Risk preferences and crop diversification amongst smallholder farmers in Burkina Faso

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Abstract

The literature considers crop diversification 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 count index, the Herfindahl index measure of crop concentration and the Shannon index of evenness. An Ordinary Least square (OLS) model is used to estimate the impact of risk aversion on crop diversification when the count index is used as the dependent variable, whereas a Tobit model is used for the Herfindahl index and the Shannon index. Our results show that risk aversion has a negative and significant effect on crop diversification. Although the effect is significant for all diversity indexes, the magnitude of the effect differs among them. Other variables also affect crop diversification. In particular, education level, distance to market, farm area and land fragmentation are associated with greater crop diversification.

Key words: Risk aversion; diversity index; crop diversification; smallholder farmers; Burkina Faso.

JEL classification: C93; D13; G11; Q12; Q57

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), these 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; 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. 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 and reduces output production shortages (Goletti, 1999; Joshi et al., 2004).

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 on several levels. The agricultural sector represents an important part of the Burkina Faso economy 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 and socio-economic environment in which they operate. These risks influence production choices and resource 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. An OLS model is used to estimate the impact of risk aversion on crop diversification when the count index is used as the dependent variable, whereas a Tobit model is used for the Herfindahl index and the Shannon index.

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 count index is used as a dependent variable, whereas a Tobit model is used for the Herfindahl index and the Shannon index. We contribute to the empirical literature on uncertainty decision making by experimentally measuring smallholder farmers' attitudes toward risk and by analyzing their relationships with crop diversification decisions.

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 (D) measures the relative abundance of crops (Magurran, 1988) and the Shannon index (H) 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. We adopted several approaches to measuring diversification in order to test the robustness of our estimates, because the results may be sensitive to the approach used. Our approach takes into account the three main methods used in the literature to characterize crop diversification.

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

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

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 Herfindahl index of farmer *i* is defined as

[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 anyway

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

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 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 with higher prices imply small changes in the value of *D*. In this sense, the 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 D, 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 Shannon index is calculated by

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

where *w*, *m* and *p* are the same parameters as in equation (2). Similar to the Herfindahl index, the Shannon index measures the relative abundance of crops at the farm level. A zero value implies that the farmer cultivates a single crop and is therefore perfectly specialized. The higher the value of the 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.

In the empirical approach, the dependent variables are the count index, the Herfindahl index and the Shannon index. Using the count index as the dependent variable, we employ an OLS regression to estimate the effect of risk aversion on crop diversification. The Herfindahl and Shannon diversity indices were estimated by a Tobit regression because these indices take values greater than or equal to zero. The general structure of the regression equations is expressed in the following simplified form:

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

where *y* is either the count index, the Herfindahl index or the 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 en suite 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 in the lottery, his payoff depends on the color of the ball drawn (Table 1).

[2] 1 USD = XOF 600

<<< Table 1 about here>>>

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.,

$$U(x_0) = 0.5 * U(x_1) + 0.5 * U(x_2) \tag{6}$$

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 145 villages, 64 of which are in the northern region and 81 of which are in the southern region. 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].

Table 2 describes the variables used in the econometric estimates.

<<< Table 2 about here >>>

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 count index, the Herfindahl index measure of crop concentration, and the 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.

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

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 et Brabez, 2016; Dube et al., 2016; Asante et al., 2017; Saenz et 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 can be 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 the amount of fertilizer used per hectare, access to agricultural tools[4], land area holding, number of plots, and ownership of plots. Access to agricultural tools for cultivation and the amount of fertilizer used could improve diversification (Mesfin et al., 2011). The number of plots is

[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.

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 good land access have more flexibility in allocating land to various crops (Asante et al., 2017).

Finally, a dummy variable indicating the region where the farmer is located was introduced to capture regional differences in crop diversification. The rainfall patterns differ between the two regions covered by the survey. Thus, this variable makes it possible to capture the effect of expected rainfall 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 chemical fertilizers is low; the average quantity used per hectare is approximately 31 kg. 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 about here>>

As shown in Table 3, farmers in the sample are quite diverse. Farmers cultivate 3 different crops on average. The Herfindahl and Shannon index values are 1.09 and 0.44, respectively, showing high crop diversification. Figure 1 shows the distribution of the crop diversification index calculated with the count index. Figure 2 shows the distribution of the Shannon index, and Figure 3 shows the distribution of the Herfindahl diversity index. 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, 2 and 3 about here>>

4. Results and discussion

The results of the estimates of crop diversification using the count index, the Shannon index and Herfindahl index measure of crop concentration and are presented in Tables 4, 5 and 6, respectively.

<< Table 4, 5 and 6 about here >>>

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 5% 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 7 to 20% with the level of risk aversion of the farmer. 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, maize 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. The price risk is also low with these crops because of the high potential local demand and the national policies that protect the local market for traditional crops against price fluctuations in the international market. We observe that risk-averse farmers tend to focus more on traditional crops to avoid the risks associated with the production of other crops (Appendix 1). Risk aversion is negatively correlated with the production of non-traditional, riskier 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. However, our result differs from that of Bezabih and Sarr (2012), who concluded that risk aversion has a positive effect on diversification.

We find that the farmer's age and gender have no statistically significant effect on crop diversification. Similar findings were made by Benin et al. (2004) in Ethiopia. However, our results differ from those of Abay et al. (2009, Ethiopia); Mwangi et al. (2013, Kenya); Ghimire et al. (2014, Nepal), Dube et al. (2016, Zambia) and Asante et al. (2017, Ghana), all of whom found that older farmers and men are more diversified. This contradiction can be explained by the fact that the previous studies focused on the characteristics of the household head rather than the characteristics of the farmer himself, whereas the latter was the focus of our study.

The level of 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 33% 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. We found that the amount of fertilizer used per hectare and access to agricultural tools have no significant effect on crop diversification. These results differ from those of Mesfin et al. (2011) and Asante et al. (2017), both of whom found a positive effect of fertilizer usage on diversification.

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 8-58% 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 count index, the Herfindahl index measure of crop concentration and the Shannon index. The count index measures crop richness at the farm level, the Herfindahl index measures the relative abundance of crops, and the Shannon index measures both the richness and relative abundance of the crops. An OLS model was employed to analyze the effect of risk aversion on diversification when the count index was used as a dependent variable, whereas a Tobit model was used with the Herfindahl and Shannon indexes.

Our results show that the intensity of crop diversification decreases with the level of 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.

Other variables also 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 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.

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Table 1. Risk experiment

Decision	Sure thing	Gamble		CRRA
		Red	Black	
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

Table 2. Variable descriptions

Variable	Type of variable	Description
Dependent variables		
Count index	Continuous	Number of crops grown weighted by crop price ratios
Herfindahl index	Continuous	Herfindahl index measure of crop concentration weighted by inverse crop price ratios.
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
Quantity of fertilizer	Continuous	Quantity of chemical fertilizer used by the farmer in kg per ha
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
Northern region	Dummy	Farmer is in the northern region

Table 3. Descriptive Statistics

Variables	Mean	SD	min	Max
Count index	1.30	0.56	0.25	3.85
Herfindahl index	1.09	0.61	0.37	4.00
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
Quantity of fertilizer (kg/ha)	31.04	40.25	0.00	250.00
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
Northern region	0.56	0.50	0.00	1.00
Observations	668			

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

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

Variables	Coefficient	Standard Errors
Risk aversion	-0.0366*	(0.0193)
Age (in years)	-0.000269	(0.00152)
Gender (1= Female)	0.0353	(0.0575)
Household head	0.0774	(0.0505)
Primary education	0.186***	(0.0645)
Secondary or post-secondary education	0.0828	(0.0880)
Household size	-0.00725**	(0.00317)
Farm size	0.0172**	(0.00807)
Agricultural implement access index	-0.0256	(0.0231)
Quantity of fertilizer (kg/ha)	-0.000235	(0.000444)
Access to credit	0.0548	(0.0561)
Extension contact	-0.0200	(0.0191)
Land owner	0.00473	(0.0374)
Number of plots	0.327***	(0.0369)
Distance to road (mn)	0.0000163	(0.0000278)
Distance to market (mn)	0.000515***	(0.000180)
Off-farm income	-0.0213	(0.0399)
Northern region	0.408***	(0.0490)
Constant	0.560***	(0.105)
Observations	668	

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

[a] The dependent variable is the number of crops grown by the farmer. Estimation of the OLS model was conducted with robust standard errors.

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

Variables	Coefficient	P-value	CAPE[b]	P-value	APE[c]	P-value
Risk aversion***	-.0219189	0.007	-.0200732	0.006	-.0215039	0.007
Age (in years)	.0000345	0.954	.0000316	0.954	.0000338	0.954
Gender (1= Female)	.0144665	0.494	.0132484	0.493	.0141926	0.494
Household head*	.0344966	0.060	.0315918	0.059	.0338435	0.060
Primary education***	.0720227	0.002	.065958	0.002	.0706591	0.002
Secondary or post-secondary education	.0179772	0.651	.0164634	0.651	.0176368	0.651
Household size***	-.0034518	0.008	-.0031612	0.007	-.0033865	0.008
Farm size***	.0086827	0.006	.0079515	0.005	.0085183	0.005
Agricultural implement access index	-.0040315	0.671	-.0036921	0.671	-.0039552	0.671
Quantity of fertilizer (kg/ha)	-.0000527	0.791	-.0000483	0.791	-.0000517	0.791
Access to credit	.0101358	0.646	.0092823	0.646	.0099439	0.646
Extension contact	-.0112145	0.168	-.0102702	0.166	-.0110022	0.167
Land owner	.0146581	0.349	.0134238	0.348	.0143806	0.349
Number of plots***	.0778188	0.000	.071266	0.000	.0763454	0.000
Distance to road (mn)	.0000129	0.241	.0000118	0.240	.0000127	0.240
Distance to market (mn) **	.0001744	0.012	.0001597	0.011	.0001711	0.012
Off-farm income	.0000139	0.999	.0000127	0.999	.0000136	0.999
Northern region***	.1510798	0.000	.138358	0.000	.1482193	0.000
Constant	.2123379	0.000				
Observations	668					

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

[a] The dependent variable is the 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 Herfindahl index measure of crop concentration (Tobit model)[a]

Variables	Coefficient	P-value	CAPE[b]	P-value	APE[c]	P-value
Risk aversion**	.0454225	0.047	.039284	0.045	.0437289	0.046
Age (in years)	-.0000311	0.984	-.0000269	0.984	-.00003	0.984
Gender (1= Female)	-.0732138	0.220	-.0633195	0.217	-.0704839	0.219
Household head	-.0622591	0.205	-.0538452	0.206	-.0599377	0.205
Primary education***	-.1678461	0.002	-.1451629	0.002	-.1615877	0.002
Secondary and post-secondary	.0245214	0.867	.0212075	0.867	.023607	0.867
Household size ***	.0126536	0.002	.0109435	0.002	.0121817	0.002
Farm size (ha)***	-.0306957	0.004	-.0265474	0.003	-.0295512	0.003
Agricultural implement access index	.0369072	0.255	.0319195	0.253	.0355311	0.254
Quantity of fertilizer (kg/ha)	.0002921	0.691	.0002526	0.691	.0002812	0.691
Access to credit	-.0350895	0.599	-.0303474	0.599	-.0337811	0.598
Extension contact *	.0487871	0.055	.0421939	0.053	.046968	0.054
Land owner	-.0477113	0.336	-.0412634	0.334	-.0459323	0.335
Number of plots ***	-.0836652	0.009	-.0723584	0.009	-.0805456	0.009
Distance to road (mn)	-.0000137	0.680	-.0000119	0.679	-.0000132	0.679
Distance to market (mn) ***	-.0006064	0.001	-.0005245	0.000	-.0005838	0.000
Off-farm income	.0476259	0.299	.0411896	0.297	.0458501	0.298
Northern region ***	-.5379694	0.000	-.4652666	0.000	-.5179103	0.000
Constant	1.55172	0.000				
Observations	668					

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

[a] The dependent variable is the Herfindahl diversity 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 $E_{Xk}\left[\frac{\partial E(y|x)}{\partial x_k}\right]$.

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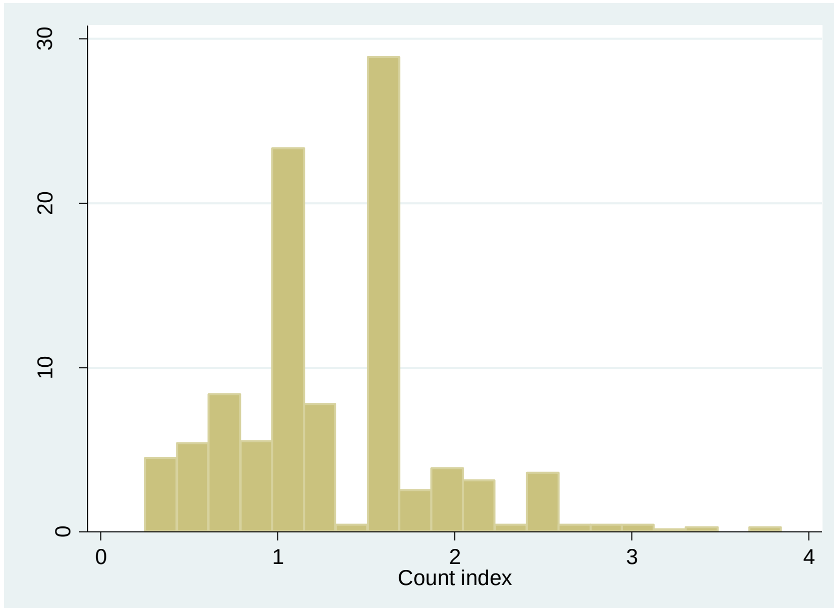

Figure 1. Distribution of count index of crop diversification

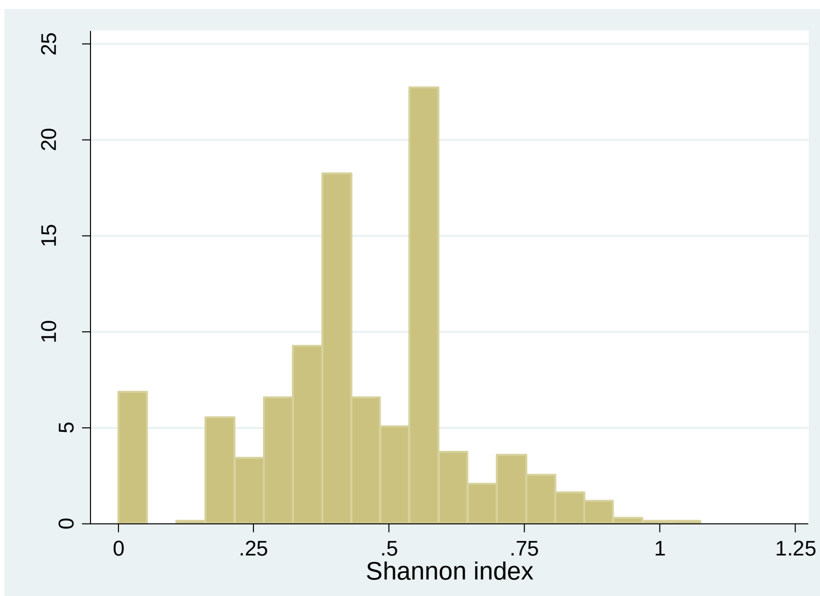

Figure 2. Distribution of Shannon index of crop diversification

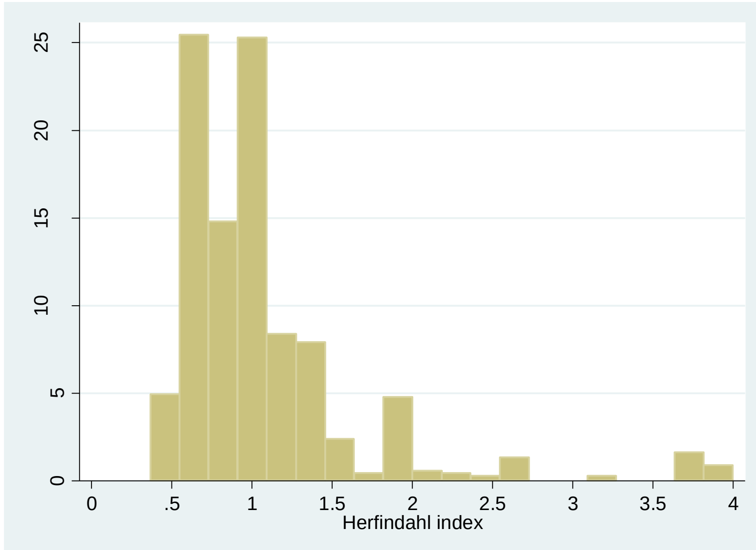

Figure 3. Distribution of Herfindahl index of crop diversification

Appendix 1. Effect of risk aversion on the incidence of crop diversification (Probit Model)[a]

Variables	Coeff	P-value	dydx[b]	P-value
Risk aversion***	-.1384335	0.008	-.0450452	0.007
Age (in years)	-.0041896	0.366	-.0013633	0.366
Gender (1= Female)	.1502786	0.367	.0488994	0.367
Household head	.163208	0.270	.0531066	0.269
Primary education**	.5039077	0.020	.1639676	0.018
Secondary or post-secondary education**	.5902697	0.021	.1920691	0.019
Household size*	-.0151708	0.098	-.0049365	0.096
Farm size	.0074918	0.747	.0024378	0.747
Agricultural implement access index***	-.2721916	0.000	-.088569	0.000
Quantity of fertilizer (kg/ha)	-.0000313	0.982	-.0000102	0.982
Access to credit**	.3473319	0.024	.113019	0.023
Extension contact	-.0403215	0.440	-.0131203	0.440
Land owner	-.0056991	0.962	-.0018544	0.962
Number of plots***	.6085589	0.000	.1980202	0.000
Distance to road (mn) *	-.0001411	0.063	-.0000459	0.061
Distance to market (mn) *	.0009823	0.080	.0003196	0.078
Off-farm income	.0109543	0.925	.0035644	0.925
Northern region***	-1.27379	0.000	-.4144811	0.000
Constant	.00316	0.991		
Observations	668			

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

[a] The dependent variable is the incidence of 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 $E_{Xk}\left[\frac{\partial E(y|x)}{\partial x_k}\right]$.