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Can Land Fragmentation Reduce the Exposure of Rural Households to Weather Variability? *

Stefanija Veljanoska†

Abstract

Climate change continuously affects African farmers that operate in rain-fed environments. Coping with weather risk through credit and insurance markets is almost inexistent as these markets are imperfect in the African economies. Even though land fragmentation is often considered as a barrier to agricultural productivity, this article aims at analyzing whether land fragmentation, as an insurance alternative, is able to reduce farmers' exposure to weather variability. In order to address this research question, I use the Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) data on Uganda. After dealing with the endogeneity of land fragmentation, I find that higher land fragmentation decreases the loss of crop yield when households experience rain deviations. Therefore, policy makers should be cautious with land consolidation programs.

JEL: Q12, Q15, Q54

Keywords: climate change, land fragmentation, rainfall, yield, insurance

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1 Introduction

Global warming is a crucial issue for the African continent and it is expected that its impacts will be even more severe in future. At the same time, Africa is the least responsible for global greenhouse gases (GHG) emissions, but it would be the most affected by their consequences as its adaptive capacity is very low [Collier et al., 2008]. The majority of the population lives in rural areas and is engaged in the agricultural sector which is highly sensitive to weather variability. Because of the lack of irrigation infrastructure, weather conditions affect directly agricultural production and livelihoods [Barrios et al., 2008, Schlenker and Lobell, 2010, Kahsay and Hansen, 2016]. Also, climate change increases the frequency and the severity of extreme events. As a result, a great part of the population in Africa experienced already a variety of stresses and shocks [Barrios et al., 2008]. Extreme events, such as floods and drought, have serious impacts on agricultural production, but gradual changes in climate can be consequential on agricultural production too. These effects are amplified by the limited capacity of African countries to deal with it. Possibilities to deal with weather risk through credit and insurance markets are almost inexistent as these markets are imperfect in the African economies.[1] Due to the lack of access to these markets, households employ different arrangements in order to cope with covariate shocks. Among others, they choose sub-optimal low-risk/low-return portfolios, or diversify the sources of income by working in the non-agricultural sector or by migrating. This article aims at verifying whether land fragmentation is an alternative for households to cope with weather shocks.

Land fragmentation is the practice of farming a number of spatially separated plots of owned or rented land by the same farmer [McPherson, 1982]. It is a phenomenon that is observed in many countries especially in developing countries. According to the World Agricultural Census by FAO, the average number of parcels operated by a farmer is 3.5 worldwide during 1995-2005. Land fragmentation is often considered as a barrier to agricultural output and productivity. There is empirical evidence that increases in land fragmentation lead to lower agricultural output and agricultural productivity [Wan and Cheng, 2001, Rahman and Rahman, 2009, Van Hung et al., 2007, Tan et al., 2010]. Another obstacle associated with land fragmentation is the distance between parcels.

[1]There are insurance products present on the African continent, such as crop insurance and index-based insurance, but their take-up rate is very low.

In particular, when parcels are dispersed, travel time and costs in moving labor and machines can increase. In this sense, it was shown in the literature that land fragmentation increases costs of production and cost of labor [Shuhao et al., 2008]. In addition, land fragmentation can hinder machinery use by farmers [Foster and Rosenzweig, 2011]. Other drawbacks of land fragmentation are fencing costs, small size and irregular shape of parcels, and conflicts among neighbors [Demetriou, 2013]. However, there is not a consensus on whether land fragmentation has a negative impact on agricultural outcomes.[2] Blarel et al. [1992] find that the level of land fragmentation has no significant impact on yield and therefore reject the hypothesis that fragmentation is inefficient in the case of Ghana and Rwanda.

Land fragmentation can in fact also provide benefits to farmers. It can facilitate risk management through seasonal and spatial diversification of crop production [Blarel et al., 1992, Bentley, 1987, Van Hung et al., 2007]. This would reduce the exposure of farmers to climatic variability and disasters as production risk is spatially spread. McCloskey [1976] is among the first economists to document the ability of scattered parcels to reduce the crop production risk. Blarel et al. [1992] found that land fragmentation reduces the variability of agricultural output per acre. Fragmentation also allows for adjustments of household labor across seasons as crop scheduling is feasible when parcels are scattered in different locations with different agro-ecological characteristics [Fenoaltea, 1976]. Furthermore, land fragmentation improves agro-biodiversity as crops are better matched with the operated soil types [Di Falco et al., 2010].

This article aims at analysing the ability of fragmented land holdings of farmers to reduce their exposure to weather variability. More precisely, the objective is to study empirically whether households with higher degree of fragmented land incur smaller reductions in their agricultural income when they are subject to rainfall irregularities compared to households with more consolidated land. Two dimensions of land fragmentation can improve the ability of farmers to diversify weather risk: the physical distance between the parcels and the different agro-ecological characteristics of the different parcels. The contribution of the paper is twofold: it does quantitative research on the incidence of

[2] Such divergence between authors might be also linked to how yields are measured. A growing literature takes into consideration measurement errors due to self-reported land surfaces and uses more objective measures such as GPS coordinates measures when studying land size and productivity relationship. This might change the direction of the debate. In this article I use both self-reported land size and GPS measures as robustness check.

fragmentation on agricultural income by taking into account rainfall variability, which to the best of my knowledge, has not been addressed by the literature; and it contributes to the cost/benefit debate of land fragmentation in the case of Uganda.

In order to test whether land fragmentation may reduce the income loss from exposure to rainfall variability, I estimate the impact of the degree of land fragmentation on agricultural yield of a household. Land fragmentation is measured by the number of parcels that the household owns and also by a Simpson Index calculated for these parcels. This index combines the number of parcels and the distribution of area among the different parcels. An important issue that arises is that land fragmentation can be affected by some unobserved factors that influence agricultural income (management ability, entrepreneurial spirit). Also, farmers may be able to choose their level of land fragmentation in order to deal with production risk. This is the case when land markets exist and land can be traded or rented. In order to deal with this issue, I instrument the fragmentation in operated land with the fragmentation in inherited land as inherited land fragmentation is exogenously imposed on the household through the inheritance process [Foster and Rosenzweig, 2011]. I use data from the Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) for the years 2005/2006, 2009/2010, 2010/2011 and 2011/2012 established by the World Bank. After instrumenting for the level of fragmentation, I find that higher land fragmentation decreases the loss of crop yield when households experience rain deviations. The results show that the higher this deviation, the higher the beneficial effect of land fragmentation. These results are found for all the different measures used for land fragmentation.

Because of the widely perceived inefficiencies of land fragmentation, some countries like Kenya, Tanzania and Rwanda, have adopted land consolidation programs. The aim of this article is not to fully support land fragmentation as it is shown by the literature to be detrimental for agricultural productivity, but to argue that in some cases it can provide insurance possibilities. If land, labor and insurance markets are imperfect, land fragmentation offers households a risk-mitigating tool with possibility to spread labor over seasons and provide food security. If the labor market is imperfect, labor supply is fixed by the household endowment and there is an important need to spread labor temporally. Moreover, farmers fail to cultivate land due to land market imperfections rather than its small size or fragmentation. Therefore, addressing land, labor and insurance market imperfections can be more suitable for agricultural productivity than land consolidation programs.

2 Background

The Constitution of Uganda includes customary, freehold, mailo and leasehold tenure systems recognized by the Land Act of Uganda 1998. The mailo system consists of a sub-division of land where the basic unit is a square mile, hence the name mailo. Mailo land is owned with individual property rights certified by a land title. Similarly, freehold land holders have full powers of ownership over their land. This implies that the holder can use it for any purpose and sell, let, lease and dispose it off. Leasehold system is a system of owning land for a particular period of time. The leasehold transactions are contractual and allow both parties to define the terms and conditions of access and usage.

Customary tenure system dominates the other systems. According to the FAO, it represents 75 percent of the total land which makes it the most common form of tenure in the country. Land is therefore mainly governed by customs, rules and regulations of the community. Due to these regulations, the main cause of land fragmentation is the inheritance system. In Uganda, population growth together with the traditional inheritance protocols are supposed to be the most important driver of the increased land fragmentation [Nkonya et al., 2004]. For instance, when the head of a household dies, his land is sub-divided among his sons.[3] The higher the number of male members of the family the lower the piece each member gets. But, division of land can be made also pre-mortem through gifts or transfers and sometimes can be unequal among family members. Also, land can be aquired as a gift from other members of the extended family than the father. This phenomenon of land sub-division continues with each passing generation on the customary freehold lands. According to the Ugandan economist Eric Kashambuzi, Ugandan farmers tend to consider fragmentation as beneficial as it allows to grow different crops on parcels with different characteristics. However, in February 2015, the president Yoweri Museveni strongly recommended farmers to stop land fragmentation, following its recent increase due to inheritance practices.

Uganda lies across the equator. Its climate is humid with very hot periods during

[3] However, woman start to take part in the process of inheritance and have property rights over parcels, even though they mainly get these rights through marriage.

the year. It has two rainfall seasons, one from March to June and another from August to November. Uganda has experienced extreme weather episodes in the last years, especially in the North. As reported by the Ugandan Ministry of Water and Environment, between 1991 and 2000, Uganda experienced seven droughts. Nevertheless, the climate is suitable for crop production and the rainfall intensities are expected to grow. The rainfall distribution across seasons will become more and more irregular. According to the World Bank indicators, about 84% of the population of Uganda lives in rural areas in 2014. As the agricultural production is of the subsistence-type and rain-fed, Ugandan farmers are much exposed to weather variability and verifying whether land fragmentation can allow for reducing its impact on agricultural income is crucial.

3 Data and descriptive statistics

In this study, I use data from the Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) for the years 2005/2006, 2009/2010, 2010/2011 and 2011/2012 established by the Bill and Melinda Gates Foundation and implemented by the Living Standards Measurement Study (LSMS) within the Development Research Group at the World Bank. The Uganda National Panel Survey (UNPS) sample includes economic and social information on about 3 200 households (with about 2 000 households that are engaged in cultivation of crops). These households were previously interviewed in the 2005/2006 Uganda National Household Survey (UNHS). The sample also includes households that were randomly selected after 2005/2006. The sample is representative at the national, urban/rural and main regional levels (North, East, West and Central regions).

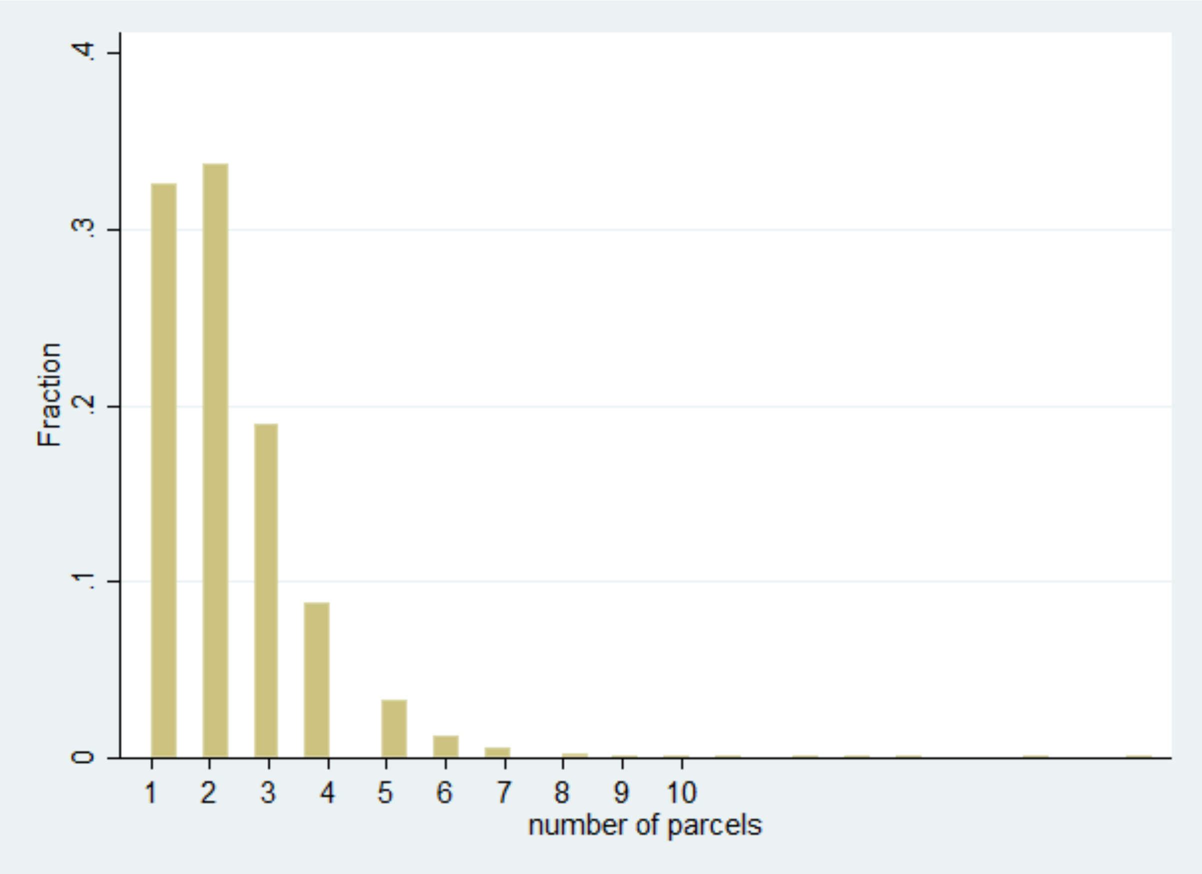
Table 1 presents definitions and the summary statistics of the dependent and explanatory variables used in the estimations. The dependant variable is crop yield in value. It represents the total crop production evaluated at each crop prices at community level and devided by the total cultivated land. The main variable(s) of interest are the total number of cultivated and owned but not cultivated parcels and the Simpson index.[4] The average number of cultivated and owned but not cultivated parcels by households

[4]More preciesly the type of parcels included are: cultivated, both owned and rented, and non-cultivaed owned parcles that might be under fallow for exemple, as the aim is to account for total actual fragmentation.

Table 1: Definition and descriptive statistics

Variable	Definition	Mean	Standard dev.	Min	Max
agprod	total agricultural production in Ugandan Shillings (UGX)	2.54e+07	2.54e+08	0	1.80e+10
yield	agprod/cultivated land	11799	125000	0	6000432
yield in log	agprod/cultivated land in log	6.206	2.464	0	15.607
Land fragmentation					
n	number of parcels	2.28	1.38	1	18
n type	number of parcels with different soil texture	1.29	0.51	1	4
n topography	number of parcels with different slope	1.36	0.57	1	5
Simpson index	calculated as described by Equation (3)	0.35	0.27	0	1
Household characteristics					
sex	the gender of the HH head; equals 1 if the HH head is male 0 if it is female	0.712	0.453	0	1
age	the age of the HH head	46.384	15.313	13	100
education	the highest school level achieved by the HH head 0-no education, 1-primary, 2-secondary	1.026	.659	0	2
adults	HH members above 16 years	2.960	1.686	0	24
Land characteristics					
cultivated land	cultivated land in acres	4.614	37.355	0 3000	
soil quality index	weighted index of soil quality with: level 1 being good quality and level 3 being poor quality	1.704	0.703	0	3
Weather characteristics					
rain dev	rain deviation in absolute terms from the long run mean divided by the long run standard deviation at time t in district d	0.668	0.614	0.005	2.628

Figure 1: Distribution of parcels



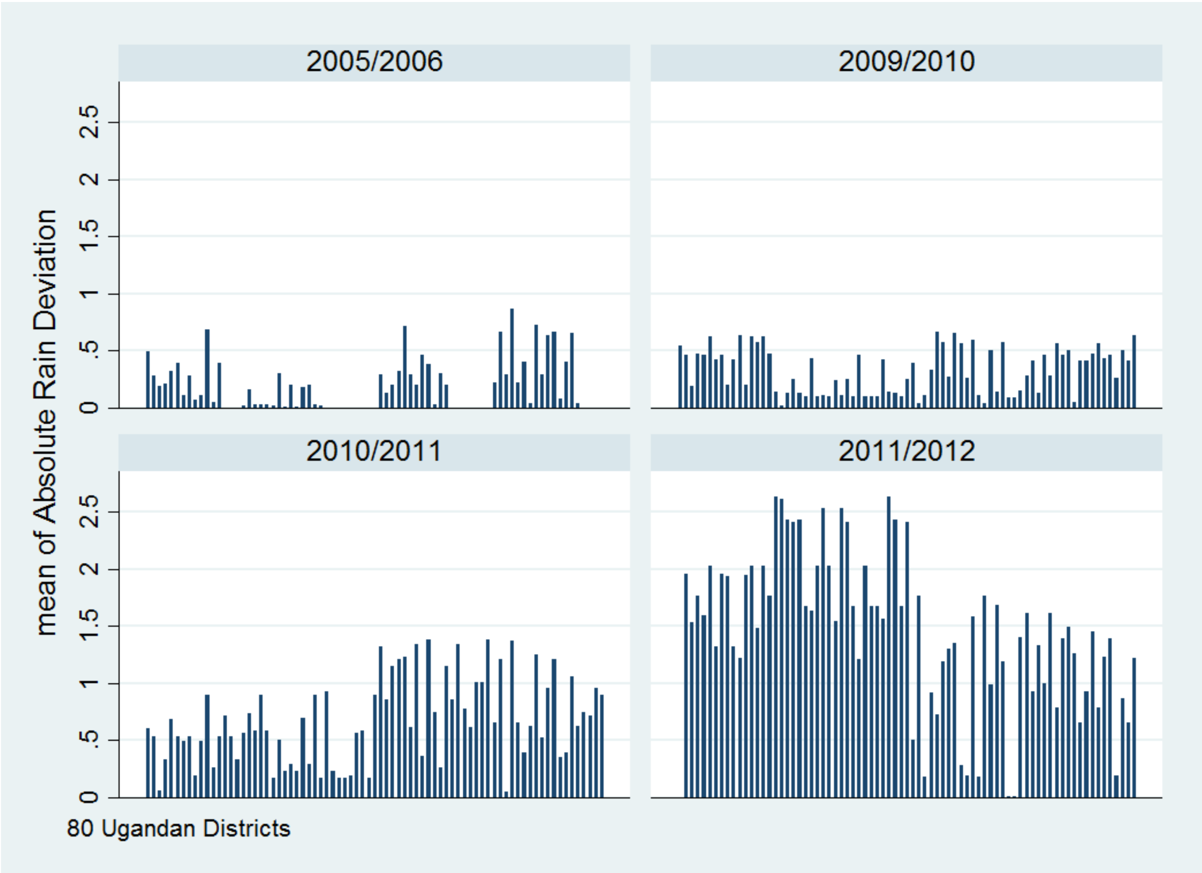
in the sample is 2.3 with the maximum being at 18. Considering the number of parcels with different texture and different slope, the average number of different parcels is 1.29 and 1.36 respectively. According to Figure 1, the distribution of parcels in the sample is skewed. The percentage of household with 1 parcel is 32.5, with 2 parcels is 34 and with 3 parcels is 19. Only 15.5 percent of households have a degree of fragmentation that exceeds 3 parcels. By definition, the Simpson index is between zero and one and the sample average is 0.35. This means that on average land shares are unevenly distributed among the different parcels. The evolution of land acquisition of the households is given in Table 2. The share of inherited land has increased over the years and the share of inherited parcels stands for half of the total parcel holdings of a given household.

Household heads have on average 46 years, are mostly male (about 70 percent) and have on average attended only primary school. Only two percent of the households did not receive any education. The average number of adult members of the households is around 3. The average size of the cultivated land is 4.6 acres and the soil quality is mostly

Table 2: Land acquisition

Parcels	2005/2006	2009/2010	2010/2011	2011/2012
Inherited	40%	47%	50%	53%
Purchased	25%	26%	25%	23%
Rented	27%	26%	23%	22%
Other	8%	1%	2%	2%

Figure 2: Average rain deviation in the 80 Districts



fair.

The data used to construct the rain deviation variable is the TS3.21 dataset from the Climatic Research Unit of the University of East Anglia. It is monthly average data on precipitations from high-resolution grids, 0.5 x 0.5 degrees, that cover more than one century (1901-2012). The precipitation anomalies are constructed as deviations at time t in the district d from the long run annual mean divided by the long run annual standard deviation of the given district, es in the following equation:

$$RAINDEV_{dt} = \frac{RAIN_{dt} - \mu_{dLR}}{\sigma_{dLR}} \tag{1}$$

where $RAIN_{dt}$ coresponds to the annual level of rainfall in the district d, μ_{dLR} is the long run (LR) rainfall mean in the same district and σ_{dLR} is the standard deviation. From the descriptive statistics in Table 1, we can see that the average rain deviation in the 80 districts included in the sample is 0.7 with the minimum being 0 and the maximum rain deviation being 2.6 in absolute terms.Figure 2 gives the absolute rainfall deviation for the different districts in Uganda in different years in the sample. The size of absolute rainfall deviation increases over the period which might be linked to the consequences of climate change.

4 Empirical strategy

In order to test whether land fragmentation may reduce the loss of agricultural income form rainfall variability, I estimate the following reduced form equation:

$$ln(\frac{Y_{ht}}{A_{ht}}) = \alpha_0 + \alpha_1 X_{ht} + \alpha_2 F_{ht} + \alpha_3 ln(A_{ht}) + \alpha_4 Z_{ht} + \alpha_5 RAINDEV_{dt} + \alpha_6 RAINDEV_{dt} * F_{ht} + \mu_h + \eta_t + \varepsilon_{ht} \tag{2}$$

where Y_{ht} represents the value of total agricultural output of household h in time t. The total agricultural output is evaluated at mean community prices for each crop that the given household produces. The dependent variable is the ratio between the value of the agricultural production and the total land cultivated in acres, and this equals total agricultural yield per acre in value. A_{ht} represents the total cultivated land net of land under fallow. X_{ht} accounts for the household socio-economic characteristics such as the number of adults which is a proxy for the labor endowment, education, gender and age of the household head and access to extension services.

The degree of land fragmentation of the household is given by the variable F_{ht}. Land fragmentation is usually measured simply by the number of parcels that the household operates.[5] This variable includes the parcels that a household owns and rents. Among the owned parcels, households mainly inherit the different parcels and a lower part of them is purchased.

The Simpson Index is also used in the literature [Blarel et al., 1992, Shuhao et al., 2008]. It is defined as:

$$SI_{ht} = 1 - \sum_{i=1}^{n} a_{it}^2 / (\sum_{i=1}^{n} a_{it})^2 \quad (3)$$

where n is the number of parcels and a_{it} is the size of parcel i in time t. A Simpson index close to zero means that the land of the household is completely consolidated; there is only one parcel. The closer the value to one, the more fragmented the land of the household is. The value of the Simpson index is therefore determined by the number of parcels, the average size of the parcels and the parcel size distribution. This index does not take into account the total size of the land holdings of the farmer, the different characteristics of the parcels and the distance to the parcels. Therefore, Z_{ht} controls for land quality.

I include a variable $RAIN_{dt}$ that measures annual deviation in rainfall from the long run mean at time t in the district d where the household h lives divided by the long run standard deviation. $RAIN_{dt}$ measures the rainfall deviations that households are exposed to. For sake of simplicity in interpretation, this variable is expressed in absolute terms. In addition, according to Figure 1, there were more positive (and extreme) rainfall deviations in the different districts of Uganda than negative, on average. The interaction term between the rainfall deviation and the degree of fragmentation tests for a possible difference in impact of rainfall variability on income between households that have different levels of land fragmentation. I expect that when households face the same rainfall deviation, more fragmented land holdings should lower the incidence on income compared to more consolidated land holdings. Finally, μ_h and η_t stand for household and time fixed effects.

A concern when estimating Equation (2) is that land fragmentation is affected by some unobserved factors that influence agricultural income (management ability, entrepreneurial spirit). Also, farmers can choose their level of land fragmentation in order

[5]Parcels under fallow are also included in the number of parcels operated by the household.

to deal with production risk. This is the case when land markets exist and land can be traded or rented. However in the case of Uganda, as land markets are incomplete we can assume that trading land is not entirely feasible. Still, the degree of land fragmentation of the household can be at least partially chosen. In order to deal with this endogeneity issue, I instrument the fragmentation in operated land with the fragmentation in inherited land, as inherited land fragmentation is exogenously imposed on the household through the inheritance process [Foster and Rosenzweig, 2011]. The other first-stage equation is therefore:

$$F_{ht} = \beta_0 + \beta_1 X_{ht} + \beta_2 Ninherited_{it} + \beta_3 ln(A_{ht}) + \beta_4 Z_{ht} + \beta_5 RAIN_{dt} + \mu_h + \eta_t + \varepsilon_{ht} \quad (4)$$

where $Ninherited$ is the number of parcels inherited by the household i in time t. The interaction variable, $RAIN_{dt} * F_{ht}$, in Equation (2) is also endogenous and it is instrumented with the interaction term between rain deviation and number of inherited parcels. The other first stage equation is therefore given as:

$$RAIN_{dt} * F_{ht} = \gamma_0 + \gamma_1 X_{ht} + \gamma_2 RAIN_{dt} * Ninherited_{it} + \gamma_3 ln(A_{ht}) + \gamma_4 Z_{ht} + \mu_h + \eta_t + \varepsilon_{ht} \quad (5)$$

5 Results

In this section the results from the estimation of Equation (2) are presented. In Table 2, I use the number of parcels n as a measure for land fragmentation and in Table 3 this is measured with the Simpson index described before. In both tables Ordinary Least Squares (OLS), Panel fixed effects (FE) and Panel Instrumental Variable (IV) estimations are included. Columns (2), (4) and (6) in each table include the soil quality index that is constructed for the last three rounds, as the data on land quality is missing from the first round, thus these estimations are run on a smaller sample.

5.1 First stage results

Before discussing the second stage results, I comment on the results for the first stage estimation and the validity of the instruments. Table 3 gives the first stage results of land fragmentation measures and suggests that the number of inherited parcels has a positive and significant impact on the number of owned parcels and on the Simpson index. If the land markets in Uganda were perfect, the coefficient in column (1) in Table 3 of the inherited fragmentation would have the value 0 as households can freely decide about the number of parcels they want to operate. The closer this coefficient is to 1, the more the household land fragmentation is determined by inheritance.

Concerning the validity of the instrument used, the Sargan statistic is 0 which indicates that the Equations (4) and (5) are exactly identified. The F-statistic is higher than 20 in both estimations and higher than the Stock and Yogo 10 percent IV size which indicates that the instruments are valid. [6]

Table 3: First stage estimation - Inherited land as instrumental variable

	n	Simpson index
Instruments		
n inherited	0.581***	0.0881***
	(0.0293)	(0.00495)
Controls	YES	YES
Validity Tests		
F-statistic	27.56	25.6
Stock and Yogo 10% IV size	7.03	7.03
Observations	8,342	8,342
R-squared	0.265	0.162
Number of HHID	2,718	2,718

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5.2 Main results

The estimation results of Equation 2 are presented in Tables 4 and 5. The measure of fragmentation changes between Tables 4 and 5, but the results are analogous which makes the empirical analysis consistent. Also, taking into account the panel dimension of the data set and treating the endogeneity of the variable(s) of interest improves the statistical significance and increases the magnitude of the coefficients. Therefore, I focus on column (5) in each Table when interpreting the results. In order to quantity the results, we have to take into consideration that the estimation equation is in a semi-log form. According to Table 4, one parcel more reduces the agricultural yield by 25 percent if the farmer does

[6] When regressing inherited land fragmentation on the different household characteristics such as sex, age and education, no single covariate has a significant impact. We can consider this as another validity check that the instrument is exogenous to household characteristics and satisfies the exclusion restrictions.

not experience any rain deviation. As expected, higher fragmentation leads therefore to lower yield per acre. Regarding the impact of rain variability, if we consider for example that the number of parcels of a farmer equals two, one rain deviation more will decrease the yield by 22 percent. If the household has the average number of parcels, 2.35, then this decrease of the yield is reduced to the level of 6.6 percent. If we assume a rain deviation equal respectively to 0.5 and 1 standard deviation, then the agricultural yield decreases by 3 percent in the first case and increases by 19 percent in the second case when the number of parcels is increased by one unit.

These results are robust to the alternative measure of land fragmentation, the Simpson index, in Table 5. If there is no rain deviation, an increase of the Simpson index by 0.1 units decreases the agricultural yield by 15 percent. When there is one standard deviation in rainfall, then the increase of the index of 0.1 leads to an increase of the yield by 8.4 percent, which offsets almost by half the impact of the previous case. If the Simpson index is equal to 0.3, 0.35 (average) or 0.5, then one standard deviation in rainfall reduces the yield by 24 percent, 12.5 percent and increases the yield by 23 percent in the last case. This confirms our *ex ante* hypothesis that land fragmentation can be beneficial for those households that are exposed to higher weather irregularities. The results demonstrate that the higher the rainfall deviation, the higher the beneficial effect of more fragmented land ownings.

From the estimated model, we can predict the yield for each level of rain deviation by considering the degree of land fragmentation. This is illustrated in Figure 2.[7] For households that have one parcel and do not face any rain deviation, the predicted yield is the highest. On the contrary, households that operate 5 parcels have the lowest level of predicted yield when there are no rain deviations. If rain deviation increases, the yield of the most consolidated land (n=1) decreases and the yield of the most fragmented land (n=5) increases. Land fragmentation can therefore be perceived as detrimental for households that are not exposed to rainfall variability. But, land fragmentation can be beneficial for households that face higher rainfall variability and do not have access to other forms of insurance. Considering the results in Table 4 column (5), the threshold above which a household can realize benefits form land fragmentation is 0.6 standard deviation in rainfall. If household faces a standard deviation in rainfall that is higher

[7]The illustration is based on the results in Table 4, column (3)

then 0.6, then having more than 3 parcels to operate will not decrease its yield.

Table 4: The impact of fragmentation: count measure

Yield (ln)	OLS (1)	OLS (2)	Panel FE (3)	Panel FE (4)	IV Panel FE (5)	IV Panel FE (6)
n	-0.0287	-0.0887**	-0.254***	-0.451***	-0.251***	-0.768***
	(0.0276)	(0.0367)	(0.0311)	(0.0484)	(0.0815)	(0.109)
rain deviation	-0.244***	-0.612***	-0.553***	-0.706***	-1.109***	-1.737***
	(0.0856)	(0.102)	(0.0894)	(0.110)	(0.188)	(0.227)
n*rain deviation	0.169***	0.206***	0.181***	0.238***	0.444***	0.697***
	(0.0340)	(0.0399)	(0.0366)	(0.0433)	(0.0867)	(0.0997)
sex	0.160**	0.228***	-0.904***	-1.006***	-0.890***	-0.986***
	(0.0625)	(0.0760)	(0.168)	(0.267)	(0.170)	(0.278)
age	0.00934***	0.00687***	0.0749***	0.0220*	0.0755***	0.0199
	(0.00190)	(0.00235)	(0.00945)	(0.0121)	(0.00847)	(0.0123)
adults	0.0962***	0.0640***	0.0962***	-0.0649*	0.0886***	-0.0706*
	(0.0170)	(0.0205)	(0.0264)	(0.0386)	(0.0274)	(0.0418)
cultivated land (ln)	-0.780***	-0.783***	-0.950***	-0.959***	-1.023***	-0.967***
	(0.0398)	(0.0502)	(0.0603)	(0.0833)	(0.0690)	(0.0947)
primary education	0.957***	0.982***	0.672***	0.669***	0.667***	0.633***
	(0.0732)	(0.0900)	(0.130)	(0.182)	(0.136)	(0.195)
secondary education	1.178***	1.178***	1.281***	1.594***	1.258***	1.496***
	(0.0873)	(0.107)	(0.187)	(0.250)	(0.196)	(0.270)
land quality index		-0.561***		-0.933***		-0.897***
		(0.0479)		(0.0508)		(0.0551)
Constant	5.530***	7.370***	4.299***	9.702***		
	(0.137)	(0.191)	(0.417)	(0.602)		
Observations	8,342	6,251	8,342	6,251	8,342	6,251
R-squared	0.071	0.090	0.080	0.139	0.070	0.115
Number of HHID			2,718	2,477	2,718	2,477

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

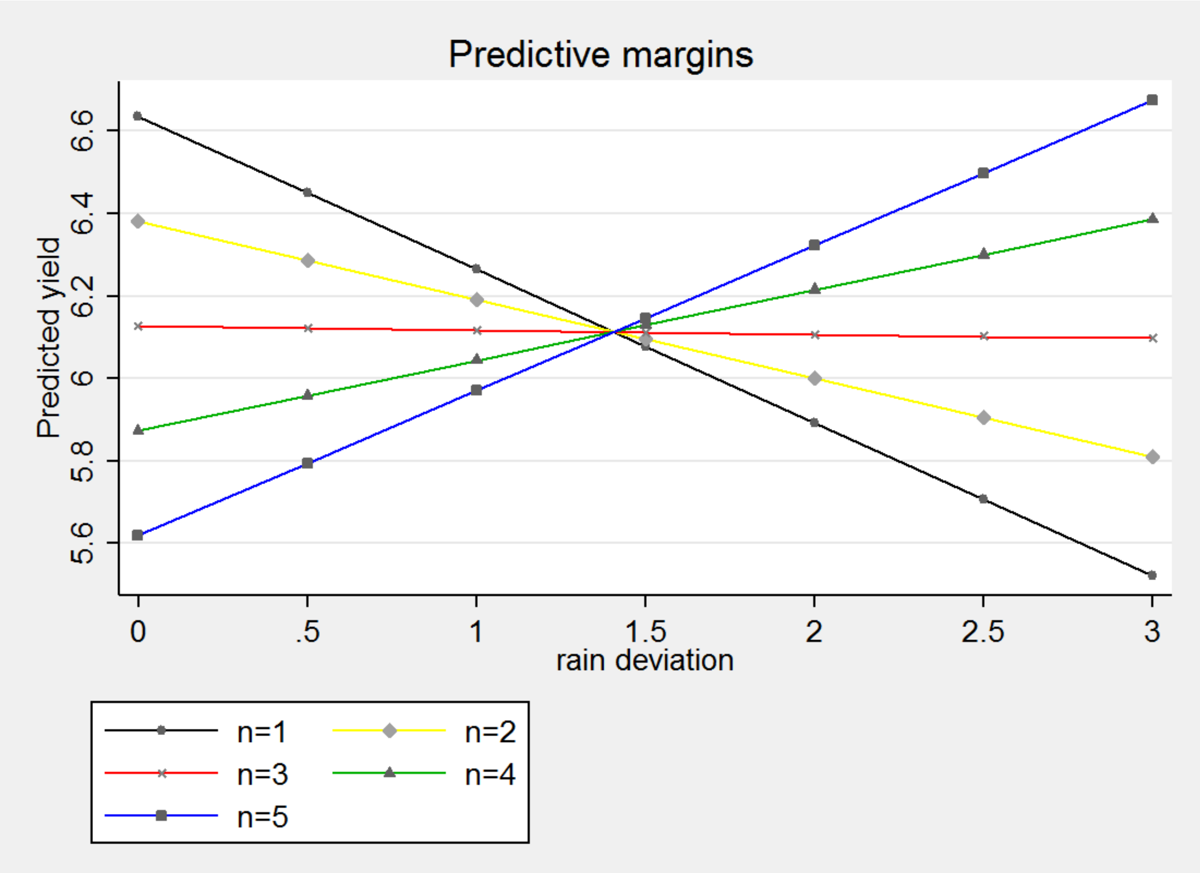
When considering the other covariates in Tables 4 and 5, having a household head that is older increases the yield. This result should be linked to the experience of the household improving agricultural efficiency. In addition, a household head with primary or secondary education earns a higher agricultural yield compared to household heads with no education. The impact is even higher in the case when the head has secondary education compared to the primary education. Concerning the production factors, labor and land, an increase in the number of adults has a positive impact on the agricultural yield. However, there is a negative relationship between the size of the cultivated land and

Table 5: The impact of fragmentation: Simpson index

	OLS	OLS	Panel FE	Panel FE	IV Panel FE	IV Panel FE
Yield (ln)	(1)	(2)	(3)	(4)	(5)	(6)
Simpson index	0.105	-0.238	-0.917***	-1.694***	-1.506***	-4.744***
	(0.142)	(0.189)	(0.176)	(0.263)	(0.537)	(0.697)
rain deviation	-0.0167	-0.349***	-0.362***	-0.447***	-0.945***	-1.568***
	(0.0681)	(0.0822)	(0.0679)	(0.0841)	(0.154)	(0.193)
Simpson*rain deviation	0.407***	0.537***	0.635***	0.824***	2.343***	3.932***
	(0.156)	(0.183)	(0.153)	(0.182)	(0.435)	(0.512)
sex	0.162***	0.232***	-0.916***	-1.016***	-0.880***	-0.936***
	(0.0625)	(0.0761)	(0.168)	(0.271)	(0.172)	(0.291)
age	0.00944***	0.00679***	0.0757***	0.0236*	0.0749***	0.0198
	(0.00190)	(0.00236)	(0.00946)	(0.0122)	(0.00851)	(0.0124)
adults	0.0976***	0.0652***	0.0925***	-0.0657*	0.0813***	-0.0816*
	(0.0170)	(0.0206)	(0.0263)	(0.0387)	(0.0276)	(0.0426)
cultivated land (ln)	-0.768***	-0.767***	-1.001***	-1.025***	-1.030***	-1.006***
	(0.0392)	(0.0497)	(0.0591)	(0.0829)	(0.0634)	(0.0911)
primary education	0.956***	0.986***	0.674***	0.687***	0.658***	0.630***
	(0.0733)	(0.0901)	(0.130)	(0.183)	(0.137)	(0.202)
secondary education	1.179***	1.183***	1.292***	1.652***	1.246***	1.545***
	(0.0874)	(0.107)	(0.187)	(0.251)	(0.197)	(0.274)
land quality index		-0.567***		-0.933***		-0.874***
		(0.0480)		(0.0505)		(0.0565)
Constant	5.408***	7.239***	4.076***	9.247***		
	(0.133)	(0.185)	(0.417)	(0.600)		
Observations	8,342	6,251	8,342	6,251	8,342	6,251
R-squared	0.069	0.088	0.076	0.131	0.059	0.079
Number of HHID			2,718	2,477	2,718	2,477

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 3: Predicted yield for different levels of rain deviation and number of parcels



the yield. In the literature it was shown that in the case of some developing countries there is an inverse relationship between farm size and productivity [Carletto et al., 2013]. The higher the soil quality index, that refers to a worse soil quality, the lower is agricultural yield, as expected.

5.3 Robustness tests

As a robustness check, instead of only taking into account the number of parcels, Table 6 includes the number of parcels with different soil type and soil topography which gives a more detailed aspect of risk diversification of a land holding. The results are consistent with what was previously found. With a higher number of parcels with different soil types, the lower is the impact of agricultural yield of a rain deviation. However this is not verified for the number of parcels with different topography. Even land with low degree of steepness can contribute to lower water infiltration and water runoffs. This might be a possible explanation why a higher number of parcels with different slope does not reduce the impact of rainfall variability on productivity. The other covariates have similar impacts as in the previous estimations.

Table 6: The impact of fragmentation: different soil type

Yield (ln)	OLS (1)	OLS (2)	Panel FE (3)	Panel FE (4)
n soil type	-0.408***	-0.404***	-0.773***	-0.762***
	(0.109)	(0.108)	(0.116)	(0.116)
n topography	0.323***	0.351***	-0.180	-0.154
	(0.103)	(0.101)	(0.126)	(0.126)
rain deviation	-0.808***	-0.501***	-1.306***	-0.737***
	(0.147)	(0.147)	(0.146)	(0.157)
n soil type*rain deviation	0.517***	0.461***	0.639***	0.530***
	(0.117)	(0.115)	(0.128)	(0.129)
n topography* rain deviation	-0.163	-0.198*	-0.0117	-0.0704
	(0.106)	(0.105)	(0.121)	(0.124)
sex	0.223***	0.235***	-0.925***	-1.024***
	(0.0769)	(0.0760)	(0.268)	(0.269)
age	0.00608**	0.00680***	0.0171	0.0207*
	(0.00237)	(0.00235)	(0.0115)	(0.0123)
adults	0.0610***	0.0641***	-0.0488	-0.0621
	(0.0208)	(0.0205)	(0.0406)	(0.0387)
cultivated land (ln)	-0.758***	-0.761***	-1.044***	-1.025***
	(0.0500)	(0.0494)	(0.0906)	(0.0839)
primary education	1.010***	0.990***	0.747***	0.665***
	(0.0910)	(0.0901)	(0.181)	(0.182)
secondary education	1.238***	1.177***	1.707***	1.617***
	(0.108)	(0.107)	(0.256)	(0.254)
quality index		-0.564***		-0.949***
		(0.0481)		(0.0510)
Constant	6.452***	7.198***	8.751***	10.03***
	(0.219)	(0.225)	(0.612)	(0.634)
Observations	6,251	6,251	6,251	6,251
R-squared	0.070	0.090	0.072	0.133
Number of HHID	2,477	2,477	2,477	2,477

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Another robustness check is to include the average distance to the parcels in order to account for the time cost. The information on distance is only given for the three last survey years, thus the sample size is thus lower. The results are given in Table 7. The average distance is calculated as the average of the time that it takes for a farmer to arrive to the different parcels. As expected, the higher this average distance, the lower the agricultural yield. The previous results and conclusions on land fragmentation and its interaction with rain deviation do not change when I control for the distance.

Table 7: The impact of fragmentation including distance

Yield (ln)	Panel FE (1)	IV Panel FE (2)	Panel FE (3)	IV Panel FE (4)
n	-0.441***	-0.760***		
	(0.049)	(0.110)		
Simpson			-1.412***	-4.703***
			(0.247)	(0.703)
rain deviation	-0.710***	-1.726***	-0.518***	-1.559***
	(0.110)	(0.226)	(0.107)	(0.193)
land frag.*rain deviation	0.242***	0.694***	0.169***	3.916***
	(0.043)	(0.099)	(0.042)	(0.511)
distance	-0.118*	-0.136*	-0.126*	-0.104
	(0.068)	(0.073)	(0.069)	(0.078)
sex	-1.014***	-0.994***	-1.043***	-0.942***
	(0.266)	(0.278)	(0.270)	(0.291)
age	0.022*	0.020	0.024**	0.020
	(0.012)	(0.012)	(0.012)	(0.012)
adults	-0.064*	-0.069*	-0.062	-0.081*
	(0.039)	(0.042)	(0.039)	(0.043)
cultivated land (ln)	-0.955***	-0.958***	-1.045***	-1.000***
	(0.083)	(0.094)	(0.082)	(0.090)
primary education	0.671***	0.634***	0.695***	0.631***
	(0.182)	(0.195)	(0.183)	(0.202)
secondary education	1.591***	1.493***	1.659***	1.542***
	(0.250)	(0.270)	(0.252)	(0.274)
land quality index	-0.930***	-0.895***	-0.933***	-0.871***
	(0.051)	(0.055)	(0.051)	(0.057)
Constant	9.868***		9.339***	
	(0.608)		(0.604)	
Observations	6,250	6,250	6,250	6,250
R-squared	0.139	0.116	0.131	0.080
Number of HHID	2,477	2,477	2,477	2,477

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

We might expect that households that hold higher number of parcels can potentially overestimate the size of their holdings. Subjective appreciation of the size of land holdings might be biased and therefore the calculation of agricultural yield could be inaccurate. One of the advantages of the dataset used in this chapter is that GPS measurements of parcel size are included for 70 percent of the parcels. In order to verify whether the previous estimates are robust, I test whether there is a significant difference between the subjective measures of acreage of farmers and the GPS measurement.[8] I only take into account households that have both measures for each of their parcels (which is the case for 45-55 percent of the households in the sample). I test the difference between the two measures and the null hypothesis that this difference is equal to zero cannot be rejected for each year of the survey and all years combined. Moreover, I run the test for each year of the survey by level of land fragmentation and no significant difference is found for the different number of parcels. These tests seem to indicate that the main results are robust, at least with regard to measurement error in land holdings.

In order to account for another climatic factor than rainfall, temperature deviations are included in the estimation in Table . When comparing the previous results to the results included in Table 8, we observe that there is no difference in terms of magnitude and statistical significance. The coefficients of the interaction terms between rain deviations and temperature deviations with the degree of fragmentation are positive and statistically significant which confirms the *ex ante* hypothesis. Compared to rainfall deviations, it is puzzling that annual temperature deviations are not harmful as such for agricultural productivity in Uganda.

5.4 Discussion: Indirect effects of land fragmentation

Finally, as discussed previously, the literature that studies the benefits of land fragmentation has argued that it leads to higher crop diversity [see among others Di Falco et al., 2010]. Because of the different agro-ecological characteristics of the fragmented parcels, crop diversification is more feasible because it matches the soil type and quality to the features of the crops. Land fragmentation could therefore have an indirect effect on the exposure of households to rainfall variability through the ability to increase the crop diversity. Figure 4 represents the average number of crops cultivated for each number of parcel. The number of cultivated crops increases with the level of fragmentation. For households cultivating only one crop, the average number of parcels for these household is 1.5. More consolidated/fragmented land holdings lead to higher crop specialization/diversification. In Table 9, I present the results from a reduced-form estimation that tests the impact

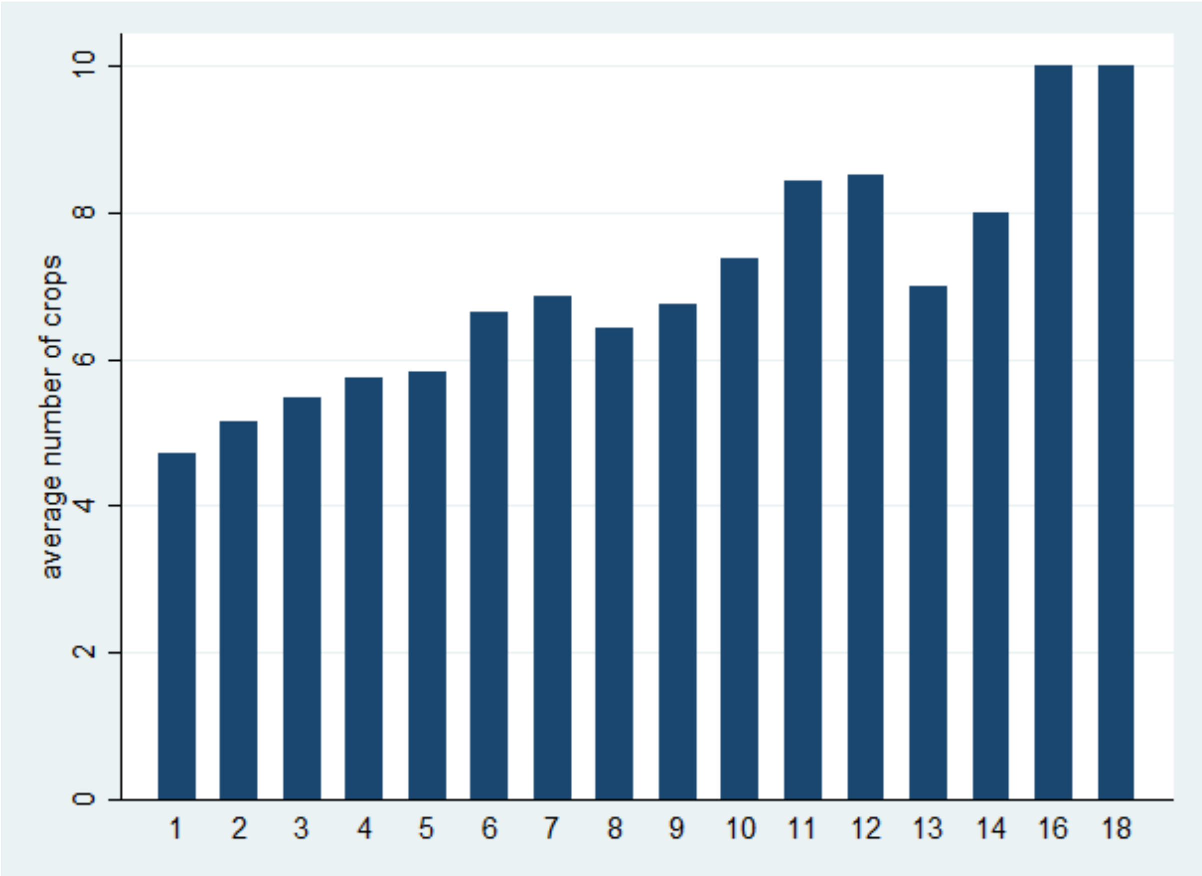
[8] I run a paired t-test in STATA for both measures.

Table 8: The impact of fragmentation including temperature

Yield(ln)	IV Panel FE (1)	IV Panel FE (2)
n	-0.646***	
	(0.191)	
Simpson		-3.804***
		(1.049)
rain deviation	-1.728***	-1.651***
	(0.171)	(0.134)
temp. deviation	2.518***	2.569***
	(0.188)	(0.148)
land frag.*rain deviation	0.236***	1.259***
	(0.079)	(0.378)
land frag.*temp. deviation	0.203**	1.173***
	(0.083)	(0.402)
sex	0.135	0.157
	(0.193)	(0.197)
age	-0.011	-0.012
	(0.008)	(0.008)
adults	0.047	0.040
	(0.029)	(0.029)
cultivated land (ln)	-1.027***	-1.027***
	(0.066)	(0.063)
primary education	-0.106	-0.133
	(0.147)	(0.147)
secondary education	0.095	0.076
	(0.201)	(0.201)
land quality index	-0.283***	-0.276***
	(0.041)	(0.041)
Observations	6,250	6,250
R-squared	0.600	0.594
Number of HHID	2,477	2,477

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 4: Crop diversification



of land fragmentation on crop diversity. The impact of the number of parcels on the number of cultivated crops is positive and significant at one percent level of statistical significance. These estimations seem to confirm that one of the mechanisms by which land fragmentation reduces the impact of rainfall deviations on agricultural yield could indeed be through an increase in crop diversity.

6 Conclusion

The aim of this chapter is to explore the role of land fragmentation when agricultural households face rainfall variability. Even though land fragmentation is mainly considered as detrimental for agricultural productivity, there is some evidence that it can allow for reduction in production risk. I use the LSMS-ISA data from Uganda to analyze the question. After instrumenting for the level of fragmentation, I find that higher land fragmentation decreases the loss of crop yield when households experience rain deviations.

Table 9: The impact of fragmentation on crop diversity

Number of crops	Panel FE (1)	IV Panel FE (2)
number of parcels	0.224***	0.255***
	(0.029)	(0.061)
Control Variables		
	YES	YES
Observations	6,250	6,250
Number of HHID	2,477	2,477

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: The set of controls are cultivated land, labor, sex, age and education of the HH head and land quality index.

The results show that the higher the deviation, the higher the beneficial effect of land fragmentation. The results are robust when including different alternative measures of land fragmentation, average distance between the parcels and temperature deviation. I also find that labor endowment and education are crucial for the agricultural productivity.

The results in this chapter indicate that developing countries should be cautious with the policy of land consolidation. If insurance markets are missing, then land fragmentation can be an alternative for farmers operating in rain-fed environments. Therefore, instead of focusing only on land consolidation programs, the imperative of policy makers might be more focused on improving other imperfect or missing markets that influence agricultural productivity.

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