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Agricultural Risk Management and Land Tenure

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Abstract

Farmers under a sharecropping contract have been shown to exert less effort than farmers renting land due to lower incentives. They do not only choose their effort level, however, but also make investment decisions between projects of different risk-return profiles. We develop a small theoretical model that integrates the effort effect of sharecropping as well as the risk-reducing aspect of sharecropping which allows analyzing the implications for production, risk-management and risk-coping. In the empirical analysis, we combine a household survey taken in eleven African countries with data on climate risk to test the theoretical predictions. We find that sharecropping is endogenous to climate: it is more frequent in regions with low rainfall and higher weather variability. In a second step we test whether sharecropping can function as a substitute to other risk adaptation strategies. We find that sharecropping farmers are less likely to own livestock and more likely to use fertilizer. In economies where formal kinds of insurance are unavailable, sharecropping thus functions as a form of insurance and reduces the need for potentially harmful risk management strategies.

JEL classification: O13, O55, Q12, Q15,

Keywords: Risk management, Agriculture, Africa, Sharecropping, Land tenure

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1 Introduction

Farmers in developing countries are exposed to substantial amounts of risk. Dercon (2002) documents a range of risk sources and calculates that harvest failure is by far the most important among them. Accordingly, farmers have developed a range of strategies to deal with the risk of harvest failure. In this paper we provide evidence that sharecropping provides a form of insurance for farmers which allows them to reduce other, and potentially more harmful, strategies to handle risk. Farmers under a sharecropping contract are, in particular, more likely to use fertilizer.

Alderman and Paxson (1994) propose classifying risk strategies into risk management, which modifies the risk and return of profits and allows income smoothing, and risk coping, which deals with the consequences of the variability of profits and allows consumption smoothing, for example through insurance. In a sharecropping contract, the tenant farmer compensates the land owner in the form of a share of the harvest. This arrangement provides a form of insurance for the farmer since he does not have to pay for the land when the harvest fails. Reducing fertilizer input is a risk management strategy as fertilizer allows larger harvests in good years, but causes costs without benefits in bad years. Keeping livestock also works as a risk management strategy. Selling livestock in years of poor harvests smoothes income, but binds productive means and thus reduces average harvests. A farmer able to reduce risk in one of these ways can thus be expected to have less need for the others.

The substitution between risk coping and risk management is highly relevant from a social perspective. From the individual perspective, sacrificing some average yield can increase welfare when it increases profits in years with adverse weather events. From a social perspective, however, idiosyncratic risks cancel out so that risk coping strategies are preferred to risk management strategies. Taking into account the risk coping aspects of sharecropping can thus allow governments to improve adaptation to weather risks. This might become increasingly important when climate change increases weather variability.

We develop a stylized theoretical model to analyze farmers' choice between sharecropping and non-sharecropping land tenure regimes. Additionally, we study the implications of tenure regime and production risk for investments into production. For the empirical analysis of the predicted behavior, we employ a comprehensive cross-sectional household survey coordinated by the Centre for Environmental Economics and Policy for Africa (CEEPA) in eleven African countries (Dinar et al., 2008). For climate variables we use the Climate Research Unit's (CRU) TS 3.10 gridded data set on monthly climatology 1901-2009 (Harris et al., 2014).

In a first step, we identify which factors contribute to the use of risk coping and management. As the main indicators of risk in agriculture, variability of temperature and rainfall during the growing season have been established (McCarl et al., 2008; Auffhammer et al., 2012; Rowhani et al., 2011). As annual temperature is highly stable, we consider variability in rainfall as the major indicator for production risk. We find that, consistent with out theoretical model, tenure regime is endogenous to climate: Farmers in areas with low precipitation or high variability of rainfall are more likely to be sharecroppers. Climate.driven production risk also influences the use of fertilizer and the ownership of livestock: Livestock has been identified as a risk coping strategy in Dercon (1996), while Dercon and Christiaensen (2011) find that farmers react to higher risk with lower fertilizer input. While we confirm the positive impact of risk on livestock ownership we reject the negative impact on fertilizer application.

Finally, we consider the correlation of risk adaptation strategies, by conducting bivariate probit regressions with the same control variables as in the first step. We find that sharecropping is negatively correlated with livestock ownership. Farmers under a sharecropping contract are thus less likely to own livestock. Sharecropping is positively correlated with fertilizer use. These findings are thus in line with the hypothesis that all three risk adaptation strategies are to some extent substitutes.

We discuss theoretical aspects of sharecropping and provide a small model in Section 2. The data and empirical method are described in 3. Results of the first step are presented in Section 4 and of the second step in Section 4.5. Section 5 concludes.

2 The theoretical framework

The data set used for this paper (see Section 3.1 for details) reveals that land tenure in Africa is quite complex. Farmers cultivate their own land, rented land or communal land or enter a sharecropping contract with a land owner. In addition, many farmers make use of several of these land tenure systems simultaneously and can also function as both a landlord and a tenant. In our theoretical analysis we abstract from this complexity and just consider the difference between purely renting, owning and sharecropping farmers.

2.1 Effort choice, tenure security and project choice

Renting and owning farmers have a fixed (opportunity) cost and receive a variable income from their harvest. Sharecropping farmers have no fixed cost for the land so that their net income depends less on their own choices and is less variable.

Marshall (1920) described one major implication of this difference in payment: Since the farmer cannot appropriate the full reward for his effort, he will invest less effort than he would under a renting contract. According to Otsuka et al. (1992), the land owner receives 50% of the harvest in most sharecropping contracts, making it quite plausible that the effort of the farmer is affected by the contract type. Laffont and Matoussi (1995) provide empirical evidence on this effect.

A second difference is land tenure security. Place (2009), Abdulai et al. (2011), and Abdulai and Goetz (2014) find that insecure land rights reduce investments because sharecropping farmers cannot be sure that they will earn the benefits of their effort and because they cannot use their land as collateral for credit. Fenske (2011) is able to differentiate results based on a metastudy. He finds that long-term investments such as trees and fallow are reduced when land rights are insecure. The evidence on short-term investments such as manure and chemical fertilizer is less robust.

Recently, Weinschenk (2014) added a third effect, the project choice of the farmer. The theoretical literature has considered risk as an element for understand sharecropping for a long time, see Otsuka et al. (1992) for a review. Weinschenk (2014) adds a crucial element to this literature: The possibility for the tenant farmer to choose between projects. The farmer thus is not only subjected to an exogenous source of risk, but can gauge the risk-return profile. One example is the use of fertilizer. Fertilizer use increases the average harvest, but also the variance of profits since the expenses for the fertilizer are not matched with higher income in years of very poor harvest.

Considering both the effect on effort and on risk behavior, sharecropping is not an ideal form of risk coping. The insurance effect is socially beneficial, the effect on effort is socially harmful. The provision of agricultural credit as analyzed in Wossen et al. (2014) or formal insurance as applied in Karlan et al. (2014) would thus be preferable to sharecropping. A country with weak institutions, however, might benefit from the simple insurance mechanism of sharecropping.

2.2 Model

In this paper we analyze risk management choices by renting and sharecropping farmers. This is related to the model of Weinschenk (2014) in that it considers both an effort and project choice component. It differs, however, in that it explicitly considers the farmer's choice on the purchase of informal insurance. The lead example of "insurance purchase" will be the reduction of fertilizer use. Fertilizer is a productive, but risk increasing investment. Any reduction in fertilizer use thus works like an insurance. Below we discuss how the model can be adjusted to livestock.

The farmer's profit Π is composed of three components. The first is his revenue, which consists of the harvest size without fertilizer times the farmgate price (productivity), H, and the amount of fertilizer used, F. The second component is the purchase of fertilizer at price k. Dercon and Christiaensen (2011) identified the amount of fertilizer applied as a major investment decisions governing the degree of risk. The third component is the payment made to the land owner. For the renting farmer this is given by the land rent r. The sharecropper pays a fraction $(1-s)(1+F)H$ of his harvest. The net profits for a renting farmer Π_{rent} and a sharecropping farmer Π_{SC} are thus given by

$$\Pi_{rent} = (1+F)H - r - kF \quad (1)$$

$$\Pi_{SC} = (1+F)sH - kF \; . \quad (2)$$

According to the Modigliani-Miller theorem on the irrelevance of the capital structure, the formulation for the renter would also apply to farmers who own the land on which they farm. Even though financial markets in rural Africa are far from perfect, we consider the two cases to be sufficiently similar for investment behavior since the main difference to the sharecropper is the share of the harvest retained by the farmer.

We define $E[H] = \mu$ the mean productivity before fertilizer use and $Var[H] = \sigma^2$ the variance of productivity. While soil conditions, exposure to pests as well as farmgate prices net of transportation costs are important determinants of μ and σ, we will consider rainfall and rainfall variability in the later empirical analysis as major control variables for μ and σ.

Binswanger and Sillers (1983) show that farmers are risk averse and therefore reduce investments in risky production techniques unless they have the means for self insurance or risk diffusion. We therefore assume utility to be concave and choose an exponential utility function for tractability,

$$U(\Pi) = -\exp(-\eta(\Pi)), \tag{3}$$

where $\eta > 0$ is the coefficient of absolute risk aversion. The farmer's certainty equivalent is

$$CE(\Pi) = E[\Pi] - \frac{\eta}{2} Var[\Pi] \; . \tag{4}$$

$E[\Pi]$ and $Var[\Pi]$ are the expected value and variance of profits. The certainty equivalent is a monotonic transformation of expected utility, so that we can assume that farmers maximize the certainty equivalent.

We can use this to determine the influence of the parameters on the choice of fertilizer use.

Proposition 1 *Fertilizer use depends positively on expected productivity μ and negatively on the fertilizer price k. For renting farmers production variability σ^2 decreases fertilizer use if and only if $\mu > k$. For sharecroppers, fertilizer use decreases in variability if and only if $s\mu > k$.*

Proof. Inserting equations (1) and (2) into (4) and maximizing (optimal) yields $F^*_{rent} = \frac{\mu-k}{\eta\sigma^2} - 1$ and $F^*_{SC} = \frac{s\mu-k}{\eta s^2\sigma^2} - 1$. Derivatives are $\frac{dF^*_{rent}}{d\sigma^2} = \frac{-(\mu-k)\eta}{(\eta\sigma^2)^2} < 0$, $\frac{dF^*_{rent}}{d\mu} = \frac{1}{\eta\sigma^2} > 0$, $\frac{dF^*_{rent}}{dk} = -\frac{1}{\eta\sigma^2} < 0$, $\frac{dF^*_{SC}}{d\sigma^2} = \frac{-(s\mu-k)\eta s^2}{(\eta\sigma^2)^2}$, $\frac{dF^*_{SC}}{d\mu} = \frac{1}{\eta s\sigma^2} > 0$, $\frac{dF^*_{SC}}{dk} = -\frac{1}{\eta s^2\sigma^2} < 0$. □

The ambiguous sign of the impact of the variance of fertilizer use depends in both cases on the profitability of fertilizer use in the absence of risk: If $E[H] = \mu > k$ (renting farmers) and $E[H] = s\mu > k$ (sharecropping farmers), risk-neutral farmers would apply an infinite amount of fertilizer due to the linear production technology. Because of risk aversion, the optimal amount will be lower. The model used here also allows for negative values of F^*, in particular if $s\mu < k$ ($s = 1$ for renters). As negative values of F are not possible in practice, a corner solution at $F = 0$ would prevail. For consistency with the later empirical latent variable model we allow for negative F^* and interpret $F^* < 0$ as the shadow price of relaxing the non-negativity condition on F (related to the disutility the farmer receives from not being able to chose $F^* < 0$).[1]

[1]This interpretation follows directly from solving the first-order conditions with the inequality constraint $F \geq 0$ and $\lambda F = 0$ the Karush-Kuhn-Tucker (KKT) condition. λ is the KKT multiplier and measures the marginal increase of the objective function relaxing the inequality condition. With $F \geq 0$ and $\lambda F = 0$, we define $\tilde{F} = F - \frac{\lambda}{\eta\sigma^2 s^2}$ (with $s = 1$ for renter), i.e. $\tilde{F}$ either equals the positive fertilizer use or the (negative) marginal impact of the inequality constraint on utility, measured in terms of hypothetical fertilizer use. As

The first order conditions of the two types of farmers reveals that both the effort and the project choice effect identified in Section 2.1 are present. Since the sharecropping farmer retains only a fraction s of the harvest his incentive to invest into fertilizer is reduced. The farmer thus exerts less effort. At the same time, the sharecropping farmer is not exposed to the same amount of risk as the renting farmer. He is thus willing to purchase more of the risky, but profitable fertilizer. The relative size of these two effects determines the relative investment of the two tenure types:

Proposition 2 *Sharecropping farmers apply more fertilizer than renting farmers if productivity is sufficiently high, i.e.* $\mu > (1 + s^{-1})k$

Proof. Substituting the optimal fertilizer use from the previous proof into $F^*_{SC} > F^*_{rent}$, we obtain the equivalent condition $\frac{s\mu - k}{s^2} > \mu - k$. The effort effect of sharecropping is captured in the nominator of the left-hand side of the inequality; the insurance (variance reducing) effect on the denominator of the left-hand side. Transforming this inequality condition further gives the claim of the proposition. □

With the endogenous fertilizer choice of the two tenure systems we can determine which tenure system the farmer would prefer. Holden et al. (2008) show that the land market in Africa started emerging only recently. If farmers do not have a choice of the contract they would like to choose, because of rigid traditions for example, it might be of little consequence what farmers prefer. Gebregziabher and Holden (2011) and Bellemare (2012), however, provide direct evidence that contract choice is to some degree endogenous in Africa with the former finding that "sharecropping is more likely where production risk is high".

Proposition 3 *Farmers prefer sharecropping to renting if (i) mean productivity is sufficiently low. If mean productivity is sufficiently high, farmers prefer sharecropping if (ii) variance in production is sufficiently high.*

Proof. Inserting the values for fertilizer choice from Proposition 1 into equations (1) and (2) and the result into (4), we have after re-arranging $CE(\Pi_{SC}) > CE(\Pi_{rent}) \Leftrightarrow r > \frac{k(s-1)(k+ks-2s\mu)}{2s^2\eta\sigma^2}$. As $\frac{d}{d\mu}\frac{k(s-1)(k+ks-2s\mu)}{2s^2\eta\sigma^2} = \frac{k(1-s)}{s\eta\sigma^2} > 0$ and the certainty equivalents are equal for $\mu = \tilde{\mu} := \frac{1}{2}\left(\frac{2\eta rsV}{k-ks} + \frac{k}{s} + k\right) > 0$, part (i) of the proposition follows. For the proof of (ii), consider the derivative of the RHS with respect to σ^2 which is $-\frac{k(s-1)(ks+k-2\mu s)}{2s^2\eta\sigma^2}$. As this

can be verified, the optimization problem with consideration of inequality constraints ($F > 0$) using the substitution for $\tilde{F}$ is equivalent to the optimization problem with no inequality constraints and $F \in \mathbb{R}$.

expression is negative if $\mu > \bar{\mu} := \frac{k(1+s)}{2s}$, the benefits from sharecropping contracts increase in σ^2 if $\mu > \bar{\mu}$. $\square$

The first part of the proposition reflects that for a given rental price r the relative cost of the land increases in mean productivity μ for the sharecropper, because it means that the sharecropper pays a higher price to the land owner. The second part of the proposition reflects the benefits of insurance: When much is at stake, the attractiveness of sharing the risk increases in variance. The insurance allows the farmer to choose projects with a higher expected return. When variance is high this benefit is more important than the harmful effort choice effect.

The model can also be applied to the use of livestock as insurance. Let $L = -F$ be the fraction of harvest sacrificed for livestock and let k be the price for livestock. The negative impact of livestock on harvest is related to the lower availability of cropland for the production of food and cash crops due to grazing or due to the production of fodder. Also, livestock ownership may require labor which is missing for crop production. Under this formal representation, positive amounts of livestock will be purchased if $\mu < k$. Notice that *less* livestock is the equivalent of *more* fertilizer, since the informal insurance consists of buying livestock or reducing fertilizer use.

3 Data

3.1 Data

In order to link the local climate to household decisions, we combine two types of data. One is a household survey, the other is climate data. Using the information on the administrative unit in which households live from the survey, we assign to each household entry the climate data from its administrative unit.

Household survey

The household survey was conducted as part of the World Bank/Global Environmental Facility project "Climate, Water and Agriculture: Impacts on and Adaptations of Agro-ecological Systems in Africa" (Dinar et al., 2008). It was coordinated by the Centre for Environmental Economics and Policy for Africa (CEEPA) at the University of Pretoria, South Africa in association with Yale University (USA).

The survey was conducted in eleven African countries: Burkina Faso, Cameroon, Ghana, Niger and Senegal in western Africa; Egypt in northern Africa; Ethiopia and Kenya in eastern Africa; South Africa, Zambia and Zimbabwe in southern Africa. Basic information for each household is a household ID, the location of the farm (country, region, district, subdivision, and village), the name of the interviewer, the time required for the interview, the type of farm entity e.g. small-scale or large-scale and the relationship of the respondent to the head of the household. The total number of households in the data set is 9,597. Households were chosen randomly within districts representing the different agro-ecological zones in a country. Most of the surveys are for the 2002-2003 agricultural year, collected in 2003-2004. Data from Cameroon, Ethiopia, Kenya and Zimbabwe are for the 2003-2004 agricultural year, collected in 2004-2005. Between 416 (South Africa) and 1087 (Burkina Faso) households per country were sampled. Figure 1 shows the spatial coverage of the surveyed districts.

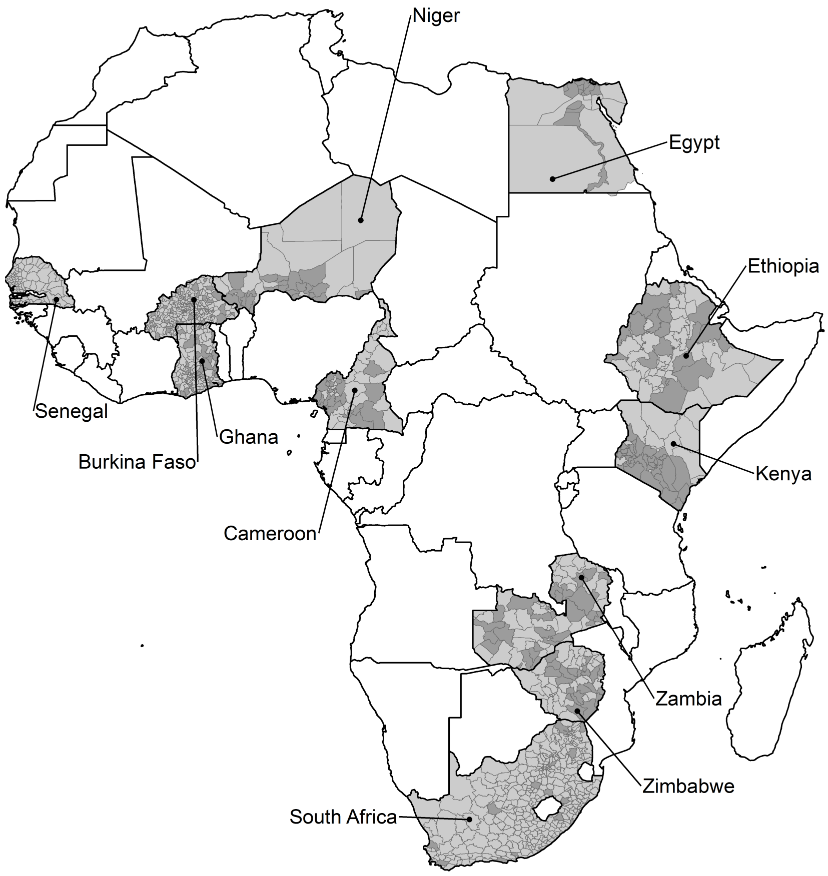

Figure 1: Map of countries (in grey) surveyed. The districts, in which the survey was taken, are highlighted in dark grey.

In over 70% of the households the head of the household was the respondent. Households were asked to classify their farm as small, medium or large-scale farm. In the entire sample, half of the households are small-scale farmers, the other half are medium- or large-scale farmers. Each farm type was surveyed in each country but in Ghana, Zambia and Zimbabwe more than 80% of the households were smallholders while in all countries except Kenya, Senegal and South Africa more than 80% of the farms were small or medium-scale farms. In contrast, 73% of all households in Senegal belong to a large-scale farm. The size of a small farm differs between countries and can vary between 0.7 ha in Egypt and 51 ha in South Africa.

The majority of households grew at least one crop on one plot in a season and continuous cropping with or without a fallow period is the most common farming system in most of the countries except for South Africa and Kenya where livestock farming dominates. About 350 households did not grow any crops.

The household survey reports cropping activities for 56 crops and tree crops which are grown on up to three plots in up to three seasons within 12 months. Some households grow up to six crops simultaneously on a plot. More than 5,000 farmers were livestock farmers. The livestock data identify the five major types of livestock in the surveyed districts as beef cattle, dairy cattle, goats, sheep, and chickens.

Climate data

From CRU TS 3.10 gridded monthly climatology (Harris et al., 2014) we calculate annual average temperature and annual total rainfall in the surveyed agricultural year as well as the variance and the coefficient of variation of rainfall and long-term averages for the 10 years before the surveyed year.

As the geographic coordinates of the surveyed households are unknown we aggregate gridded climate variables to the same administrative units as used in the household survey. For the majority of countries these are administrative units of level 2 i.e. districts or departments except for Egypt (level 1, "governorate" and Senegal (level 3, "arrondissment"). If grid cells overlap with more than one administrative unit their climate variables are used to calculate an average value for all these units depending on their area share.

Although several households are assigned to the same climate data within their district, we have climate data for 331 different districts with, on average, 22.2 households per district (see appendix). While annual mean temperature varies hardly between districts, mean precipitation and the temporal variability of precipitation (risk) exhibits substantial spatial variability within each country (see appendix). Thus precipitation exhibits sufficient variability in our sample for including country-fixed effects in our regression.

3.2 Data quality issues and corrections

There are several issues regarding data quality that need some consideration. First, for only 14 of 816 Kenyan households land tenure types have been recorded – for the remaining households, land tenure type information was missing. We therefore dropped Kenya completely from our data set. Second, concerning fertilizer use, the data in Cameroon, Ghana and Kenya do not contain "zero" entries but several missing entries. For other countries, in most cases the fertilizer data for all entries except plot 1 and season 1 are also missing (instead of zero). Missing entries could refer either to no fertilizer use (which seems to be the case for most instances) or due to any other recording or enumeration issue despite positive fertilizer use. We treated the missing values as zero. A similar problem arises for livestock use where also several entries are missing which we interpreted as zero.

Other household characteristics data are missing or incomplete for some countries. Education and gender data is, for example completely missing for Zimbabwe (and therefore not used as co-variate later) and data on distance to markets is always zero in Zimbabwe. Market distance to input and selling markets is also incomplete or contains zeros. We use distance to selling market as major geographical variable; if missing, we replace it by distance to input markets and add an interaction dummy with market distance to control for systematic difference in distance to selling and input market. We create an additional dummy, *mdzero*, which is one if market distance is zero. For farm value, we consider the farm selling value and use the farm buying value (together with an interaction term in the same way as for market distance) if the selling value is missing but the buying value is available. We create a dummy if the farm value is zero in the original data set. As after this procedure, more than 13 percent of the farm values are still missing and dropping them from the analysis would reduce sample size remarkably, we set the missing values to zero and add an additional dummy to control for missing value. For few households, missing household size data was replaced by calculating the number of persons of the same household for which age data was available.

As we are interested in the impact of sharecropping for smallholder farmers that usually do not have access to formal insurance or credit markets, we drop all households with acreage higher than 20 hectares and acreage per household member higher than 1 ha. This removes almost 5 percent of the observations. As self-classification of farm-type is subjective and location-specific, we do not use the self-reported farm-type to identify smallholder farmers. We use a stricter criterion to label farmers as smallholder as a robustness check.

Table 1 shows the descriptive statistics of the data used for the subsequent analysis. We use the inverse hyperbolic sine function transformation for market distance, farm value, land size, tropical livestock units owned and kg of fertilizer applied as these variables contain also zeros.[2] We define sharecroppers as households who have at least 50 percent of their farmland under a share cropping tenure regime. We checked variations from this value (e.g. to 30 percent) and observed little qualitative impact on the final results. With this definition, only 2% of households in the survey use sharecropping. As sharecropping has been described as an important form of land tenure in Africa (Fenske, 2011; Abdulai et al., 2011) it appears that sharecroppers are underrepresented in the data.

[2]The inverse hyperbolic sine function $f(x) = \ln(x + (x^2 + 1)^{1/2})$ is a monotonic transformation similarly to the logarithmic transformation with $f(0) = 0$.

4 Empirical analysis

The underlying idea of the subsequent analysis is that farmers who are more exposed to risk will have a different demand for risk coping and risking management. We therefore want to assess (i) whether sharecropping is endogenous to climate risk and (ii) to what extent fertilizer application and livestock use as risk management strategies interact with sharecropping.

Dercon (2002) shows that harvest failure is the most important source of risk for farmers. Variability in rain and temperature in turn are important drivers of harvest variability, see Cooper et al. (2008), Wossen et al. (2014) and Karlan et al. (2014) for Africa, Rosenzweig and Binswanger (1993) for India and McCarl et al. (2008) for the United States. As annual temperature is highly stable in African countries and spatial variability very low, we thus use variability in rainfall variables as main risk variable for farmers in Africa.

Price volatility for agricultural products has also been identified as a source of risk in African agriculture (Barrett, 1996; Jayne et al., 2010). We do not include this additional risk into our analysis for two reasons. First, prices are endogenous to several of the variables included in our data and farmers are affected by higher prices both negatively (as buyers) and positively (as sellers). These complex interactions would thus require a separate, detailed analysis. Second, we are not aware of suitable data for our entire study area. Nevertheless, price risk can be managed in similar ways as weather risk, since both affect the market value of the harvest.

We use one form of risk coping, sharecropping, and two forms of risk management, fertilizer use and livestock, as dependent variables. In Subsections 4.2 to 4.4 we test whether these variables are indeed, as predicted by theory, measures used by farmers to adapt to risk.

4.1 Empirical methods

Based on the theoretical model in Section 2.2, in particular Proposition 3, we estimate the households decision to choose being a sharecropper with the latent variable model:

$$SC^*_{ij} = \beta_1 X_{ij} + \beta_2 D_{ij} + \beta_3 R_{ij} + \beta_4 V_{ij} + \beta_5 \tilde{R}_{ij} V_{ij} + \mu_j + \varepsilon_{1ij} \qquad (5)$$

$$SC_{ij} = \begin{cases} 1 & \text{if } SC^*_{ij} \geq 0 \\ 0 & \text{otherwise} \end{cases} \qquad (6)$$

Variable	Variable Description	Type/Unit	Obs	Mean	SD	Min	Max
Explanatory variables							
Precipitation (mean)	The annual precipitation averaged over the ten years before planting	mm	6969	914	477	189	2668
Precipitation (variance)	The variance of annual precipitation over the ten years before planting	$\times 10^3$	6969	22.94	22.22	0.98	271.32
Temperature (mean)	The mean annual temperature averaged over the ten years before planting	Kelvin	6969	298	3.5	287.27	302.97
Market distance	Distance to selling market; transformed using inverse hyperbolic sine (similar to log)	km	6969	10.70	19.52	0	350
Zero market distance	Dummy. =1 if market distance equals to zero	binary	6969	0.13	0.34	0	1
Land size	The sum of the plots farmed by the household in the last 12 months before the interview	ha	6969	4.39	4.02	0	31.5
Household size	The number of household members of the owner of the farm	integer	6969	7.51	4.33	1	48
Farm value	The sale value of the farm (incl. land, buildings, equipment and livestock)	Local currency $\times 10^6$	6969	10.1	49.8	0	1410
Dependent variables							
Sharecropper	Dummy. =1 if >50% of area is under sharecropping regime	binary	6969	0.02	0.14	0	1
Livestock owner	Dummy = 1 if farm owns livestock	binary	6947	0.80	0.40	0	1
TLU owned	Tropical livestock units owned		7035	4.80	47.48	0	3606.67
Fertilizer use	Dummy = 1 if fertilizer has been applied in the growing season 12 months prior to the interview	binary	6969	0.45	0.50	0	1
Fertilizer use (kg)	Amount of fertilizer applied	kg	6969	310.92	1568.56	0	55200

Table 1: Descriptive statistics of variables used in the regression models

SC_{ij} is a dummy variable and equals one if household i is a sharecropper. As farmers often cultivate more than one plot and in many cases these plots are under different forms of land tenure, the dummy variable takes a value of one when the household uses sharecropping on more than 50% of its area under cultivation and zero otherwise.[3] The latent variable SC^*_{ij} can be interpreted as the difference between the certainty-equivalent utility between choosing sharecropping or not (see the proof of Proposition 3). β_1 measures the impact of a set of covariates X, in particular mean temperature (a proxy for elevation) and further geographical variables (distance to input market, zero distance to selling market) and household characteristics (land size, household size and farm value). μ_j is a country fixed-effect for country j which controls, for example, also for institutional and cultural differences.

Our main variables of interest are mean rainfall R as a proxy for mean productivity μ and the variance of rainfall V as a proxy for production risk σ^2. We assign to each farm in the data set the weather variables of his district. This way we can systematically compare the behavior of farmers between the different districts. Distance to selling market D is included as it affects the mean value of production μ negatively due to higher transportation costs. Sichoongwe et al. (2014) have shown that the distance to a market has an important role for farming households, since it allows them, among others, to buy farming inputs and to sell their harvest more easily. Additionally, market distance controls for the possibility that remote areas systematically vary both in customs on land tenure and weather. Many of the households reported a market distance of zero, which might reflect that the interviewed person could not give a precise answer or that the household lives in a village with a market. We thus control separately for a market distance of zero with the dummy variable "mdzero" which is set to one whenever the market distance has been recorded with zero. $\tilde{R}$ is standardized rainfall (z-score) relative to county j's mean rainfall and standard deviation of rainfall. This normalization addresses the heterogeneity between countries in rainfall.

Proposition 3 predicts that $\beta_2 > 0$ and $\beta_3 < 0$. The sign of β_4 is not a priori clear but the interaction term β_5 should exhibit a positive sign as farmers prefer sharecropping if rainfall and variance are high. β_4 thus determines the turning point of the critical rainfall level which changes the sign of the impact of the rainfall variance. We estimate (6) using a univariate probit model.[4]

[3] We use different alternatives for the robustness checks in the appendix.

[4] Logit as well as complementary log-log models have been used as a robustness check. The results hardly changed by these alternative models. We use the probit model for the univariate case to be consistent with the bivariate probit model used later.

To model the interaction of sharecropping with other risk management strategies (livestock use and no fertilizer application), we estimate the following latent variable model (based on the theoretical model section):

$$F_{ij}^* = \alpha_1 X_{ij} + \alpha_2 D_{ij} + \alpha_3 R_{ij} + \alpha_4 V_{ij} + \alpha_5 SC_{ij} + \mu_j + \varepsilon_{2ij} \tag{7}$$

$$F_{ij} = \begin{cases} F_{ij}^* & \text{if } F_{ij}^* \geq 0 \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

F_{ij} is a truncated variable measuring the amount of fertilizer used by the i-th household.[5] We alternatively use a dummy variable specification where $F_{ij} = 1$ if the household applies fertilizer.[6] Similarly to (5), α_1 measures the impact of a set of covariates X. Proposition 1 predicts that $\alpha_2 < 0$ (distance reduces the mean value of production and, thus, fertilizer use) and $\alpha_3 > 0$ (rainfall increases fertilizer use). The sign of $\alpha_4 < 0$ (production risk) is a priori not clear. Proposition 2 further caims that the sign of $\alpha_5 > 0$ (being sharecropper) is ambivalent.

A third model is estimated for livestock use L_{ij}, using the same structure as (7–8). Contrary to fertilizer, livestock reduces production risk – the signs of α_l are therefore expected to be exactly opposite to the α_l of the fertilizer regression.

The model in (7–8) assumes implicitly that the choice of being sharecropper is exogenous, e.g. determined by local customs and traditions or by preferences of the land lord. The regressions in (5–6) may indicate, however, that sharecropping is endogenous. Sharecropping and ferilizer use or livestock ownership may also operate on different temporal scales; e.g. the prevalence of sharecropping contracts might respond only slowly to changing production risks while fertilizer use and livestock use can easily be changed. To account for the possibility that sharecropping and other risk management strategies are employed simultaneously, we

[5]Negative values of F_{ij}^* can be interpreted as the shadow price of relaxing the non-negativity constraint in fertilizer use, see Proposition 1.

[6]The binary model may be less susceptible to measurement errors in the amount of fertilizer which may also be affected by additional variables we do not have data for. Furthermore, the binary model specification is comparable to the bivariate probit model used later that involves also the decision of becoming sharecropper.

estimate the bivariate probit model

$$SC^*_{ij} = \beta_1 X_{ij} + \beta_2 D_{ij} + \beta_3 R_{ij} + \beta_4 V_{ij} + \beta_5 \tilde{R}_{ij} V_{ij} + \mu_j + \varepsilon_{1ij} \quad (9)$$

$$F^*_{ij} = \alpha_1 X_{ij} + \alpha_2 D_{ij} + \alpha_3 R_{ij} + \alpha_4 V_{ij} + \alpha_5 SC_{ij} + \mu_j + \varepsilon_{2ij} \quad (10)$$

$$\rho = Cov(\varepsilon_{1ij}, \varepsilon_{2ij}) \quad (11)$$

A positive ρ indicates that households who are sharecropper are also more likely of using fertilizer, conditional on all other co-variates that influence both choices. Thus, sharecropping and fertilizer use can be interpreted as complements, or, sharecropping can be interpreted as substitute to the risk management strategy *no fertilizer use.* A similar reasoning holds for livestock ownership.

4.2 Sharecropping

Results concerning sharecropping are presented in Table 2. The first two columns use the full sample of all countries available in the data set, columns (3) and (4) reflect the results only for the countries where more than 5% of households make use of sharecropping: Ghana, Cameroon and South Africa. Columns (1) and (3) use only exogenous control variables from climate and geography. Columns (2) and (4) include household characteristics, which might be endogenous.

	(1) Full Sample	(2) Full Sample	(3) GHA, CMR, ZAF	(4) GHA, CMR, ZAF
Temperature	0.00542	0.00767	-0.165***	-0.174***
(mean)	(0.20)	(0.28)	(-3.40)	(-3.46)
Precipitation	-1.13e-3***	-1.1e-3***	-1.79e-3***	-1.77e-3***
(mean)	(-5.87)	(-5.58)	(-5.95)	(-5.71)
Precipitation	-8.69e-6**	-9.95e-6**	-2.47e-6	-4.58e-6
(variance)	(-2.23)	(-2.41)	(-0.48)	(-0.84)
Precipitation	4.72e-6***	5.07e-6***	5.54e-6***	5.72e-6***
(mean#variance)	(3.21)	(3.43)	(3.14)	(3.12)
Market distance	-0.0965***	-0.0905**	-0.0266	-0.0220
	(-2.66)	(-2.47)	(-0.51)	(-0.41)
Geo controls	Yes	Yes	Yes	Yes
HH controls	No	Yes	No	Yes
N	6969	6969	1727	1727
χ^2	212.1	227.3	69.56	74.33
p r2_p	0.149	0.159	0.0924	0.0988

t statistics in parentheses. Dependent variable: Sharecropper.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2: Determinants of sharecropping as a form of land tenure

Consistent with Proposition 1, we find that lower rainfall leads in all specifications to a higher likelihood of using sharecropping. The variance of rainfall has a negative impact in the full sample. The statistical significance of rainfall risk diminishes, however, in the sample which considers only Ghana, Cameroon and South Africa. These are countries where more than 5% of the households are sharecroppers. Both findings do not contradict our theoretical model. The interaction term between mean rainfall and the variance of rainfall is in all cases positive, as predicted by Proposition 1. The impact of market distance is for the full sample contrary to what we expected from the theoretical model, which might be related to poor data quality. The findings are robust for a large set of alternative specifications (see appendix)

Overall, our results confirm the predictions of our theoretical model. We find that sharecropping is indeed endogenous to climate conditions: Households in drier regions are more likely to use sharecropping; households in regions with high rainfall but high variance of rainfall are also more likely to be sharecropper. These findings indicate that higher rainfall puts more weight on the 'effort effect' as production becomes more valuable. As sharecropping taxes production, the costs of sharecropping are higher for households living in favorable climatic conditions. Only if risk increases substantially, these households would opt again for sharecropping.

4.3 Livestock

Table 3 shows the results of the probit (column 1 and 2) and tobit (column 3 and 4) regressions on livestock ownership. Columns (1) and (3) again include only the exogenous variables as controls while columns (2) and (4) also include the household variables. Consistent with our theoretical model, we find that livestock ownership is more likely in dry regions and in locations that are far away from selling markets. Rainfall risk (variance) exhibits no clear sign – a finding that is again in line to the ambivalent impact of risk in our theoretical model. Why the theory was inconclusive on the impact of sharecropping on livestock ownership, we find in the empirical analysis that sharecropping reduces the likelihood of livestock ownership as well as the quantity of livestock owned. This indicates that sharecropping interacts with other risk management strategies as sharecroppers rely less on livestock ownership. The findings are robust for a large set of alternative specifications (see appendix).

	Probit (1)	Probit (2)	Tobit (3)	Tobit (4)
Temperature	0.0224*	0.0142	0.0534***	0.0426***
(mean)	(1.69)	(1.05)	(4.80)	(4.01)
Precipitation	-3.37e-4***	-3.34e-4***	-4.58e-4***	4.17e-4***
(mean)	(-4.00)	(-3.89)	(-6.01)	(-5.72)
Precipitation	2.16-6*	2.12e-6*	-7.0e-7	-6.6e-7
(variance)	(1.83)	(1.74)	(-0.77)	(-0.77)
Sharecropper	-0.312***	-0.292**	-0.386***	-0.297***
	(-2.72)	(-2.55)	(-3.29)	(-2.69)
Market distance	0.0414**	0.0282	0.100***	0.0771***
	(2.35)	(1.57)	(6.72)	(5.44)
Geo controls	Yes	Yes	Yes	Yes
HH controls	No	Yes	No	Yes
N	6947	6947	6914	6914
χ^2	1073.1	1261.9	1384.9	2074.6
r2_p	0.155	0.182	0.0621	0.0930

t statistics in parentheses. Dependent variable: (1) and (2) livestock ownership (dummy); (3) and (4) tropical livestock units owned (IHS transformation)
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Determinants of livestock ownership

4.4 Fertilizer

The results of the regression on fertilizer use are shown in Table 4. Column (1) and (2) show the results for the probit model (fertilizer use as dummy) and column (3) and (4) show tobit model results with kg fertilizer applied. Columns (1) and (3) again include only the exogenous variables as controls while columns (2) and (4) also include the household variables.

Contrary to the prediction from theory, we find that high rainfall reduces fertilizer use and distance to markets increase fertilizer use. As we find that sharecropping increases fertilizer use, the risk insurance effect of sharecropping seems to outweigh the effort effect of sharecropping.

The impact of rainfall risk on fertilizer use is positive and highly significant. While our theoretical model does not predict a clear sign for rainfall risk, the result is surprising as most farmers are non-sharecroppers and the sign should be negative for those farms where fertilizer use is profitable under risk-neutrality. The strong finding on rainfall risk is also at odds to related literature: Morris et al. (2007), Chapter 4, notes that "Weather-related uncertainty has a negative impact on farmers' incentives to use yield-enhancing inputs (or to use them at recommended levels) because this can be unprofitable in years of poor rainfall". Dercon and Christiaensen (2011) find that the possibility of low consumption outcomes when harvests fail discourages the use of fertilizer in Ethiopia. Our contrasting results could indicate that the (generally low) fertilizer use in Africa is driven by other considerations than rainfall, be it access to input markets, credit constraints, education, participation in subsidy or voucher schemes, or soil conditions. As we have no data for these factors in our data set, we cannot control for these additional covariates.

	Probit (1)	Probit (2)	Tobit (3)	Tobit (4)
Temperature	-0.162***	-0.162***	-0.816***	-0.809***
(mean)	(-14.14)	(-13.95)	(-14.52)	(-14.52)
Precipitation	-1.95e-4***	-1.94e-4**	-1.03e-3***	-1.07e-3***
(mean)	(-2.60)	(-2.56)	(-2.78)	(-2.92)
Precipitation	4.03e-6***	4.01e-6***	1.9e-5***	1.92e-5***
(variance)	(4.47)	(4.44)	(4.62)	(4.73)
Sharecropper	0.320***	0.346***	1.272**	1.425***
	(2.91)	(3.13)	(2.41)	(2.74)
Market distance	0.124***	0.118***	0.661***	0.603***
	(8.46)	(7.96)	(9.40)	(8.66)
Geo controls	Yes	Yes	Yes	Yes
HH controls	No	Yes	No	Yes
N	6969	6969	6969	6969
χ^2	742.7	838.0	810.9	957.0
r2_p	0.0774	0.0874	0.0319	0.0376

t statistics in parentheses. Dependent variable: (1) and (2) fertilizer use (dummy); (3) and (4) amount of fertilizer used in kg (IHS transformation)
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Determinants of fertilizer use

4.5 Substitution between risk strategies

Farming households apply risk management and risk coping techniques in order to smooth consumption and in particular to avoid very low consumption levels in years of failed harvests. If one way of smoothing consumption is available, other ways will be less likely to be used. The purpose of this section is thus to analyze to what extent these risk adaptation strategies are substitutes, using bivariate probit regressions. Since the effect of sharecropping is of principal interest we test for correlation of sharecropping first with fertilizer use and then with livestock ownership.

Table 5 presents the bivariate probit regression results of sharecropping and fertilizer use (1) and sharecropping and livestock ownership (2). Magnitude and significance levels are highly consistent to the univariate models in Table 2, 3 and 4. The new result here appears as the ρ in the last line. It shows a highly significant positive correlation of the error terms for sharecropping and fertilizer use. Thus, sharecropping and fertilizer use are complements: Those who are sharecroppers are more likely to apply also fertilizer use, conditional on the other covariates. The opposite is the case for livestock ownership and sharecropping: Sharecroppers are less likely to own livestock, conditional on all covariates.

Since *reductions* in fertilizer use is a risk management strategy a positive value for ρ implies that sharecropping and fertilizer use are substitutes as risk adaptation strategies. Both results provide additional evidence that sharecropping is a substitute to other risk management strategies (livestock ownership, no fertilizer use).

The substitution between sharecropping and fertilizer might have more dramatic consequences for aggregate productivity than the substitution with livestock. While the decision to buy livestock does not affect the quality of crop production directly, the decision to not buy fertilizer reduces the yields. Livestock owners, however, might grow less food crops as some of the area is needed for grazing or growing feed crops. Thus, aggregate food production might also be affected negatively by livestock ownership. Both risk management strategies (livestock ownership, no fertilizer use) can be a rational response of the individual farmer to insure against very low income events. From the point of view of society in which idiosyncratic risks are poorly correlated and 'average out', however, both risk management strategies might incur efficiency losses or lower food production.

	(1)		(2)	
	Sharecropper	Fertilizer use	Sharecropper	Livestock ownership
Temperature	-0.000773	-0.162^{***}	0.00793	0.0223^{*}
(mean)	(-0.03)	(-14.15)	(0.30)	(1.69)
Precipitation	$-1.12e\text{-}3^{***}$	$-2.16e\text{-}4^{***}$	$-1.12e\text{-}3^{***}$	$-3.13e\text{-}4^{***}$
(mean)	(-5.71)	(-2.90)	(-5.86)	(-3.74)
Precipitation	$-9.6e\text{-}6^{**}$	$4.04e\text{-}6^{***}$	$1.06e\text{-}6^{**}$	$2.16e\text{-}6^{*}$
(variance)	(-2.33)	(4.49)	(-2.50)	(1.83)
Precipitation	$4.83e\text{-}6^{***}$		$5.6e\text{-}6^{***}$	
(mean#variance)	(3.29)		(3.79)	
Market distance	-0.0938^{***}	0.123^{***}	-0.0998^{***}	0.0424^{**}
	(-2.60)	(8.39)	(-2.73)	(2.41)
Geo controls	Yes	Yes	Yes	Yes
HH controls	No	No	No	No
N	6969		6947	
χ^2	860.7		1023.2	
ρ	0.137^{***}		-0.152^{***}	

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Bivariate probit regression of sharecropping and fertilizer use and of sharecropping and livestock ownership

5 Conclusion

We present empirical evidence that weather related production risk influences risk coping techniques and conjecture, based on the literature and our theoretical model, that the same applies to risk management. The use of these risk management and risk coping techniques are negatively correlated in bivariate estimates, thus providing support for the theoretical hypothesis that the techniques partially serve as substitutes. The partial insurance provided by sharecropping might thus provide farmers with the means to reduce the use of other risk coping and, importantly, risk management techniques. Based on this evidence we conclude that sharecropping, as a risk coping mechanisms available even in countries with weak institutions, has the potential of increasing efficiency in African agriculture.

As climate change is likely to increase weather variability, agriculture is likely to become more risky as well. When farmers adapt to this risk in the form of risk management, agricultural productivity might decrease beyond the direct effect of the changed climate. This will have obvious negative consequences for food security. Governments will thus need a precise understanding of risk management strategies of farmers. This paper points out the role of land tenure in risk management. Some forms of land tenure, like sharecropping, involve less risk for farmers, while others, like renting land, involve more risk. Governments which are unable to offer sophisticated risk coping strategies (like formal insurance) for farmers could thus consider encouraging land tenure systems like sharecropping as a way of increasing the resilience of agricultural production.

The paper supplies some first empirical support to the novel theoretical prediction that project choice is an important component in understanding the investment efficiency of sharecropping in contrast to other forms of land tenure. This idea could thus become a promising avenue for refining the understanding of risk behavior in agriculture.

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A Tables

Country	Number of districts	Obs. per district			Total N
		Mean	Min	Max	
Burkina Faso	48	21.7	3	30	1043
Cameroon	30	25.6	17	50	769
Ethiopia	32	27.0	9	60	864
Ghana	59	13.8	1	24	814
Niger	30	28.5	23	30	855
Senegal	62	14.5	3	20	896
South Africa	17	8.5	1	35	144
Zambia	30	29.9	18	48	897
Zimbabwe	23	29.9	14	68	687
Sum	331				6969
Mean	36,8	22.2	9.9	40.6	774.3

Table 6: Number observations (household and district level)

Country	Variation (CV) between districts within country		
	Temperature (annual mean)	Precipitation (annual mean)	Precipitation (CV over years)
Burkina Faso	0,002	0,221	0,192
Cameroon	0,006	0,230	0,225
Ethiopia	0,011	0,348	0,253
Ghana	0,002	0,097	0,240
Niger	0,002	0,264	0,255
Senegal	0,004	0,418	0,468
South Africa	0,007	0,409	0,328
Zambia	0,003	0,215	0,233
Zimbabwe	0,005	0,204	0,094

Table 7: Spatial variability of climate variables within countries

B Robustness checks

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Temperature (mean)	0.00542	-0.00395	-0.000945	0.00836	0.0127	-0.0242	-0.0310	0.00851
	(0.20)	(-0.18)	(-0.04)	(0.31)	(0.47)	(-0.38)	(-0.49)	(0.29)
Precipitation (mean)	-0.00113***	-0.000769***	-0.000782***	-0.00115***	-0.000907***	-0.00253***	-0.00242***	-0.00110***
	(-5.87)	(-5.14)	(-5.21)	(-4.39)	(-4.97)	(-5.81)	(-5.84)	(-5.38)
Precipitation (variance)	-0.00000869**	-0.00000447	-0.00000470*	-0.0000143*	-0.00000529	-0.0000190**	-0.0000185**	-0.00000820**
	(-2.23)	(-1.59)	(-1.65)	(-1.73)	(-1.35)	(-2.15)	(-2.16)	(-2.05)
Precipitation (mean#variance)	0.00000472***	0.00000264**	0.00000273**	9.07e-09		0.0000105***	0.0000102***	0.00000398**
	(3.21)	(2.08)	(2.15)	(1.29)		(3.11)	(3.06)	(2.41)
Market distance	-0.0965***	-0.0607*	-0.0608*	-0.0900**	-0.0887**	-0.200**	-0.191**	-0.0540
	(-2.66)	(-1.92)	(-1.91)	(-2.50)	(-2.47)	(-2.40)	(-2.36)	(-1.27)
Distance input market	0.0196	0.0554	0.0585	0.0355	0.0364	0.0735	0.0711	0.00114
	(0.23)	(0.80)	(0.84)	(0.43)	(0.44)	(0.41)	(0.42)	(0.01)
Zero market distance	-0.0159	0.469***	0.466***	-0.0346	-0.0331	0.00525	0.00901	0.192
	(-0.08)	(3.15)	(3.13)	(-0.18)	(-0.17)	(0.01)	(0.02)	(0.93)
N	6969	6969	6907	6969	6969	6969	6969	4931
χ^2	212.1	277.3	277.3	204.7	203.0	211.5	211.0	182.3
p	7.23e-37	2.83e-50	2.84e-50	2.39e-35	1.34e-35	9.57e-37	1.24e-36	8.27e-31
r2_p	0.149	0.139	0.139	0.144	0.142	0.148		0.160

t statistics in parentheses. Endogenous variable: Sharecropping (binary). All regressions include geographical controls and country dummies but no household controls. Specifications are as follows (1) basic regression, (2) endogenous variable (sharecropping) equals one if at least one plot under sharecropping, (3) endogenous variable: share of area under sharecropping (continuous), (4) using non-standardized precipitation for the interaction term with rainfall variance, (5) without variance–mean rainfall interaction term, (6) logit regression, (7) cloglog regression, (8) consider only farms smaller than 5 ha.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 8: Determinants of sharecropping as a form of land tenure

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Temperature (mean)	0.0224*	0.0411*	0.0219*	0.0204	0.0584**	0.0472***	0.0219*	0.0224*
	(1.69)	(1.70)	(1.65)	(1.52)	(2.51)	(3.14)	(1.66)	(1.69)
Precipitation (mean)	-0.000337***	-0.000578***	-0.000335***	-0.000334***	-0.000526***	-0.000388***	-0.000250***	-0.000350***
	(-4.00)	(-3.99)	(-3.98)	(-3.96)	(-4.43)	(-4.20)	(-3.32)	(-3.82)
Precipitation (variance)	0.00000216*	0.00000412*	0.00000220*	0.00000216*	0.00000871***	0.00000212*		0.00000176
	(1.83)	(1.87)	(1.86)	(1.83)	(2.76)	(1.66)		(1.09)
Sharecropper	-0.312***	-0.494***	-0.267***		-0.209	-0.238*	-0.305***	-0.315***
	(-2.72)	(-2.58)	(-2.82)		(-1.52)	(-1.86)	(-2.67)	(-2.74)
Market distance	0.0414**	0.0744**	0.0413**	0.0404**	-0.0398	-0.0215	0.0416**	0.0410**
	(2.35)	(2.45)	(2.34)	(2.28)	(-1.21)	(-1.02)	(2.36)	(2.32)
Distance input market	0.0304	0.0850	0.0318	0.0509	0.0791	0.0257	0.0296	0.0297
	(0.64)	(0.97)	(0.67)	(1.04)	(1.17)	(0.49)	(0.62)	(0.62)
Zero market distance	-0.390***	-0.659***	-0.370***	-0.384***	-1.117***	-0.635***	-0.392***	-0.389***
	(-3.69)	(-3.75)	(-3.49)	(-3.63)	(-6.85)	(-5.37)	(-3.70)	(-3.68)
Sharecropping area				-0.359***				
				(-2.92)				
Precipitation (coef. of variation)							0.840*	
							(1.92)	
Precipitation (mean#variance)								0.000000273
								(0.37)
N	6947	6947	6947	6885	1707	4915	6947	6947
χ^2	1073.1	1075.0	1073.6	1056.4	104.8	752.9	1073.3	1073.2
p	2.90e-219	1.12e-219	2.19e-219	1.09e-215	1.67e-18	9.58e-151	2.57e-219	2.34e-218
r2_p	0.155	0.155	0.155	0.153	0.0460	0.142	0.155	0.155

t statistics in parentheses. Endogenous variable: Livestock ownership (binary). All regressions include geographical controls and country dummies but no household controls. Specifications are as follows (1) basic regression, (2) logit regression, (3) sharecropper dummy variable equals one if at least one plot under sharecropping regime, (4) share of area under sharecropping (continuous), (5) sharecropper countries only (Ghana, Cameroon, South Africa), (6) consider only farms smaller than 5 ha, (7) use coefficient of variation of rainfall instead of variance, (8) consider interaction term of rainfall mean and variance.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 9: Determinants of livestock ownership

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Temperature (mean)	-0.162***	-0.267***	-0.162***	-0.158***	0.0342	-0.159***	-0.163***	-0.162***
	(-14.14)	(-13.89)	(-14.13)	(-13.53)	(1.43)	(-12.31)	(-14.17)	(-14.14)
Precipitation (mean)	-0.000195***	-0.000311**	-0.000201***	-0.000225***	-0.000613***	-0.000308***	-0.0000232	-0.000150*
	(-2.60)	(-2.46)	(-2.69)	(-2.99)	(-4.99)	(-3.62)	(-0.34)	(-1.83)
Precipitation (variance)	0.00000403***	0.00000646***	0.00000403***	0.00000401***	0.0000144***	0.00000317***		0.00000521***
	(4.47)	(4.27)	(4.48)	(4.46)	(4.48)	(3.02)		(4.16)
Sharecropper	0.320***	0.541***	0.222**		0.168	0.382***	0.333***	0.329***
	(2.91)	(3.00)	(2.45)		(1.21)	(3.10)	(3.02)	(2.99)
Market distance	0.124***	0.201***	0.124***	0.124***	-0.0337	0.0772***	0.125***	0.125***
	(8.46)	(8.42)	(8.43)	(8.40)	(-1.03)	(4.18)	(8.52)	(8.53)
Distance input market	-0.143***	-0.237***	-0.143***	-0.136***	-0.130*	-0.153***	-0.143***	-0.141***
	(-4.13)	(-4.07)	(-4.14)	(-3.88)	(-1.89)	(-3.45)	(-4.14)	(-4.09)
Zero market distance	-0.368***	-0.630***	-0.381***	-0.376***	-1.190***	-0.565***	-0.368***	-0.371***
	(-3.43)	(-3.38)	(-3.54)	(-3.50)	(-5.95)	(-4.59)	(-3.42)	(-3.45)
Sharecropping area				0.256**				
				(2.17)				
Precipitation (coef. of variation)							1.319***	
							(3.96)	
Precipitation (mean#variance)								-0.000000860
								(-1.36)
N	6969	6969	6969	6907	1727	4931	6969	6969
χ^2	742.7	744.7	740.3	726.1	191.2	545.9	737.7	744.5
p	1.45e-148	5.48e-149	4.84e-148	5.00e-145	2.34e-36	1.06e-106	1.67e-147	4.22e-148
r2_p	0.0774	0.0777	0.0772	0.0764	0.0866	0.0810	0.0769	0.0776

t statistics in parentheses. Endogenous variable: Fertilizer use (binary). All regressions include geographical controls and country dummies but no household controls. Specifications are as follows (1) basic regression, (2) logit regression, (3) sharecropper dummy variable equals one if at least one plot under sharecropping regime, (4) share of area under sharecropping (continuous), (5) sharecropper countries only (Ghana, Cameroon, South Africa), (6) consider only farms smaller than 5 ha, (7) use coefficient of variation of rainfall instead of variance, (8) consider interaction term of rainfall mean and variance.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 10: Determinants of fertilizer use

	(1)			(2)
	Sharecropper	Fertilizer use	Sharecropper	Livestock ownership
Temperature	0.00114	-0.162***	0.0109	0.0141
(mean)	(0.04)	(-13.95)	(0.39)	(1.04)
Precipitation	-0.00108***	-0.000217***	-0.00109***	-0.000311***
(mean)	(-5.43)	(-2.88)	(-5.54)	(-3.65)
Precipitation	-0.0000108**	0.00000402***	-0.0000119***	0.00000212*
(variance)	(-2.50)	(4.45)	(-2.66)	(1.74)
Precipitation	0.00000510***		0.00000592***	
(mean#variance)	(3.45)		(3.97)	
Market distance	-0.0887**	0.117***	-0.0939**	0.0292
	(-2.43)	(7.89)	(-2.54)	(1.62)
Distance input	0.00332	-0.142***	0.00206	0.0525
market	(0.04)	(-4.10)	(0.02)	(1.07)
Zero market	0.0633	-0.381***	-0.214	-0.445***
distance	(0.33)	(-3.49)	(-0.96)	(-4.10)
N	6969		6947	
χ^2	951.2		1129.3	
p	8.56e-173		5.20e-210	
ρ	0.142***		-0.152***	

t statistics in parentheses. Regression with household characteristics (coefficients omitted from table).
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 11: Bivariate probit regression of sharecropping and livestock ownership and of sharecropping and fertilizer use