultural production conditions. The disturbance term is determined by actual weather conditions in the given production period, that is, $\varepsilon = R$. Therefore, the probability of experiencing any crop failure, F, can be expressed in the following reduced form:

$$F = \mathrm{f}(L_S, X_S, I, R; \Phi_{\mathrm{Agro}}). \tag{3}$$

In this conceptual section two questions have been elaborated (i) are more risk-averse farmers with climatically sensitive production systems more/less likely to adopt MVs (Eq. (2)); and (ii) does MV adoption reduce/increase the probability of being affected by crop failure (Eq. (3)). These are crucial questions to explore in the context of climatic risk and safety-first behavior of farm-households. As both relationships are very much context dependent, these questions have to be addressed empirically to gain insights into the role of MVs in reducing the exposure to downside production risks in the study region.

4. Econometric analysis

In the context of extreme climatic risks, there is a need to go beyond mean-variance approaches. A standard econometric procedure would be to extend Just and Pope (1978) production functions to higher moments, as in Di Falco and Chavas (2009). Yet such methods are based on the assumption of a normal distribution of the stochastic disturbance term, reflecting climatic risks. As we only have cross-sectional data from 1 year of extreme drought, this disturbance term is highly negative, so that the yield distribution is found to be skewed to the right. In order to explore the connection between MV adoption and downside risk exposure more limited econometric models have to be applied, such as analyzing the likelihood of sorghum crop failure.

MVs are adopted if marginal benefits from their utilization exceed marginal adoption costs. As these are unobserved, the difference in marginal benefits and costs can be modeled by the unobserved latent variable, y_1^* and MV adoption is undertaken if this variable crosses a normalized threshold, that is, $y_1^* > 0$. In accordance with Eq. (2), we model MV adoption as a function of a vector of explanatory variables, x_1'. In our framework and as expressed in (3) we also want to assess the probability of being affected by crop failure, and particularly how MV adoption influences the probability of experiencing crop failure. The probability of crop failure can be modeled as a cumulative distribution function of another unobserved latent variable, y_2^*. This is determined by a vector of explanatory variables (x_2') and by a binary variable for the utilization of improved varieties (y_1).

Accordingly, the following equation system applies:

$$y_1^* = x_1'\beta_1 + \mu_1, \qquad y_1 = 1 \quad \text{if } y_1^* > 0, \quad \text{else } 0$$
$$y_2^* = x_2'\beta_2 + y_1\alpha + \mu_2, \qquad y_2 = 1 \quad \text{if } y_2^* > 0, \quad \text{else } 0,$$

α, β_i are the parameters to estimate while μ_i are the error terms.

This recursive simultaneous probit model can be estimated by fitting a maximum likelihood bivariate probit model (Greene, 1998). This approach allows for an endogeneity test by providing a likelihood-ratio test for the correlation coefficient of the error terms (rho) between the two equations (Knapp and Seaks, 1998). The endogeneity assumption is supported for several model specifications at 10% significance levels. For the final model, exogeneity is rejected at 8.6% (see Table 5). The error

Table 5
Endogeneity-test in the maximum-likelihood estimation of the bivariate probit model

	Mean	Std	$P > z$
Rho: correlation coefficient of error terms	−0.721	0.235	
Fisher's z transformed rho	−0.910	0.490	0.063
Likelihood-ratio test of rho = 0	$\text{chi}^2(1) = 2.950$		$\text{Prob} > \text{chi}^2 = 0.086$

Source. Authors' calculation using FNPP data set.

terms are negatively correlated at 6.3% significance level. This implies that the random effect of MV adoption has a negative impact on sorghum failure.

4.1. Explanatory variables

As elaborated in the conceptual model, explanatory variables for MV adoption include (i) land endowments, (ii) household demographics, (iii) access to social capital, (iv) access to market, (v) agro-ecological conditions, (vi) household assets, and (vii) climatic risk; whereas for sorghum failure the same agro-ecological variables as in (v) are used in addition to household demographics and input variables (viii). The descriptive statistics for the LR growers and MV adopters are summarized in Table 6.

Land endowments are expressed by the operated land area and its squared value to control for differences between smaller and larger landholdings. Table 6 indicates the sample population comprises very small average size of landholdings (4.2 timmad corresponding to slightly more than 0.5 ha).

Household demographic variables include household size, dependency ratio (i.e., ratio between dependants and labor force within the households), ethnicity, and gender. Agricultural knowledge and experience, expressed by years of formal education and age of the household head complement household demographic information. On average, households consist of seven family members, with a 40-year-old household head and with a low level of education. Ninety percent of the sample households belong to the Oromo ethnic group and only 7% are headed by females.

Access to seeds is facilitated by networks at different levels (see Lipper et al., 2009; Nagarajan and Smale, 2006; Winters et al., 2006) as expressed by a number of seed-distribution related social capital variables such as dummy variables for inter-household seed exchange (65%), intra-community farm-associations (14%), inter-community organizations that provide seeds (27%), and HCS-participation (47%).

Market accessibility is controlled for by distance to the closest city for the remoteness of large hub-markets and by distance to the next smaller local market. Distance to input shop is a proxy for the accessibility of farm inputs that may be needed for certain technologies that MV adoption requires (Benin et al., 2006). With an average of almost four hours to the next city, 9 km to the next market, and 20 km to the next input shops, sorghum household farms in the sample can be considered rather remote.

Information about soil color, as a proxy for fertility, as well as data on slope, irrigation, and altitude reflect the agro-ecological environment in which the farms operate. Data show that land quality is on average poor with steep slopes and poor soils, although some variation is reported given the values of standard deviation.[12] Dummies for the woredas of Meta and Chiro are included to control for regional fixed effects.

Variables that reflect households' ability to cope with risks include agricultural and nonagricultural assets as well as livestock. Most households are very poor, holding very little assets. The highest values, although still very low, are through livestock holdings.[13] Access to seed aid (31%) represents a kind of *ex post* emergency assistance and thus a sort of insurance mechanism. Last but not least in this group of variables, 43% of the households report credit constraints, representing yet another difficulty for coping with downside risk production.

Climatic risk variables are proxied by the number of times sorghum stresses occurred in the previous 10 years (on average nearly four per household between 1991 and 2001) and by the number of substantial harvest losses due to drought in the same period (on average three per household between 1991 and 2001). While the former variable reflects risks associated with sorghum production, the latter controls for risks at a larger scale, such as livelihood vulnerability.

Sorghum production inputs include the operated land area, labor time, both human and livestock labor used in cultivation (land preparation, planting, and weeding), in addition to fertilizers. The use of human and animal labor as well as fertilizers is rather low, indicating that sorghum production in the study site is not labor-intensive with fairly low capital inputs.

Weather conditions are proxied by a dummy for households that reported overall production conditions in 2002 as having been very bad (78%). Finally, the Berger index for relative abundance is included as a measure for intra-crop diversity to check its potential role on influencing the chances of crop failure.

4.2. Econometric results

Regression results for the determinants of MV adoption are shown in Table 7. Household preferences seem not to play a key role in adoption decisions, as only age of the household head is weakly significant. Contrary to what has been found in many other contexts (e.g., Bellon and Taylor, 1993; Benin et al., 2006) agro-ecological variables do not seem to influence adoption decisions either.

On the other hand, regional dummies are highly significant indicating that the likelihood of MV adoption is higher in Dire Dawa, where modern sorghum varieties have been distributed

[12] Not reported here.
[13] One ETB corresponds to 0.12USD at the end of 2002.

Table 6
Descriptive statistics of explanatory variables for sorghum grower households in Hararghe region

Variable name	Description	Total mean	Only LR growers	MV adopters
(i) Land endowments				
Operated area	Total area of operated plots in production year 2002 in timmad	4.25	4.36	3.45
(ii) Household demographics				
Household size	Number of household members at the beginning of the year	6.96	7.01	6.58
Dependency	Number of children and old members in proportion to total household size	0.50	0.50	0.49
Ethnicity	Dummy = 1 if household belongs to the ethnic group of Oromo, else 0	0.90	0.91	0.80
Female head	Dummy = 1 if household is female headed, else 0	0.07	0.07	0.08
Age head	Age in years of household head	40.30	40.27	40.50
Education	Average years of education of all household members	3.97	3.82	5.14
(iii) Social capital				
Seed exchange	Dummy = 1 if household exchanges seed with other farmers, else 0	0.65	0.66	0.54
Farmers association	Dummy = 1 if any household member belongs to intra-community farmers/production group, else 0	0.14	0.14	0.18
Seed organization	Dummy = 1 if contact with any inter-community organization for seed provision, else 0	0.27	0.27	0.22
HCS	Dummy = 1 if household participates in HCS, else 0	0.47	0.47	0.46
(iv) Market variables				
Closest city	Distance in minutes from PA to nearest town	208.66	212.73	176.42
Distance to market	Distance in km from PA to next market	9.05	9.24	7.52
Distance to inputshop	Distance in km from PA to next inputshop	20.32	20.45	19.26
(v) Agro-ecological conditions				
Meta	Dummy = 1 if woreda is Meta, else 0	0.38	0.37	0.46
Chiro	Dummy = 1 if woreda is Chiro, else 0	0.42	0.44	0.26
Altitude	Altitude of PA in meters	1,922.84	1,919.40	1,950.12
Black soil	Dummy = 1 if plot with black soil is cultivated, else 0	0.53	0.52	0.60
Gentle terrain	Dummy = 1 if plot with nonsteep terrain is operated, else 0	0.61	0.60	0.72
Irrigated	Dummy = 1 if irrigated plot is operated, else 0	0.30	0.29	0.36
(vi) Household assets and insurance				
Agricultural assets	Total value of agricultural assets (not including livestock) in birr	88.98	89.02	88.71
Nonagricultural assets	Total value of nonagricultural assets in birr	53.97	52.61	64.67
Livestock	Total value hold in livestock in birr	560.97	551.85	633.17
Credit restricted	Dummy = 1 if credit request was not approved or if household did not ask for credit because of difficult access conditions, else 0	0.43	0.42	0.52
Seed aid	Dummy = 1 if household receives seed in case of emergency from other farmers, else 0	0.31	0.30	0.36
(vii) Climatic risk				
Sorghum stresses in the past	Number of sorghum stresses in the last 10 years	3.73	3.72	3.82
Harvest losses in the past	Number of harvest losses due to drought in the last 10 years	2.99	3.03	2.64
Very bad rain	Dummy = 1 if household judges overall production conditions as very bad, else 0	0.78	0.80	0.66
(viii) Sorghum production inputs				
Labor for planting	Total labor force for planting sorghum in no. of days	6.55	6.58	6.30
Labor for land preparation	Total labor force for preparing sorghum in no. of days	8.05	7.95	8.80
Labor for weeding	Total labor force for weeding sorghum in number of days	13.67	13.52	14.88
Animal time	Total animal use in sorghum production in number of days	5.75	5.89	4.64
Fertilizer	Kilogram of fertilizer for sorghum production	72.35	74.15	58.16

Notes. All variables are at household level as they enter in the analysis presented in following tables and conducted at household level.
Source. Authors' calculation using FNPP data set.

by external organizations (Mulatu, 2005) and where access to market is relatively easier than in the other woredas. In addition variables expressing access to markets and to social capital seem to be among the most crucial factors in adoption decision, similar to findings from Winters et al. (2006) and Benin et al. (2006) for variety choice and seed access. Adoption of improved varieties of sorghum is positively correlated with proximity to local markets. Even though farmers reported no difficulties in accessing seeds of MV as described in Section 2.2, these regression results imply that seed supply networks are indeed more effective when built on local market transactions. Seed exchanges on a more ad-hoc one-to-one or as-needed basis reduces the likelihood of adopting improved seed by 8.2% supporting the observation that informal transactions facilitate the

Table 7
MV adoption: Maximum-likelihood estimates of the bivariate probit model

Variable	dy/dx	$P > \|z\|$ value
Operated area	−0.018	0.258
Operated area squared	0.008	0.534
Household size	−0.009	0.210
Dependency	0.004	0.693
Ethnicity	−0.085	0.122
Female head	0.002	0.972
Age head	0.009*	0.084
Age head squared	−0.906*	0.099
Education	0.003	0.23
Seed exchange	−0.082***	0.007
Farmers association	0.068	0.124
Seed organization	−0.035	0.188
HCS	0.025	0.431
Closest city	−0.003	0.814
Distance to market	−0.006***	0.004
Distance to inputshop	−0.002	0.282
Meta	−0.136**	0.038
Chiro	−0.150***	0.007
Altitude	0.006	0.531
Black soil	0.031	0.225
Gentle terrain	0.044	0.103
Irrigated	−0.001	0.975
Agricultural assets	0.001	0.420
Nonagricultural assets	0.001	0.343
Livestock	0.000	0.849
Credit restricted	0.010	0.689
Seed aid	0.010	0.735
Sorghum stresses in the past	0.011*	0.072
Harvest losses in the past	−0.037***	0.004
Constant	−0.742	0.589

Notes. *, **, and *** denote variables significant at 10%, 5%, and 1%, respectively. Marginal effects of the explanatory variables on the dependent variables are calculated for a one unit change holding all other variables constant at their mean, but of **dummy variables** for a discrete change from 0 to 1, of dependency ratio for one more dependent, of **closest city** for one more hours of travel time, of **altitude** for an increase by 100m, and of **all assets** for an increase by 10ETB.
Source: Authors' calculation using FNPP data set.

Table 8
Sorghum failure: maximum-likelihood estimates of the bivariate probit model

Variable	dy/dx	$P > \|z\|$ value
Operated area	−0.033	0.256
Operated area squared	0.027	0.243
Age head	−0.007	0.438
Age head squared	−0.322	0.425
Education	−0.009*	0.059
Labor for planting	−0.011**	0.044
Labor for land preparation	0.005	0.183
Labor for weeding	0.003	0.161
Animal time	0.013**	0.036
Fertilizer	0.000	0.965
Very bad rain	0.220***	0.000
Meta	0.343***	0.000
Chiro	0.385***	0.000
Altitude	−0.003	0.816
Black soil	−0.098**	0.045
Gentle terrain	−0.049	0.341
Irrigated	−0.124**	0.025
MV	0.351*	0.073
Berger index	0.267*	0.082
Constant	−1.253	0.16

Notes. *, **, and *** denote variables significant at 10%, 5%, and 1%, respectively. Marginal effects of the explanatory variables on the dependent variables are calculated for a one unit change holding all other variables constant at their mean, but of dummy variables for a discrete change from 0 to 1, of altitude for an increase by 100m, and of Berger-index for a change in the index from 1 to 2.
Source. Authors' calculation using FNPP data set.

exchange of traditional varieties, as reported in Section 2.2. Against expectations, participation in the HCS program, aiming at the distribution of varieties, was not found to promote modern sorghum variety adoption.

Contrary to the findings of many other studies (see, e.g., Bellon and Taylor, 1993; Benin et al., 2006), the probability of MV adoption was not significantly affected by size of landholding, asset holdings, nor credit accessibility. Findings of this study suggest that in the Hararghe region MVs are neither planted by farmers with larger landholdings as a form of experimentation, nor by farmers with a higher ability to bear the risks of such a technology adoption. In this context, however, it is important to stress that landholding is relatively limited and scattered to allow for such experimentation.

Most interestingly, both climatic risk variables enter the regression significantly, but with contrary signs. The average farmer holding all variables at their mean, is 1.1% more likely to adopt MVs for each additional time sorghum stress was experienced in the past 10 years, and 3.7% less likely to do so for each additional substantial loss of harvest due to drought they experienced. Thus, farmers who are subject to moderate production risks seem to adopt MVs to mitigate the risk of sorghum failure. Yet farmers that experienced catastrophic risks, such as complete harvest losses, are less likely to do so, relying on LRs to maintain food security. In other words, nonadoption appears to be the "safety-first" strategy of the most vulnerable households.

This finding is supported by the results in Table 8 showing the drivers of sorghum failure in a year of extreme drought. Controlling for exogenous factors such as agro-ecological conditions and input variables, and holding all these variables constant at their mean values, we find that MV adopters are 35% more likely to experience failure of at least one of their planted varieties at a 10% significance level. The MVs used in the Hararghe region are bred with early maturity traits and do not thus seem to be an efficient means of risk mitigation, as they seem to be more likely to fail under adverse rainfall conditions. Early maturing varieties provide drought escape rather than drought tolerance, which our results suggest are less appropriate for risk management in the context of the study site.

Land quality variables, such as access to black soil or irrigation were all found to decrease the likelihood of sorghum failure, as would be expected. The question arises whether crop failure associated with MV adoption is linked to land quality. Are the adopters on poor quality lands the most vulnerable to failure, and do sorghum improved varieties need to be produced under relatively good conditions in order to reduce downside risk? To explore this issue further we created variables measuring the interaction between land quality variables and MV adoption. The addition of these variables do not greatly change any of the coefficients in the estimations however, and the interaction terms are not significant, indicating that the MV crop failures cannot be linked solely to land quality; but rather a more complex set of factors is at work. Furthermore, the risk of crop failure increases by 26.7% when moving from a fully specialized system to a system where land is more equally distributed across a wider range of varieties, as indicated by the Berger index. This result is not unexpected, as the more varieties planted, the more likely it is that one of these varieties will fail in response to rainfall conditions.[14]

The highly variable pattern of rainfall and weather conditions in the area unsurprisingly has a significant impact on increasing the likelihood of crop failure. Households affected by very bad rainfall conditions are indeed 22% more likely to experience crop failure. In addition, location specific effects, expressed by location dummies, are another important determinant of sorghum failure. In particular, households in Meta and Chiro woredas are significantly more likely to have a crop failure in sorghum than households residing in the area of Dire Dawa.

Last but not least, increasing the level of education appears to be one important way to reduce the likelihood of experiencing crop failure. More educated farmers are indeed more likely to be able to avoid crop failures.

5. Conclusions

The analysis conducted provides interesting insights on the role of downside risk production on MV adoption as well as on the potential of MV adoption to reduce the probability of crop failure. The analysis indicates that exposure to weather variability plays a key role in the decision to adopt sorghum MVs in eastern Ethiopia, along with access to markets and social networks. Farmers who experienced moderate production stresses and climatic risk tend to adopt MVs, while those who have been most vulnerable to extreme weather events, mainly consisting of droughts that have led in the past to crop failure, prefer to stick to LRs. This finding suggests that the sorghum MVs currently available in the area are not an effective means of coping with the catastrophic risk that drought represents in the study site. However, MVs of sorghum in the area were bred with the purpose of drought escape rather than for drought tolerance. In other words, the MV available in the area require moisture over a shorter period than most LRs, thus providing a higher likelihood of harvest or offering the alternative to plant another crop or variety in the second season of the year. Whilst these MVs offer such traits they are more susceptible to failure if rainfall shortages occur over the period they are grown. This conclusion is supported by results showing that MV adopters are more likely to suffer from crop failure in a year of extreme drought, like the one analyzed, when controlling for exogenous factors such as other input variables and agro-ecological conditions. While it is possible that the rainfall in the 2002–2003 year was so scant as to be insufficient for even short season varieties to provide some harvest, different results could be experienced in milder drought years.

Effective risk production coping strategies have assumed even greater importance in the context of climate change and the predicted increase in extreme weather events. Improving germplasm to produce varieties more adaptable to climatic changes and extreme weather events is a crucial means of achieving food security that will become even more important as climate change progresses. While the findings of the present analysis suggest the adoption of improved sorghum varieties does not represent an effective risk management strategy, the finding is confined to the specifics of the type of drought risk present, as well as the MVs available and the production and marketing context of this study. However, broader implications can be derived.

First is the importance of considering the nature of the risk to be confronted when looking for effective coping strategies. The type of germplasm needed to cope with catastrophic versus chronic risks is different, and this affects the farm level demand and use of varieties (Anderson et al., 2006). In this case, it appears that LRs are more suitable for coping with catastrophic risks, whereas the types of MVs currently available are more suitable for managing chronic risk.

Second, preserving the richness of infra-crop diversity and promoting the accessibility to a diverse range of crop varieties may be an important part of facilitating farmer capacity to manage their risk. A number of studies, including McGuire (2005) and more recently Di Falco et al. (2007) and Di Falco and Chavas (2009), found that diversity within crops managed on Ethiopian farms is an important way of reducing downside production risk. Likewise, in the Haraghe region sorghum farmers use infra-specific diversity as a strategy to manage moderate production risks even though such intra-crop diversity is undermined by regularly occurring droughts.

Third, crossover effects seem to play an important role under the production conditions of eastern Ethiopia, where LRs perform better than improved varieties due to marginal production conditions and limited use of complementary inputs. In this situation, the potential for improved varieties to outperform LRs seems to be limited, since the crop is used primarily for subsistence purposes, with low rates of complementary input use and low farm level returns (Ahmed et al., 2000). These are factors that can also explain the low levels of MV adoption in the area in combination with breeding efforts that are mainly tailored to more favorable production areas (Bellon, 2006).

Fourth, the results presented indicate that given the production and marketing conditions found in the area, the adoption of improved sorghum varieties increases rather than reduces

[14] The inclusion of other diversity measures in the crop-failure model does not provide any information on the extent to which sorghum diversity does influence sorghum performance.

on-farm diversity measured by different types of diversity indexes including the number of varieties, evenness, and relative abundance. Yet the data indicate that farmers who do adopt MVs plant the majority of their sorghum production area to these improved varieties. Whilst MV adopters might be trading the potential of achieving higher yields with MVs for the greater security that LRs can provide, our results suggest this as a risky strategy given the potential harsh weather conditions in the area and given the limited capacity of the farmers to access other forms of coping strategies.

Finally, given that sorghum is the most important staple crop in the area and a crucial crop to achieve food security under the area's difficult weather conditions, the results suggest that focusing further breeding research on drought tolerance traits would be beneficial. Although not generalizable to any level and type of drought or weather conditions, given also the restricted types of MV in our sample, our results suggest that while adoption of MVs bred for drought escape may be risk reducing under certain conditions, they are likely to increase the risk of crop failure in situations of high climate risk.

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