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Determinants of Crop Diversification in Burkina Faso What is the Impact of Risk Preference?

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Determinants of Crop Diversification in Burkina Faso
What is the Impact of Risk Preference?

Kotchikpa Gabriel Lawin [*, †], *Lota D. Tamini* [‡, §]

Abstract

The literature considers crop diversification to be a risk management strategy at the farm level. In this article, we combine experimental data on risk aversion with survey data to identify the extent to which risk aversion affects crop diversification decisions. We conduct experiments to measure the risk aversion of smallholder farmers in Burkina Faso and a field survey to gather data on various socio-economic variables. To measure crop diversification, we use three indices of spatial diversity in crop species adapted from the ecological economics literature, i.e., the weighted count index, the weighted Herfindahl index measure of crop concentration and the weighted Shannon index of evenness. An Ordinary Least square (OLS) model is used to estimate the impact of risk aversion on crop diversification when the weighted count index and the weighted Herfindahl index are used as the dependent variable, whereas a Tobit model is used for the weighted Shannon index. Our results show that risk aversion has a negative and significant effect on crop diversification. Risk-averse producers focus more on the production of traditional, less risky and low market value crops. Other variables also affect crop diversification. In particular, education level, distance to market, farm area and land fragmentation are associated with greater crop diversification.

Keywords: Risk Aversion, Diversity Index, Crop Diversification, Smallholder Farmers, Burkina Faso

JEL Codes: C93, D13, G11, Q12, Q57

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1 Introduction

Many types of risks affect agricultural activities, including production risks (e.g., climate risk, production yield risk, and disease); risk associated with fluctuations in the exchange rate; price risk; and the risk of competition in international markets (Abay et al., 2009; Ullah et al., 2016). In developing countries where rain-fed agriculture is the dominant farming system (Hardaker et al., 1997; Akcaoz and Ozkan, 2005), the above-mentioned risks affect agricultural farmers' welfare because they make income, costs, and agricultural profits more difficult to predict. The lack of an agricultural insurance system to manage these risks has led farmers to develop several risk management strategies.

Many scholars have provided evidence that farmers are risk averse, and crop diversification is often cited as a farm-level risk management strategy (Benin et al., 2004; Ashfaq et al., 2008; Abey et al., 2009; Di Falco and Chavas, 2009; Mesfin et al., 2011; Rehima et al., 2013; Asante et al., 2017; Khanal and Mishra, 2017). However, few empirical studies explicitly analyze the impact of farmers' risk aversion on crop diversification in developing countries (Akcaoz and Ozkan, 2005; Di Falco and Perrings, 2005; Engle-Warnick et al., 2011; Bezabih and Sarr, 2012; Chavas and Di Falco 2012). Crop diversification has several economics, social and environmental benefits for smallholder farmers. It increases farm household income and employment opportunities for farm workers, improves conservation of natural resources, soil fertility and food security, reduces output production shortages (Goletti, 1999; Joshi et al., 2004, Jones et al., 2014; Pellegrini and Tasciotti, 2014; Islam et al., 2018) and increases farm technical efficiency and productivity (Coelli and Fleming, 2004; Di Falco and Chavas, 2009; Rahman, 2009; Ahmed and Melesse, 2018)

The objective of this article is to analyze the effect of risk aversion on crop diversification among smallholder farmers in Burkina Faso. The case of Burkina Faso is interesting in several ways. The agricultural sector represents an important part of the economy (Ministry of Agriculture, Livestock and Hydraulics, 2016) and is dominated by smallholder farmers. Burkina Faso is an arid country with low rainfall, and agriculture is predominantly rain-fed. Consequently, farmers are exposed to various risks, including the risk of crop losses due to drought, yield risks, price risks, and other climatic risks related to the biophysical environment in which they operate. These risks influence production choices and resources allocation at the farm level.

To achieve our goal, we combined experimental data on risk aversion with survey data to determine the extent to which risk aversion affects crop diversification decisions. We conducted field experiments to measure the risk aversion of smallholder farmers in Burkina Faso and executed a field survey to collect data on various socio-economic variables. To measure crop diversification, we use three indices of spatial diversity in crops species adapted from the ecological economics literature: the count index, the Herfindahl index measure of crop concentration and the Shannon index of evenness (Hutchenson, 1970; Jain et al., 1975; Magurran, 1988). The count index is used to estimate the richness of crops species; the Herfindahl index is used to estimate the relative abundance of crops species; and the Shannon index is used to estimate the evenness of crops species by combining richness and relative abundance. Unlike previous studies, all three diversity indexes were weighted by crop price ratios to account for market information in the diversification measures.

Our risk measurement is based on the expected utility theory. We assumed that farmers' preferences can be represented by a Von Neumann-Morgenstern utility function with the constant risk aversion hypothesis (CRRA). Using the experiment data, we generated the CRRA coefficients that represent the farmers' risk aversion level. On the econometric level, an OLS model is employed to estimate the impact of risk aversion on crop diversification when the weighted count index and the weighted Herfindahl index are used as a dependent variable, whereas a Tobit model is used for the weighted Shannon index. We contribute to the empirical literature on the impact of risk preference on crop diversification decisions by using different diversification indexes that account for market information. Our results show that risk aversion has a negative and significant effect on crop diversification. Risk-averse producers focus more on the production of traditional, less risky and low market value crops. These results are robust whatever the index used.

The rest of the article is organized as follows. Section 2 presents methods for estimating crop diversification and measuring risk aversion and discusses econometric approaches. Data sources, variables and descriptive statistics are presented in Section 3. Section 4 presents the results and discussion. Finally, Section 5 concludes.

2 Methodology

2.1 Measurement of crop diversification and econometric approaches

Studies on crop diversification have often used diversification index models (Benin et al., 2006; Asante et al. 2017; Saenz and Thompson, 2017). These models provide a single measure of diversification and make inferences about the factors that influence farmer diversification choices. The diversification indices used in this article are the count index, the Herfindahl index and the Shannon index.

The count index measures the richness of species at the farm level (Smale et al., 2001; Smale, 2006). The Herfindahl diversity index (H) measures the relative abundance of crops (Magurran, 1988) and the Shannon index (D) measures both the richness and relative abundance of crops at the farm level (Abey et al., 2009). The indexes were weighted by crop price[1] ratios to account for market information in the diversification measures. The crop with the highest price per kilogram was chosen as the reference in the calculation of the price ratios.

The weighted count index (C) counts the number of crops grown by the farmer during the agricultural season to capture the level of diversification. Higher is the index, more diversified is the farmer. The weighted count index of farmer *i* is defined by

$$C_{il} = \sum_{l=1}^{m} w_{il}\, N_{il} \qquad (1)$$

where *m* is the number of crops grown by farmer *i* during the agricultural season; *w* is the crop price ratio, and *N* is an indicator variable that takes a unit value for each crop grown.

The weighted Herfindahl index of farmer *i* is defined as

$$H_{il} = \sum_{l=1}^{m} (1/w_{il})\, p_{il}^{2} \qquad (2)$$

where *w* is the crop price ratio; *m* is the number of crops grown; and **p** is the share of the total area planted by farmer *i* that is allocated to crop *l*. The weighted Herfindahl index gives more weight to the most cultivated crops (in terms of the area allocated) and to crops with lower prices. In contrast, secondary crops in term of share of area allocated or crops

[1] Crop price is proxies by the median crop sale value per kilogram in each region instead of own price obtained per crop. This is a limitation of our approach since it not captures the vector price faced by individual farmer. However, even if we had own prices, there likely would be a large number of missing price values in cases where an output was used for home consumption or had not yet been sold and thus would be proxied at a higher level.

with higher prices imply small changes in the value of H. In this sense, the weighted Herfindahl index measures the relative abundance or dominance of crops and gives very little weight to crop richness at the farm level. The higher the H, the lesser the diversity of production. Thus, a zero value indicates perfect diversification; a value greater than zero indicates a certain level of specialisation.

The weighted Shannon index is calculated by

(3) $$D_{il} = -\sum_{l=1}^{m} w_{il} p_{il} ln(p_{il})$$

where w, m and p are the same parameters as in equation (2). Similar to the weighted Herfindahl index, the weighted Shannon index measures the relative abundance of crops at the farm level. A zero value implies that the farmer cultivates a single crop and, therefore, is perfectly specialized. The higher the value of the weighted Shannon index, the more diversified the farmer is in his production choices. Thus, according to Smale (2006), the Shannon index measures both richness and relative abundance of crops at the farm level.

To assess the impact of risk aversion on crop diversification, we employ an OLS regression for the weighted count index and the weighted Herfindahl index while using a Tobit for the weighted Shannon diversity index. The general structure of the regression equations is expressed in the following simplified form:

(4) $$y_i = a_i + b_i x + c_i z + e_i$$

where y is either the count index, the weighted Herfindahl index or the weighted Shannon index; x is a vector of socio-economic characteristics of the farmer, his household, his farm and his community; Z is the farmer's risk aversion coefficient; e is the set of unobservable factors; and a, b and c are the parameters to be estimated.

2.2 Risk aversion measurement

Our main independent variable is the measure of farmer risk aversion. During the survey, an experiment in the form of a lottery game was organized with all respondents; this experiment forms the basis of our measures of risk aversion. The structure of the game is similar to those of Cohen et al. (1985), Harrison et al. (2010) and Barham et al., (2014). The experiment session comprises a series of eight simultaneous decisions wherein the farmer has a choice between a sure payoff and participation in a lottery with an average expected payoff greater than or equal to the sure payoff.

At the beginning of the experiment, the interviewer explains to the respondent that although the questions in the game involve money, they are only hypothetical assumptions for the purpose of the research and no donations will be given as a result of the game. The purpose of this clarification is to minimize bias in the experiment. The experiment includes a risk game with a 50% chance of receiving a high payoff and a 50% chance of receiving a low payoff compared with the sure payoff (50/50 risk game).

The experiment begins with a series of exercises as an example to ensure that the farmer understands the basic logic of the game. As in Barham et al. (2014), during the practice game, the farmers make a series of 8 decisions, which were presented simultaneously rather than sequentially. Each decision is a choice between a sure payoff and an uncertain payoff that depends on the rain during the next agricultural season. If the rain is good during the agricultural season, the hypothetical payoff is higher than if there is a drought. Similarly, for the actual experiment, the farmers make a series of 8 simultaneous decisions between a sure payoff of XOF 2000[2] and an uncertain payoff that depends on the color of a ball drawn from a bag. The interviewer has a bag containing 20 balls, some of which are red and some of which are black. When the farmer decides to participate, his payoff depends on the color of the ball drawn (Table 1).

Table 1. Risk experiment

	Sure thing	Gamble		
Decision		Red	Black	CRRA
1	XOF 2000	XOF 4000	XOF 2000	∞
2	XOF 2000	XOF 4000	XOF 1500	2.92
3	XOF 2000	XOF 4000	XOF 1200	1.51
4	XOF 2000	XOF 4000	XOF 900	0.81
5	XOF 2000	XOF 4000	XOF 700	0.52
6	XOF 2000	XOF 4000	XOF 500	0.31
7	XOF 2000	XOF 4000	XOF 300	0.15
8	XOF 2000	XOF 4000	XOF 0	0.00

Farmers were told that there were 10 red balls and 10 black balls in the bag. Following Barham et al. (2014), we used the results from the game to measure farmers' risk aversion. We assume that farmers' preferences can be represented by a Von Neumann-Morgenstern utility function with the constant relative risk aversion hypothesis (CRRA), as follows:

$$U(x) = \left(\frac{1}{1-\gamma}\right)(x^{1-\gamma}),\ with\ x > 0 \tag{5}$$

where x represents the payoff and γ is the Arrow-Pratt CRRA coefficient (Pratt, 1964). With that specification of the CRRA, $\gamma = 0$ indicates risk neutrality, $\gamma > 0$ indicates risk aversion, and $\gamma < 0$ indicates risk attraction. The CRRA coefficient is the value of the utility that makes the farmer indifferent between the sure thing and the gamble, i.e.,

[2] 1 USD = XOF 600 at the time of the survey (Central Bank of the States of West Africa, www.bceao.int).

$$(6) \qquad U(x_0) = 0{,}5 * U(x_1) + 0{,}5 * U(x_2)$$

where x_0 is the sure payoff, x_1 is the payoff when a red ball is drawn, and x_2 the payoff when a black ball is drawn. Pratt (1964) shows that with a CRRA utility function, γ is a sufficient comparative static for measuring the degree of risk aversion. Our risk aversion measure is the minimum value of the CRRA corresponding to the round in the game at which the farmer chooses the sure option and declines to participate in the lottery for the first time (Table 1). For example, a farmer who accepts the lottery 4 times and chooses the sure payoff in the fifth round is given a CRRA coefficient of 0.52. We chose the CRRA coefficient to measure risk aversion because it is a purely ordinal variable that depends on the design of the experiment without regard for the amounts involved in the game. Moreover, the behaviors represented by the CRRA utility function do not change with the wealth level of the farmer (Barham et al., 2014).

Farmers who always choose the gamble can be considered risk lovers. Although such behavior is rational, we decided to remove these individuals because their CRRAs could be negative infinity.

3 Data source, variables and descriptive statistics

3.1 Data source

The data used in this article come from a survey conducted in 2016 by the Institute of the Environment and Agricultural Research of Burkina Faso (INERA). These are the data from the baseline survey of the Financial Services and Deployment of Agricultural Innovations project in Burkina Faso, which was funded by the International Development Research Center (IDRC) and implemented by Desjardins International Development (DID) in

Partnership with the *Réseau des Caisses Populaires du Burkina* (RCPB), INERA and Laval University.

The survey included 668 individual farmers in 145 villages, 64 of which are in the northern part of the study site, provinces of Passoré and Zondoma and 81 of which are in the southern part of the study site, provinces of Nahouri and Ziro (see Map1 in appendix). The farmers included in the sample are all members of farmers' organizations. The data contain information on the socio-economic characteristics of the farmers; the characteristics of their plots, production, savings and credit behavior; their access to extension services; and their risk preferences. The empirical analysis presented here is conducted at the farmer level. Broadly speaking, the farmer is an individual within a household who is in charge of the management and decision making for a given farm[3]. In the southern part of the study site, the main production is maize while it is sorghum in the northern part of the study site (See panel B in Table 3).

Table 2 describes the variables used in the econometric estimates.

[3] Each farm is subdivided into plots, which are the most disaggregated unit of land identified in the dataset. The survey has information about each of the crops planted on each plot.

Table 2. Variable descriptions

Variable	Type of variable	Description
Dependent variables		
Weighted Count index	Continuous	Number of crops grown weighted by crop price ratios
Weighted Herfindahl index	Continuous	Herfindahl index measure of crop concentration weighted by inverse crop price ratios.
Weighted Shannon index	Continuous	Shannon index weighted by crop price ratios.
Risk aversion measure		
Risk aversion	Continuous	Risk aversion coefficient
Socio-economic and farm characteristics		
Age	Continuous	Farmer's age in years
Gender	Dummy	Farmer's gender (1=female; 0= male)
Household head	Dummy	Variable representing farmer's status (1 = household head, 0 = otherwise)
Primary education	Dummy	Farmer has primary education
Secondary or post-secondary education	Dummy	Farmer has secondary or post-secondary education
Household size	Continuous	Number of persons in household
Farm size	Continuous	Total farm area (in ha) cultivated per farmer
Agricultural implement access index	Dummy	Variable capturing farmer access to agricultural tools
Extension contact	Categorical	Frequency of contacts with extension agents
Access to credit	Dummy	Farmer has access to credit
Number of plots	Continuous	Number of parcels cultivated by the farmer
Land owner	Dummy	Farmer owns at least one parcel of land
Distance to road	Continuous	Distance from the plot to the nearest all-weather road (in mn)
Distance to market	Continuous	Distance from the plot to the nearest market (in mn)
Off-farm income	Dummy	Farmer has off-farm income
Province dummies (reference: ZONDOMA province)		
PASSORE province	Dummy	Farmer is in the PASSORE province
ZIRO province	Dummy	Farmer is in the ZIRO province
NAHOURI province	Dummy	Farmer is in the NAHOURI province

3.2 Dependent variable

As explained in the methodology section, our dependent variable is the diversity index, which is measured by three different indicators: the weighted count index, the weighted Herfindahl index measure of crop concentration, and the weighted Shannon index.

3.3 Independent variables

Our main independent variable is the measure of risk aversion estimated using the method described in the methodology section. We also include control variables in the estimates. These variables were selected from recent empirical studies on crop diversification (Benin et al., 2006; Ashfaq et al., 2008; Abay et al., 2009; Abro, 2012; Rehima et al., 2013; Benmehiaia and Brabez, 2016; Dube et al., 2016; Asante et al., 2017; Saenz eand Thompson, 2017) and consider available data.

Control variables include household size, the farmer's socio-economic characteristics and farm characteristics. Household size is used as a proxy for agricultural labor availability in the household. Household size can have a mixed effect on diversification. In some cases, it can increase crop diversification through the heterogeneity of preferences and availability of labor (Benin et al., 2004). In contrast, other studies in the literature have found a negative effect of household size on crop diversification (Van Dusen and Taylor, 2005; Benin et al., 2006).

The socio-economic characteristics included in the models are age, gender, household head status, and level of education. The farmer's age is generally used as a proxy for his farming experience and is an important determinant of his production choices. On one hand, given that older farmers are more likely to have access to productive resources and information, they are more likely to diversify (Asante et al., 2017). On the other hand, younger farmers could be more educated and have greater access to a diversified source of information on agricultural innovations and therefore may be more willing to experiment with new crops. Thus, the effect of age on diversification may be positive or negative.

The effect of gender on diversification is difficult to predict because it depends not only on the influence of gender on crop choice within the household but also on access to productive resources. The influence of gender on diversification is specific to the local context. Farmers who are household heads generally have more access to productive resources and are more likely to diversify their production. Thus, we hypothesize that being the head of household has a positive effect on crop diversification.

The level of education of the farmer can have a positive or negative effect on diversification. Education can positively influence diversification if it increases the farmer's ability to obtain agricultural information and enhances managerial capacity (Gauchan et al., 2006; Van Dusen et Taylor, 2005; Bravo-Ureta et al., 2006; Ashfaq et al., 2008; Rahman, 2008; Ibrahim et al., 2009). However, Benin et al. (2006) found that education had a negative effect on crop diversification in Ethiopia.

The models also include institutional variables, such as access to credit and frequency of contact with extension agents. We hypothesize that these variables will have a positive effect on diversification. In addition, access to off-farm income is included as a control variable. Off-farm income provides the farmer with an additional source of resources to finance production activities. However, substantial off-farm income could also lessen the farmer's interest in increasing investment in agriculture (Rahman, 2008). Thus, the effect of this variable on diversification may be positive or negative.

To capture the farmer’s access to the market, the control variables also include the distance from the farmer’s parcel to an all-weather road (access to a good road network) and the distance to the nearest market. These variables are assumed to have a mixed effect on diversification. The distance to the nearest all-weather road is used as a proxy for the cost of transport and could have a negative relationship with crop diversification. The farther the parcel is from a good road network, the higher the farmer's transaction or marketing costs. In addition, greater distance to a good road network can increase the risk of post-harvest loss.

Distance to market is a proxy for physical access to input and output markets. Farmers who are closer to markets tend to diversify in response to changing market demands for various products (Asante et al, 2017). Moreover, Benin et al. (2004) found that proximity to the road and to the market have a positive effect on diversification. However, farmers who are far from roads and markets may diversify their production to meet their own food needs (Benin et al., 2006; Gauchan et al., 2006).

Farm characteristics are also included in the model. These variables include access to agricultural tools[4], land area holding, number of plots, and ownership of plots. Access to agricultural tools for cultivation could improve diversification (Mesfin et al., 2011). The number of plots is used as a proxy for land fragmentation. We assume that land fragmentation will have a positive effect on crop diversification (Benin et al., 2006). A binary variable indicating whether the farmer owns at least one plot is included in the model and is assumed to have a positive effect on diversification. Farmers with access to good land have more flexibility in allocating land to various crops (Asante et al., 2017).

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[4] Access to agricultural tools is measured with an "agricultural index" that is created using principal component analysis and dummies for holding the following resources: (a) sickle, (b) axe, (c) pickaxe, (d) traditional plough, (e) modern plough, (f) water pump, and (g) agricultural livestock availability.

Finally, a dummy variable indicating the province where the farmer is located was introduced to capture the heterogeneity in production environment. Thus, this variable makes it possible to capture the effect of the agro ecological zone (rainfall, soil type, topography differences) on diversification, among other things.

3.4 Descriptive Statistics

Table 3 presents descriptive statistics for the variables used in the estimates. The mean risk aversion coefficient for the sample is 1.08, which indicates that risk aversion is an important factor in the behavior of the sampled farmers. The average risk aversion score in our sample is comparable to those found in similar experiments with farmers (Harrison et al., 2010, Barham et al., 2014). The average age of the farmers in the sample is 41 years, and they are predominantly female. Approximately 87% of farmers have no schooling, and they come from large households (12 members on average).

The average farm size is approximately 3 ha, and approximately 54% of the farmers own at least one of the plots they cultivate. The use of plows is predominant in the sample (85%). Small portions of the farmers have access to credit (13%) and to extension (16%). Farmers' plots are generally far from all-weather roads and markets.

Table 3. Descriptive Statistics

Variables	Mean	SD	min	Max
PANEL A: Variables include in the models				
Weighted Count index	1.30	0.56	0.25	3.85
Weighted Herfindahl index	1.09	0.61	0.37	4.00
Weighted Shannon index	0.44	0.20	0.00	1.08
Number of crops grown	2.74	0.85	1.00	6.00
Risk aversion	1.08	1.02	0.00	2.92
Age (in years)	40.93	12.43	18.00	80.00
Gender (1= Female)	0.61	0.49	0.00	1.00
Household head	0.46	0.50	0.00	1.00
Primary education	0.07	0.26	0.00	1.00
Secondary or post-secondary education	0.06	0.23	0.00	1.00
Household size	11.51	6.50	1.00	42.00
Farm size	3.21	2.91	0.00	20.00
Agricultural implement access index	-0.05	1.02	-1.66	2.88
Access to credit	0.13	0.34	0.00	1.00
Extension contact	0.44	1.10	0.00	6.00
Land owner	0.54	0.50	0.00	1.00
Number of plots	1.44	0.68	1.00	5.00
Distance to road (mn)	552.60	730.53	1.00	3600.00
Distance to market (mn)	107.70	100.73	2.00	780.00
Off-farm income	0.41	0.49	0.00	1.00
PASSORE province	0.38	0.49	0.00	1.00
ZIRO province	0.22	0.41	0.00	1.00
NAHOURI province	0.22	0.42	0.00	1.00

PANEL B: Proportion of farmer cultivating each crop below as main crop per province

	PASSORE	ZONDOMA	NAHOURI	ZIRO
Millet	32%	20%	7%	10%
Sorghum	66%	56%	15%	31%
Maize	1%	3%	53%	62%
Cowpea	32%	42%	3%	2%
Observations	668			

The number of observations is 668 after excluding the missing values and risk-loving farmers ($\gamma < 0$).

As shown in Table 3, farmers in the sample are quite diverse in sense of crop diversity across all crop diversification measures. Farmers cultivate 3 different crops on average. The weighted Herfindahl and the weighted Shannon index values are 1.09 and 0.44, respectively, showing high crop diversification. Figures 1-3 show the distribution of the crop diversification index calculated with the weighted count index, the weighted Shannon index and the weighted Herfindahl diversity index respectively. These figures show that approximately 7% of farmers specialize in the production of a single crop. This result is comparable to those obtained by Ogundari (2013) in Nigeria and Asante et al. (2017) in Ghana in their respective studies on crop diversification.

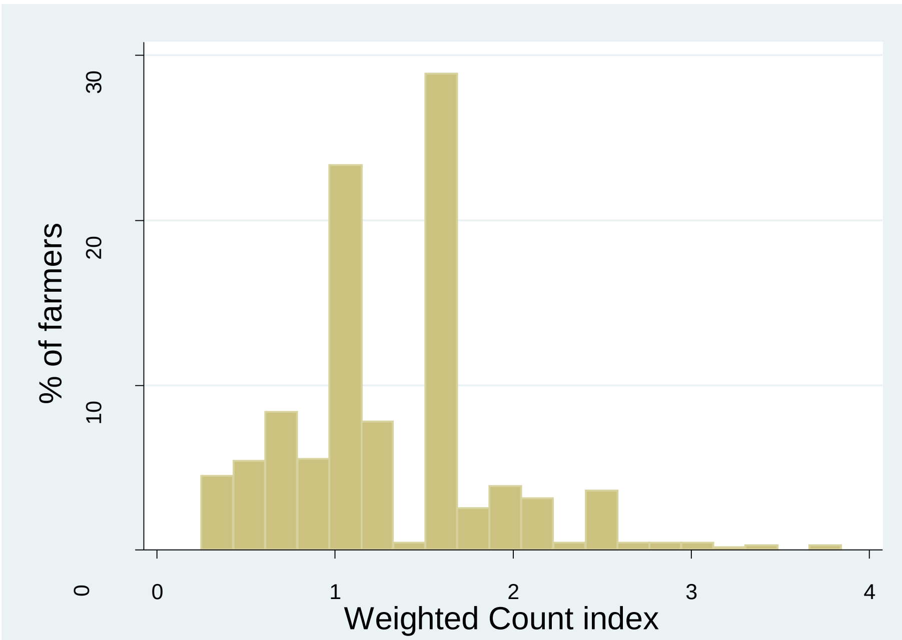


Figure 1. Distribution of the weighted count index of crop diversification

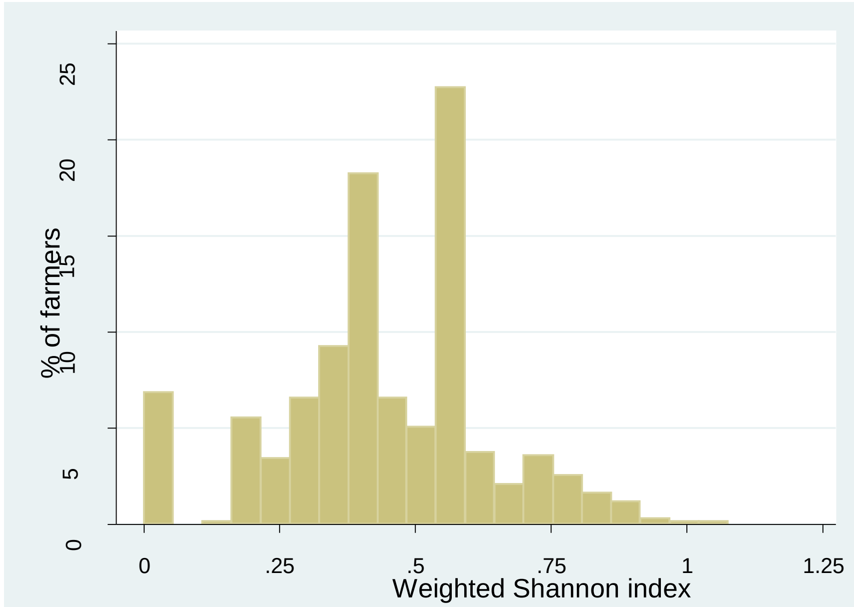


Figure 2. Distribution of the weighted Shannon index of crop diversification

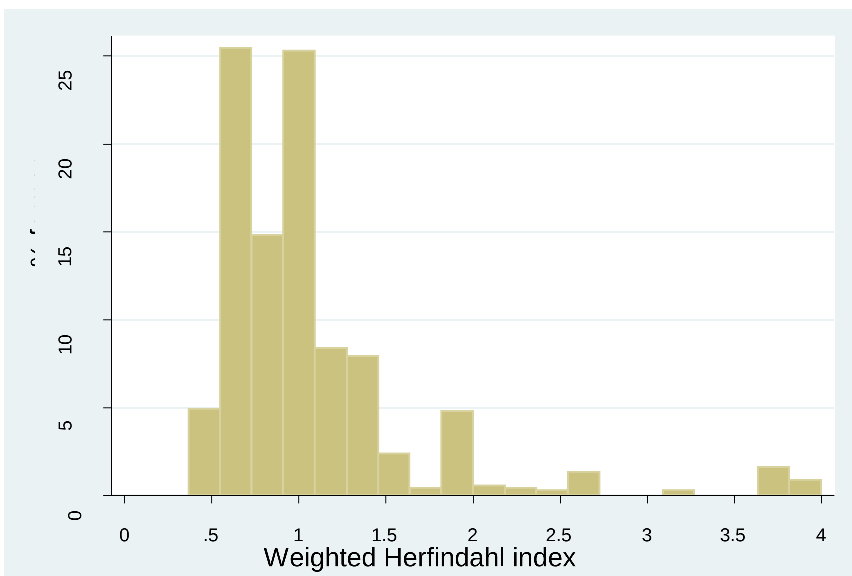


Figure 3. Distribution of the weighted Herfindahl index of crop diversification

4 Results and discussion

The results of the estimates of crop diversification using the weighted count index, the weighted Shannon index and the weighted Herfindahl index measure of crop concentration and are presented in Tables 4, 5 and 6, respectively. Other model specifications including interaction variables are presented in Tables A1, A2 and A3 in the appendix[5].

Table 4. Estimation of crop diversification with the weighted count index (OLS model)[a]

Variables	Coefficient	P-value
Risk aversion	-0.03570*	0.066
Age (in years)	-0.00025	0.872
Gender (1= Female)	0.03972	0.500
Household head	0.07708	0.129
Primary education	0.18463***	0.004
Secondary or post-secondary education	0.07786	0.387
Household size	-0.00731**	0.020
Farm size	0.01808**	0.029
Agricultural implement access index	-0.02562	0.288
Access to credit	0.05215	0.355
Extension contact	-0.02013	0.292
Land owner	0.00181	0.966
Number of plots	0.32571***	0.000
Distance to road (mn)	0.00002	0.580
Distance to market (mn)	0.00051***	0.005
Off-farm income (dummy)	-0.02412	0.553
Province dummies (ref: ZONDOMA)		
PASSORE Province	0.00177	0.974
ZIRO Province	-0.41919***	0.000
NAHOURI Province	-0.40250***	0.000
Constant	0.96114***	0.000
Observations	668	
Fstat	15.08044	
Prob > Fstat	0.00000	
Adjusted R-squared	0.33795	

* $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$. [a] The dependent variable is the number of crops grown by the farmer weighted by price ratio. Estimation of the OLS model was conducted with robust standard errors.

[5] In addition to these models, we have estimated alternative models by including interaction variables between risk aversion and sex, age, region, provinces, farm size, and off-farm income. But the results have not been conclusive and are not presented in this article.

Table 5. Estimation of crop diversification with weighted Shannon index (Tobit model)[a]

Variables	Coefficient	P-value	CME[b]	ME[c]
Risk aversion	-0.02140***	0.008	-0.01960***	-0.02100***
Age (in years)	0.00003	0.966	0.00002	0.00002
Gender (1= Female)	0.01589	0.459	0.01455	0.01559
Household head	0.03394*	0.063	0.03108*	0.03330*
Primary education	0.07151***	0.002	0.06549***	0.07016***
Secondary or post-secondary education	0.01630	0.686	0.01493	0.01599
Household size	-0.00344***	0.008	-0.00315***	-0.00337***
Farm size	0.00901***	0.005	0.00825***	0.00884***
Agricultural implement access index	-0.00396	0.689	-0.00362	-0.00388
Access to credit	0.00939	0.674	0.00860	0.00921
Extension contact	-0.01142	0.161	-0.01046	-0.01120
Land owner	0.01350	0.437	0.01236	0.01324
Number of plots	0.07692***	0.000	0.07044***	0.07546***
Distance to road (mn)	0.00001	0.264	0.00001	0.00001
Distance to market (mn)	0.00017**	0.014	0.00016**	0.00017**
Off-farm income (dummy)	-0.00148	0.926	-0.00136	-0.00145
Province dummies (ref: ZONDOMA)				
PASSORE Province	0.00684	0.770	0.00660	0.00681
ZIRO Province	-0.15126***	0.000	-0.13838***	-0.14850***
NAHOURI Province	-0.14399***	0.000	-0.13217***	-0.14151***
Constant	0.35901***	0.000		
Sigma	0.03382***	0.000		
Observations	668		668	668
Log livelihood	106.38690			
Fstat	12.47202			
Prob > Fstat	0.00000			
Pseudo-R-squared	-7.19380			

* $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$., CME= Conditional Marginal Effects; ME= Marginal Effects

[a] The dependent variable is the weighted Shannon index. The estimation of the Tobit model was conducted with robust standard errors.

[b] Conditional marginal effects are estimated by $E_{Xk}\left[\frac{\partial E(y|x.\ \ y>0)}{\partial x_k}\right]$.

[c] Marginal effects are estimated by $E_{Xk}\left[\frac{\partial E(y|x)}{\partial x_k}\right]$.

Table 6. Estimation of crop diversification with the weighted Herfindahl index measure of crop concentration (OLS model)[a]

Variables	Coefficient	P-value
Risk aversion	0.04012*	0.090
Age (in years)	-0.00002	0.988
Gender (1= Female)	-0.09491	0.124
Household head	-0.05834	0.247
Primary education	-0.15820***	0.004
Secondary or post-secondary education	0.05862	0.695
Household size	0.01219***	0.003
Farm size	-0.03429***	0.002
Agricultural implement access index	0.02482	0.472
Access to credit	-0.02569	0.710
Extension contact	0.04963*	0.054
Land owner	-0.01410	0.796
Number of plots	-0.08072**	0.010
Distance to road (mn)	-0.00000	0.976
Distance to market (mn)	-0.00057***	0.002
Off-farm income (dummy)	0.05761	0.245
Province dummies (ref: ZONDOMA)		
PASSORE Province	-0.03466	0.497
ZIRO Province	0.59951***	0.000
NAHOURI Province	0.44504***	0.000
Constant	1.03425***	0.000
Observations	668	
Fstat	8.57300	
Prob > Fstat	0.00000	
Adjusted R-squared	0.21459	

* $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$.

[a] The dependent variable is the weighted Herfindahl diversity index. The estimation of the OLS model was conducted with robust standard errors.

The results of the three estimated models show that risk aversion has a negative and statistically significant effect on crop diversification. The coefficient of this variable is significant at the 10% threshold in all models. Thus, the more risk averse the farmer is, the less he diversifies his production. The intensity of crop diversification decreases on average by 4 to 20% with the risk aversion of the farmer. The intensity of crop diversification decreases further among non-educated and landless producers (see tables A1, A2 and A3 in the appendix). This result is counter-intuitive and contradicts the claims in the literature that farmers use crop diversification as a risk management strategy.

We interpret this result by invoking the composition of farmers' crop portfolios. The predominant crops in our sample are millet, sorghum and cowpea, which can be considered less risky crops because of the farmers' long experience with their production and the suitability of these crops to local climatic conditions. The endemic nature of traditional crops helps to minimize the risk of production. Price risk of these crops is also low because of high local demand and national policies that protect the local market for traditional crops against price fluctuations in the international market. Sakurai and Reardon (1997) show that in the context of Burkina Faso, crop diversification involves risk increasing when it consists of adding cash crops, such as cotton or maize, to traditional drought-resistant crops. We run a Probit model where the dependent variable is the incidence of cash crop diversification, which is a dummy variable that takes the value 0 if the farmer grows only traditional crops (millet, sorghum and cowpea) and 1 otherwise. The results presented in Table A4 in Appendix shows that risk-averse farmers tend to focus more on traditional crops to avoid the risks associated with the production of other crops. Risk aversion is negatively correlated with the production of non-traditional, riskier crops. In particular, the probability of producing a non-traditional crop decreases by 4.1% with risk aversion. Our result suggests who have a tolerance for risk tend to add non-traditional crops to their portfolio. As a result, producers who have a tolerance for risk have a higher degree of diversification because they make crop choices from a wider pool of crops.

Our result is similar to that of Engle-Warnick et al. (2011), who found that risk aversion in Peru is negatively associated with crop diversification.[6] However, our result differs from that of Di Falco and Perrings (2005) and Bezabih and Sarr (2012), who concluded that risk aversion has a positive effect on diversification.

We find that primary education has a positive and significant effect on crop diversification at the 5% threshold. Farmers with a primary education have a diversification level that is 7 to 18% higher than those who have no schooling. This result is similar to previous studies, which have found that improving managerial capacity through education and farmers' training prepares farmers to diversify their production (Bravo-Ureta et al., 2006; Ashfaq et al., 2008; Engle-Warnick et al., 2011).

There is an inverse relationship between household size and crop diversification. The coefficient of the household size variable is negative and significant at the 5% threshold in all models. Van Dusen and Taylor (2005) and Benin et al. (2006) also found a negative effect of household size on diversification. In contrast, a null effect was found in Ethiopia (Benin et al., 2004, Mesfin et al., 2011) and Peru (Engle-Warnick et al., 2011).

The frequency of contact with extension agents has no effect on diversification, except for the Herfindahl index, for which contact with extension agents seems to have a negative and significant effect on diversification. Frequent contact with extension agents therefore leads the producer to concentrate on his main production. We found that access to agricultural

[6] The estimations made with non-weighted indices give the same qualitative results. However, marginal impacts of risk on crop diversification is about twice higher than marginal impacts when using weighted crop diversifications indices. The estimations are available upon request.

tools have no significant effect on crop diversification. These results contradict those of Mesfin et al. (2011) and Asante et al. (2017).

As expected, farmers with larger farm areas are more diverse. The coefficient of the farm size variable is positive and significant at the 1% threshold in all models. A 1-hectare increase in farm size increases the intensity of crop diversification by 1 to 3% on average. This result is in line with those of other studies in Ethiopia (Benin et al., 2004), Peru (Engle-Warnick et al., 2011) and Algeria (Benmehaia and Brabez, 2016). However, Mesfin et al. (2011, Ethiopia) and Asante et al. (2017, Ghana) found that farm size has no statistically significant effect on crop diversification.

The coefficient of the plot number variable is positive and significant at the 1% threshold in all models. An increase in plot number increases the intensity of crop diversification by 7-33% depending on the diversity index under consideration. This result implies that farmers with more agricultural parcels are more likely to diversify their production by growing different crops on each plot. The cultivation of several plots may allow farmers to benefit from the variation in local agro-climatic and soil conditions, such as rainfall, that favor crop diversification. A similar result was found by Mesfin et al. (2011) in Ethiopia.

Distance to market has a positive effect on diversification. In other words, the closer the farmer is to the market, the more he tends to specialize in his production. Proximity to the market reduces the costs of transporting products to the market and therefore farmers are able to specialize in the production of high value-added crops without necessarily diversifying (Asante et al., 2017).

5 Conclusion and policy implications

In this paper, we examined the effect of risk aversion on crop diversification among smallholder farmers in Burkina Faso. We combined experimental data on the measurement of risk aversion with survey data. We used three diversity indexes adapted from ecological indexes of spatial diversity to measure crop diversification at the farm level. These indexes include the weighted count index, the weighted Herfindahl index measure of crop diversification and the weighted Shannon index. The weighted count index measures crop richness at the farm level, the weighted Herfindahl index measures the relative abundance of crops, and the weighted Shannon index measures both the richness and relative abundance of the crops.

Our results show that the intensity of crop diversification decreases with risk aversion. In other words, the most risk-averse farmers tend to be specialized (less diversified) in their production. We interpret this result by invoking the composition of the farmers' crop portfolios. Risk-averse farmers focus more on traditional, less risky crops and with low market value.

Other variables have a significant effect on crop diversification. The farmer's level of formal education, distance to market, farm size and land fragmentation are associated with greater crop diversification. In contrast, age, gender, access to credit, contact with extensions, fertilizer, agricultural tools and off-farm income have no statistically significant effect on diversification. Household size has a negative and significant effect on diversification.

Consequently, policies that support investment in research and development of drought resistant varieties and promote crop insurance especially for non-traditional crops may reduce production risks and thus favor crop diversification. In addition, extension services must increase farmers' awareness of crop diversification.

6 References

Abay, F., Bjørnstad, A., and Smale, M. (2009). Measuring on farm diversity and determinants of barley diversity in Tigray, Northern Ethiopia. *Momona Ethiopian Journal of Science, 1(2): 44–66*.

Abro, A.A. (2012). Determinants of crop diversification towards high value crops in Pakistan. *International Journal of Business Management & Economic Research 3: 536–545*.

Ahmed, M.H., and Melesse, K.A. (2018). Impact of off-farm activities on technical efficiency: evidence from maize producers of eastern Ethiopia. *Agricultural and Food Economics, 6(3):1-15*

Akcaoz, H. and Ozkan B (2005). Determining risk sources and strategies among farmers of contrasting risk awareness: a case study for Cukurova region of Turkey. *Journal of Arid Environments 62(4): 661–675*.

Asante, B. O., Villano, R. A., Patrick, I. W. and Battese, G.E. (2017). Determinants of farm diversification in integrated crop–livestock farming systems in Ghana. *Renewable Agriculture and Food Systems, forthcoming, 1-19.*

Ashfaq, M., Hassan, S., Naseer, M.Z., Baig, I.A., and Asma, J. (2008). Factors affecting farm diversification in rice–wheat. *Pakistan Journal of Agricultural Science 45:91–94*.

Barham, B. L., Chavas, J-P., Fitz, D., Salas, V. R. and Schechter, L. (2014). The roles of risk and ambiguity in technology adoption. *Journal of Economic Behavior & Organization, 97: 204-218.*

Benin, S., Smale, M., and Pender, J. (2006). Explaining the diversity of cereal crops and varieties drown on household farms in the highlands of northern Ethiopia. In M. Smale (Ed.), *Valuing crop biodiversity: On farm genetic resources and economic change (pp. 78–96)*. Published by CABI in association with IFPRI, FAO, and Biodiversity International (formerly IPGRI), Retrieved from http://ebrary.ifpri.org/cdm/ref/collection/p15738coll5/id/1274. Accessed on January 26, 2017.

Benin, S., Smale, M., Pender, J., Gebremedhin, B and Ehui, S. (2004). The economic determinants of cereal crop diversity on farms in the Ethiopian highlands. *Agricultural Economics, 31: 197-208*.

Benmehiaia, M. A., and Brabez, F. (2016). Determinants of On-Farm Diversification Among Rural Households: Empirical Evidence from Northern Algeria. *International Journal of Food and Agricultural Economics, 4 (2): 87-99*.

Bezabih, M. and Sarr, M. (2012). Risk Preferences and Environmental Uncertainty: Implications for Crop Diversification Decisions in Ethiopia. *Environmental and Resource Economics, 53:483–505*.

Bravo-Ureta, B. E., Cocchi, H., and Solís, D. (2006). Output Diversification among Small-Scale Hillside Farmers in El Salvador. Inter-American Development Bank Washington, D.C, Office of Evaluation and Oversight, OVE, *Working Paper: OVE/WP-17/06*.

Chavas J-P., and Di Falco S. (2012). On the role of risk versus economies of scope in farm diversification with an application to Ethiopian farms. *Journal of Agricultural Economics, 63(1): 25-55.*

Coelli, T., & Fleming, E. (2004). Diversification economies and specialisation efficiencies in a mixed food and coffee smallholder farming system in Papua New Guinea. *Agricultural Economics, 31(2–3): 229–239.*

Cohen, M., Jaffray, J.Y., and Said, T. (1985). Individual behavior under risk and under uncertainty: an experimental study. *Theory and Decision, 18 (2): 203–228.*

Di Falco, S., & Chavas, J. P. (2009). On crop biodiversity, risk exposure, and food security in the highlands of Ethiopia. *American Journal of Agricultural Economics, 91(3), 599–611*.

Di Falco, S., and Perrings, C. (2005). Crop biodiversity, risk management and the implications of agricultural assistance. *Ecological Economics 55 (4): 459 – 466.*

Dube, L., Numbwa, R., and Guveya, E. (2016) Determinants of Crop Diversification amongst Agricultural Co-operators in Dundwa Agricultural Camp, Choma District, Zambia. *Asian Journal of Agriculture and Rural Development, 6 (1): 1-13*.

Engle Warnick, J. C., Escobal, J. and Laszlo, S. C. (2011). Ambiguity Aversion and Portfolio Choice in Small-Scale Peruvian Farming. *The B.E. Journal of Economic Analysis &Policy, 11(1):1-56*.

Gauchan, D., Smale, M., Maxted, N., and Cole, M. (2006). Managing rice biodiversity on farms: The choices of farmers and breeders in Nepal. In M. Smale (Ed.), *Valuing crop biodiversity: On-farm genetic resources and economic change (pp. 162–175)*. Published by CABI in association with IFPRI, FAO, and Biodiversity International (formerly IPGRI).

Goletti, F. (1999). *Agricultural diversification and rural industrialization as a strategy for rural income growth and poverty reduction in Indochina and Myanmar (No. 30).* Washington, D.C.: International Food Policy Research Institute (IFPRI).

Hardaker, J.B., Huirne R.B.M., and Anderson, J.R. (1997) *Coping With Risk in Agriculture*. New York, Oxon: CAB International Publishing.

Harrison, G. W., Humphrey, S. J., and Verschoor, A. (2010). Choice under uncertainty: Evidence from Ethiopia, India and Uganda. *The Economic Journal, 120 (543): 80-104.*

Hutchenson, K., (1970). A test for comparing diversities based on the Shannon formula. *Journal of Theoretical Biology*, 29 (1): 151-154.

Ibrahim, H., Rahman, S., Envulus, E., and Oyewole, S. (2009). Income and crop diversification among farming households in a rural area of north central Nigeria. *Agro-Science: Journal of Tropical Agriculture, Food, Environment and Extension 8:84–89*.

Islam, A. H. M., von Braun., J., Thorne-Lyman., A. L., and Ahmed, A.U. (2018). Farm diversification and food and nutrition security in Bangladesh: empirical evidence from nationally representative household panel data. *Food Security, 10(3): 701:720*.

Jain, S.K., Qualset, C.O., Bhatt, G.M., and Wu, K.K. (1975). Geographical patterns of phenotypic diversity in a world collection of durum wheat. *Crop Science, 15: 700–704*.

Jones, A. D., Shrinivas, A., & Bezner-Kerr, R. (2014). Farm production diversity is associated with greater household dietary diversity in Malawi: findings from nationally representative data. *Food Policy, 46, 1–12*.

Joshi, P. K., Gulati, A., Birthal, P. S., and Tewari, L. (2004). Agriculture diversification in South Asia: Patterns, determinants and policy implications. *Economic and Political Weekly, 39(24): 2457–2467.*

Khanal, A. R. and Mishra, A. K. (2017). Enhancing food security: Food crop portfolio choice in response to climatic risk in India. *Global Food Security, 12: 22-30*.

Magurran, A. (1988). *Ecological Diversity and its Measurement*. Princeton University Press, Princeton, NJ.

Mesfin, W., Fufa, B., and Haji, J. (2011). Pattern, trend and determinants of crop diversification: Empirical evidence from smallholders in Eastern Ethiopia. *Journal of Economics and Sustainable Development 2:78–89*.

Ministère de l'Agriculture et des Aménagements Hydrauliques. (2016). *Plan National de Développement Économique et Social (PNDES) 2016-2020*, 134 pages.

Ogundari, K. (2013). Crop diversification and technical efficiency in food crop production: A study of peasant farmers in Nigeria. *International Journal of Social Economics 40 (3): 267–287.*

Pellegrini, L., and Tasciotti, L. (2014). Crop diversification, dietary diversity and agricultural income: Empirical evidence from eight developing countries. *Canadian Journal of Development Studies /Revue Canadienne D'études Du Développement, 5189 : 1–17*.

Pratt, J.W. (1964). Risk aversion in the small and in the large. *Econometrica, 32(1/2): 122–136.*

Rahman, S. (2008). Determinants of crop choices by Bangladeshi farmers: A bivariate probit analysis. *Asian Journal of Agriculture and Development 5:30–14*.

Rahman, S. (2009). Whether crop diversification is a desired strategy for agricultural growth in Bangladesh? *Food Policy, 34(4), 340–349.*

Rehima M., Belay K., Dawit A., and Rashid S. (2013). Factors Affecting Farmers' Crops Diversification: Evidence from SNNPR, Ethiopia. *International Journal of Agricultural Sciences*, 3(8): 558-565.

Saenz, M. and Thompson, E. (2017). Gender and Policy Roles in Farm Household Diversification in Zambia. *World Development, 89, 152–169.*

Sakurai, T., and Reardon, T. (1997). Potential Demand for Drought Insurance in Burkina Faso and Its Determinants. *American Journal of Agricultural Economics, 79 (4): 1193–1207.*

Smale, M. (2006). Concepts, metrics and plan of the book. In M. Smale (Ed.), *Valuing crop biodiversity: On-farm genetic resources and economic change (pp. 1–16)*. Published by CABI in association with IFPRI, FAO, and Biodiversity International (formerly IPGRI).

Smale, M., Bellon, M. R., and Aguirre Gomez, J. A. (2001). Maize diversity, variety attributes, and farmers' choices in southeastern Guanajuato, Mexico. *Economic Development and Cultural Change, 50(1): 201–225*.

Ullah, R., Shivakoti, G.P., Zulfiqar, F. and Kamran, M. A. (2016). Farm risks and uncertainties: Sources, impacts and management. *Outlook on Agriculture, 45(3): 199–205*.

Van Dusen, M. E., and Taylor, J. E. (2005). Missing markets and crop diversity: Evidence from Mexico. *Environment and Development Economics, 10: 513–531*.

Appendix

Appendix 1. Risk aversion experiment questionnaire

Maintenant, je voudrais vous poser des questions liées à une situation hypothétique. Les questions incluent des sommes d'argent mais je voudrais vous faire savoir qu'il ne s'agit que d'hypothèses. Aucun don d'argent ne sera lié à ces questions.

Il y a une série de **8 jeux** simultanés présentés ci-dessous. Pour chaque jeu, vous avez le choix entre gagner avec certitude ou participer à une loterie. Nous avons **au total 20 boules** dans ce sac. Il y a des **boules rouges et des boules noires dans le sac**. Si vous décidez de participer à la loterie, nous allons tirer au hasard une boule dans le sac et votre gain dépendra de la couleur de la boule tirée. Par exemple pour le premier jeu, si vous décidez de participer à la loterie, si une boule rouge est tirée, vous gagnerez 4000 FCFA. Mais si c'est la boule noire qui est tiré, vous gagnerez 2000 FCFA.

Jeu	Gain certain (FCFA)	Participer à la loterie		Quel choix préférez-vous? 1= Prendre le gain certain (2000 FCFA) 2= Participer à la loterie
		Gain si la boule rouge est tirée (FCFA)	Gain si la boule noire est tirée(FCFA)	
1	2000	4000	2000	[__]
2	2000	4000	1500	[__]
3	2000	4000	1200	[__]
4	2000	4000	900	[__]
5	2000	4000	700	[__]
6	2000	4000	500	[__]
7	2000	4000	300	[__]
8	2000	4000	0	[__]

Table A1. Other specification of estimation of crop diversification with the weighted count index (OLS model)

	Specification 1		Specification 2		Specification 3	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Risk aversion	-0.05014**	0.019	-0.08154***	0.000	-0.09243***	0.000
Age (in years)	-0.00018	0.906	-0.00033	0.827	-0.00026	0.862
Gender (1= Female)	0.04390	0.456	0.02844	0.634	0.03335	0.577
Household head	0.07673	0.128	0.07297	0.151	0.07297	0.149
Primary education	0.13643	0.134	0.17974***	0.005	0.14403	0.116
Secondary or post-secondary education	-0.12075	0.334	0.07411	0.417	-0.11461	0.369
Household size	-0.00729**	0.020	-0.00741**	0.018	-0.00739**	0.018
Farm size	0.01794**	0.032	0.01793**	0.029	0.01789**	0.032
Agricultural implement access index	-0.02512	0.290	-0.03060	0.202	-0.02990	0.206
Access to credit	0.05408	0.333	0.04031	0.477	0.04264	0.448
Extension contact	-0.02066	0.275	-0.02024	0.285	-0.02082	0.269
Land owner	0.00018	0.997	-0.09421	0.104	-0.09100	0.118
Number of plots	0.32468***	0.000	0.33020***	0.000	0.32897***	0.000
Distance to road (mn)	0.00002	0.560	0.00001	0.662	0.00001	0.643
Distance to market (mn)	0.00053***	0.004	0.00047**	0.012	0.00049***	0.010
Off-farm income (dummy)	-0.02221	0.584	-0.03846	0.343	-0.03575	0.377
Province dummies (ref: ZONDOMA)						
PASSORE Province	-0.00040	0.994	0.01237	0.818	0.00956	0.860
ZIRO Province	-0.42642***	0.000	-0.41817***	0.000	-0.42528***	0.000
NAHOURI Province	-0.39935***	0.000	-0.39089***	0.000	-0.38871***	0.000
Risk aversion * Primary education	0.04190	0.484			0.03174	0.590
Risk aversion * Secondary education and above	0.15420**	0.013			0.14662**	0.022
Risk aversion * Land owner			0.08955**	0.021	0.08510**	0.030
Constant	0.97229***	0.000	1.02334***	0.000	1.03002***	0.000
Observations	668		668		668	
Fstat	13.84108		14.67781		13.51260	
Prob > Fstat	0.00000		0.00000		0.00000	
Adjusted R-squared	0.34153		0.34319		0.34615	

Table A2. Other specifications of the estimation of crop diversification with the weighted Shannon index (Tobit model)

	Specification 1		**Specification 2**		**Specification 3**	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Risk aversion	-0.02949***	0.001	-0.04407***	0.000	-0.05029***	0.000
Age (in years)	0.00006	0.916	-0.00002	0.979	0.00002	0.968
Gender (1= Female)	0.01901	0.373	0.01034	0.631	0.01384	0.519
Household head	0.03387*	0.059	0.03195*	0.076	0.03205*	0.071
Primary education	0.05407	0.126	0.06915***	0.002	0.05772	0.104
Secondary or post-secondary education	-0.10599*	0.086	0.01462	0.720	-0.10275	0.101
Household size	-0.00344***	0.007	-0.00349***	0.007	-0.00349***	0.006
Farm size	0.00905***	0.005	0.00892***	0.005	0.00901***	0.005
Agricultural implement access index	-0.00367	0.702	-0.00632	0.515	-0.00592	0.531
Access to credit	0.01035	0.634	0.00365	0.870	0.00484	0.825
Extension contact	-0.01188	0.136	-0.01144	0.156	-0.01193	0.132
Land owner	0.01262	0.458	-0.03365	0.148	-0.03190	0.169
Number of plots	0.07620***	0.000	0.07914***	0.000	0.07830***	0.000
Distance to road (mn)	0.00001	0.246	0.00001	0.329	0.00001	0.309
Distance to market (mn)	0.00018***	0.010	0.00015**	0.033	0.00016**	0.024
Off-farm income (dummy)	-0.00024	0.988	-0.00847	0.596	-0.00679	0.668
Province dummies (ref: ZONDOMA)						
PASSORE Province	0.00530	0.822	0.01209	0.607	0.01020	0.666
ZIRO Province	-0.15596***	0.000	-0.15067***	0.000	-0.15533***	0.000
NAHOURI Province	-0.14246***	0.000	-0.13815***	0.000	-0.13714***	0.000
Risk aversion * Primary education	0.01570	0.449			0.01083	0.596
Risk aversion * Secondary education and above	0.09375***	0.001			0.09004***	0.001
Risk aversion * Land owner			0.04407***	0.006	0.04164***	0.009
Constant	0.36505***	0.000	0.38957***	0.000	0.39327***	0.000
Sigma	0.03325***	0.000	0.03337***	0.000	0.03285***	0.000
Observations	668		668		668	
Log livelihood	112.52848		110.99492		116.68409	
Fstat	11.84579		12.26363		11.59361	
Prob > Fstat	0.00000		0.00000		0.00000	
Pseudo-R-squared	-7.66682		-7.54870		-7.98688	

Table A3. Other specifications of the estimation of crop diversification with the weighted Herfindahl index (OLS model)

	Specification 1		**Specification 2**		**Specification 3**	
Variables	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Risk aversion	0.06623***	0.009	0.07409**	0.034	0.09512***	0.007
Age (in years)	-0.00017	0.914	0.00004	0.979	-0.00011	0.943
Gender (1= Female)	-0.10579*	0.083	-0.08655	0.162	-0.09858	0.108
Household head	-0.05837	0.226	-0.05529	0.270	-0.05580	0.245
Primary education	-0.11991	0.161	-0.15457***	0.005	-0.12510	0.144
Secondary or post-secondary education	0.46584*	0.054	0.06140	0.682	0.46164*	0.057
Household size	0.01217***	0.003	0.01227***	0.003	0.01224***	0.002
Farm size	-0.03450***	0.002	-0.03418***	0.002	-0.03446***	0.002
Agricultural implement access index	0.02390	0.471	0.02852	0.405	0.02716	0.410
Access to credit	-0.02909	0.666	-0.01691	0.808	-0.02128	0.754
Extension contact	0.05124**	0.037	0.04971*	0.053	0.05135**	0.036
Land owner	-0.01074	0.840	0.05706	0.403	0.05155	0.447
Number of plots	-0.07845**	0.011	-0.08404***	0.008	-0.08138***	0.009
Distance to road (mn)	-0.00000	0.964	0.00000	0.967	0.00000	0.983
Distance to market (mn)	-0.00060***	0.001	-0.00053***	0.004	-0.00057***	0.002
Off-farm income (dummy)	0.05253	0.278	0.06824	0.172	0.06178	0.205
Province dummies (ref: ZONDOMA)	0.00000	.	0.00000	.	0.00000	.
PASSORE Province	-0.02889	0.572	-0.04251	0.407	-0.03570	0.488
ZIRO Province	0.61546***	0.000	0.59875***	0.000	0.61467***	0.000
NAHOURI Province	0.44004***	0.000	0.43644***	0.000	0.43278***	0.000
Risk aversion * Primary education	-0.03622	0.482			-0.02927	0.566
Risk aversion * Secondary education and above	-0.31590***	0.001			-0.31072***	0.001
Risk aversion * Land owner			-0.06637	0.133	-0.05814	0.176
Constant	1.01654***	0.000	0.98815***	0.000	0.97710***	0.000
Observations	668		668		668	
Fstat	7.78282		8.18692		7.47862	
Prob > Fstat	0.00000		0.00000		0.00000	
Adjusted R-squared	0.23146		0.21629		0.23250	

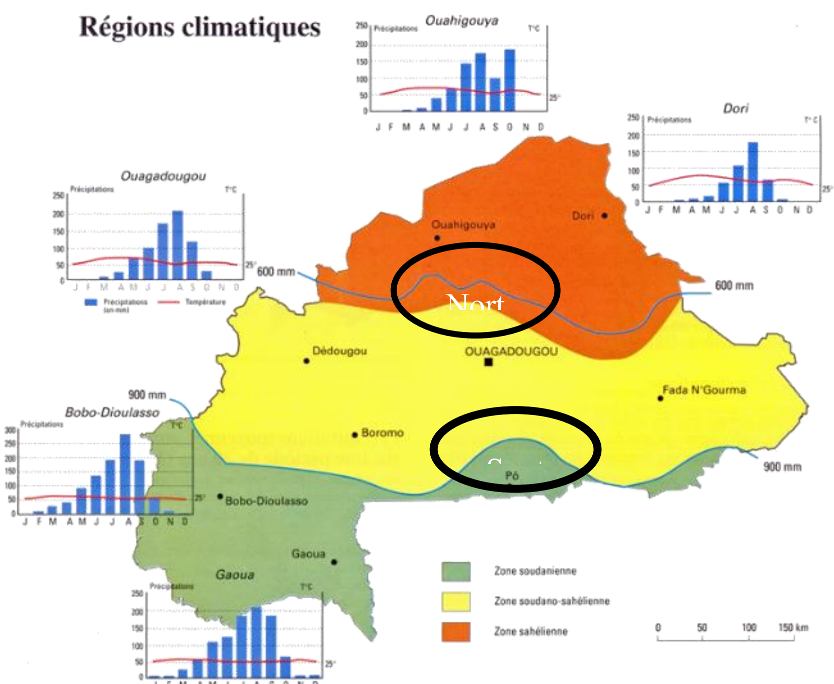
Table A4. Effect of risk aversion on the incidence of crop diversification (Probit Model)[a]

Variables	Coeff	P-value	dydx[b]	P-value
Risk aversion	-0.12749**	0.015	-0.04071**	0.013
Age (in years)	-0.00389	0.407	-0.00124	0.406
Gender (1= Female)	0.23994	0.160	0.07661	0.159
Household head	0.15472	0.308	0.04940	0.307
Primary education	0.47157**	0.029	0.15057**	0.027
Secondary or post-secondary education	0.44421*	0.088	0.14184*	0.086
Household size	-0.01246	0.173	-0.00398	0.171
Farm size	0.01926	0.400	0.00615	0.400
Agricultural implement access index	-0.20711***	0.006	-0.06613***	0.005
Access to credit	0.31789**	0.041	0.10150**	0.039
Extension contact	-0.03702	0.473	-0.01182	0.474
Land owner	-0.16301	0.211	-0.05205	0.209
Number of plots	0.61779***	0.000	0.19726***	0.000
Distance to road (mn)	-0.00021***	0.006	-0.00007***	0.006
Distance to market (mn)	0.00081	0.163	0.00026	0.161
Off-farm income (dummy)	-0.00276	0.981	-0.00088	0.981
Province dummies (ref: ZONDOMA)				
PASSORE Province	-0.02400	0.882	-0.00754	0.882
ZIRO Province	0.92219***	0.000	0.31877***	0.000
NAHOURI Province	1.62613***	0.000	0.52035***	0.000
Constant	-1.24820***	0.000		
Observations	668		668	
Log livelihood	-376.00918			
Wald Chi2	146.55330			
Prob > chi2	0.00000			
Pseudo-R-squared	0.18792			

* $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$.

[a] The dependent variable is the incidence of cash-crop diversification, which is a dummy variable that takes the value 0 if the farmer grows only traditional crops (millet, sorghum and cowpea) and 1 otherwise. The estimation of the Probit model was conducted with robust standard errors.

[b] Marginal effects are estimated by $E_{Xk}\left[\frac{\partial E(y|x)}{\partial x_k}\right]$.



Map.1. Burkina Faso map highlighting the 4 surveyed provinces