Risk Aversion, Crop Diversity and Food Security

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Abstract

Does cultivating one crop secure more food than cultivating five crops for smallholder farmers in developing countries? How do farmers’ risk aversion affect crop diversification and food security choices at the household level? The effect of risk preference on crop diversification has been widely studied. It is unclear, however, how risk aversion, crop diversity, and food security are linked in a causal chain. This article investigates (i) the effect of crop diversification on food security and (ii) the direct effect of risk aversion on food security without a bias from crop diversification. Using the causal chain empirical strategy (Acharya et al., 2016), I estimate the direct effect of risk aversion, so-called the controlled direct effect. From our unique experimental data collected in rural Ethiopia, our result shows there exist (i) a negative effect of crop diversification on household food security and (ii) a positive direct effect of household head risk aversion on household food security. The contribution of this article consists of two parts. First, it develops the first theoretical framework to show the causal chains of risk aversion, crop diversity, and food security by adapting Sandmo’s (1971) model. Second, this article provides the original evidence that crop diversity decreases food security. The contribution of our paper provides agricultural development policy implications related to crop diversification programs for rural smallholder farmers in developing countries.

Keywords: food security; risk; uncertainty; crop diversification; causal chains; controlled direct effect; Ethiopia
1. INTRODUCTION

Food security of rural farmers in developing countries is essential for sustainable development. Agricultural productivity has been dramatically increased over last decades in developing countries. There are, however, over one billion people still live under poverty line spending less than $1.25 a day. Although most of developing countries has been urbanized since 1970’s leading the urban poor, over seventy-five percent of the world’s poor population live in rural areas depending on agriculture production as their primary source of livelihoods (citations). A large amount of literature has attempted to improve food security in multi-dimensional approaches such as trade, institutions, nutrition, or technology adoption that have less focused on farming practices by smallholder farmers.

Crop diversification refers the farmers’ practice of producing more than one variety of crops in a given land area in the form of rotations or intercropping. Not only for agrobiological advantages but also for agricultural economics, crop diversification is considered an option for managing uncertainties in agricultural practices (Culas and Mahendrarajah, 2005). In production, farmers make crop decision considering the trade-off between specialization in a staple crop to insure and crop diversification with a mixed set of staple and cash crops that bring a large expected return along with higher risk. In this context of rural development, crop diversification has been shed light on to analyze the relationship between farmers’ risk aversion and adoption of crop diversity (DiFalco et al. 2007; Warnick et al. 2008; Difalco and Chavas 2009; Liu 2011). Given that food security is the critical challenge of rural development, it is not, however, clear if crop diversification secures more food security of the poor rural smallholders. Moreover, the

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1 In agrobiology, crop diversification is improving soil fertility (Lin, 2011) and reducing pests (Truscott et al., 2009).
relationship between farmers’ risk attitude, crop diversification, and food security is not investigated in both theory and empirical studies.

This paper addresses the two research questions: (i) Do more diverse cropping choices increase food security? and (ii) Do more risk-averse households secure more food? Similar studies have analysed the relationship between risk aversion and welfare, but this paper examines the causal chain between risk aversion, crop diversification, and food security to answer the research questions.

These research questions are important in estimation because crop diversification might participate in a causal chain for the effect of risk aversion on food security as a mediator. Also, the causal relationship between risk aversion and food security has received little attention. Several developing country studies have shown that food security is positively correlated with food assistance programs, adaptation to climate change, and contract farming (Barrett, Reardon, and Webb 2001; Di Falco, Veronesi, and Yesf 2011; Bellemare and Novak 2016). However, farmers’ crop risk aversion as a treatment to reduce household food insecurity is less researched.

Unfortunately, the effect of one’s risk aversion to his alternatives on his outcomes is puzzling. First, measuring risk aversion is controversial in behavioural economics and it is not feasible in many cases. Second, there might be some hidden mediators in the causal chain between a farmer’s risk aversion and observed crop choices. That is why it is difficult to show the direct causal effect of risk aversion on our interest. Following Acharya et al. (2016), our article proposes and identifies a causal chain in order to measure the direct effect of risk aversion to food security. This causal chain approach permits the identification of the direct effect of risk aversion on food security without a bias through crop diversification.
The contribution of this article consists of two parts. First, it develops the first theoretical framework to show the causal chains of risk aversion, crop diversity, and food security. Second, this article provides the original evidence that crop diversity decreases food security at household level. The contribution of this article provides agricultural development policy implications related to crop diversification programs for rural smallholder farmers in developing countries.

The remainder of this paper is organized as follows. In Section 2, I develop the theoretical framework to present two testable predictions. Section 3 provides the empirical framework that discusses the identification and implementation strategy as well as measures of food security and crop diversification. Section 4, I describe the data with descriptive statistics. Finally, I summarize nonparametric and core results in Section 5. Robustness checks and potential limitations are also presented. Section 6 gives the conclusion of this study with policy implications.
2. Theoretical Framework

In this section, I adapt the theory of the competitive firm under price uncertainty (Sandmo, 1971) and incorporate crop diversification decision making with a goal of motivating and structuring the empirical analysis.

Primitives and Assumptions

In the context of production under uncertainty, a household is a producer and the vector of consumption goods of interest as profit in alternative states. If the producer’s preferences for profit in alternative states satisfy rationality, nonsatiation, monotonicity, and continuity, then a real value utility function can be derived to characterize these preferences.

Suppose that a household maximizes a von Neumann-Morgenstern utility function defined over profit \( r \). Let \( W(r) \) represent the producer’s utility of profit in different states. The utility function \( W(\cdot) \) is twice continuously differentiable and preferences are monotonic such that

\[
\frac{\partial W}{\partial r_s} \geq 0 \text{ for all state } s = 1, \ldots, S \text{ (i.e., more profit never decreases the producer's utility).}
\]

Also, I assume preferences are strictly convex, so we are guaranteed to have a unique solution to our maximization problem. Thus, the utility function \( W(\cdot) \) will have the same properties as the utility function used in general consumer theory.

Adapting a stochastic production function under uncertainty introduced by Just-Pope (1979), the profit function is defined as \( r(d, \epsilon) = f(d) + h(d)\epsilon \) where \( f \) is a mean profit function and \( h \) is a state-dependent profit function with respect to crop diversity \( d \) such that \( d \geq 0 \) and \( E(\epsilon) = 0 \) and \( E(\epsilon^2) = 1 \).

We define the stochastic production function as
\[ r_5(d) = r(d, \varepsilon_s) \text{ where } f'(d) < 0, h'(d) < 0, \varepsilon_{s+1} > \varepsilon_s \text{ for all } s, \]

and \( r(d) = (r_1(d), ..., r_5(d)) \)

**Maximization Problem and Testable Prediction**

The household’s maximization problem is the following:

\[
\max_d \quad EW(r(d)) \\
\text{subject to } d \geq 0
\]

Suppose a household is a risk-averse producer and a crop-diversity decision maker. Two testable hypotheses (Proposition I and II) on production risk aversion and crop diversification are derived based on the expected utility theorem and Sandmo’s model (1971).

**Proposition I. If crop diversity increases, the producer’s expected utility decreases.**

**Proof.**

Take the derivative of \( W \) with respect to \( d \)

\[
\frac{dW}{dd} = \frac{dW}{dr} \cdot \frac{dr(d, \varepsilon)}{\partial d} = \frac{dW(r)}{dr} \sum_{s=1}^{s} (f'(d) + h'(d)\varepsilon_s)
\]

\[
= \frac{dW(r)}{dr} [Sf'(d) + h'(d) \sum_{s=1}^{s} \varepsilon_s] < 0
\]
Since we have $f' < 0$, $E[\varepsilon] = 0$, and $W' > 0$, the last expression is less than 0 (i.e., $\frac{dW}{dd} < 0$).

Thus, the producer’s expected utility decreases as the crop diversity increases. ■

**Proposition II.** If the producer is more risk averse, then the producer will less diverse crops and the expected utility will increase.

**Proof.**

Let crop diversity ($d$) be a function of Arrow Pratt absolute risk aversion parameter ($\alpha$) (i.e., $d = d(\alpha)$). The household’s maximization problem is

$$\max_d EW(r(d))$$

The first-order necessary condition is

$$\text{w.r.t. } d: \sum_{s=1}^{S}(f'(d^*) + h'(d^*)\varepsilon_s) \frac{\partial W(r(d^*),\alpha)}{\partial r_s} = 0$$

By totally differentiating with respect to $d^*$ and $\alpha$,

$$\frac{dd^*}{d\alpha} = -\frac{\sum_{s=1}^{S}(f'(d^*) + h'(d^*)\varepsilon_s) \frac{\partial^2 W(r(d^*),\alpha)}{\partial r_s \partial \alpha}}{\sum_{s=1}^{S}[(f'(d^*) + h'(d^*)\varepsilon_s) \frac{\partial W(r(d^*),\alpha)}{\partial r_s} + (f'(d^*) + h'(d^*)\varepsilon_s) \frac{\partial^2 W(r(d^*),\alpha)}{(\partial r_s)^2}]}$$

Assuming the second order condition holds, the denominator in equation (1) is negative. Thus, the sign of $\frac{dd^*}{d\alpha}$ will depend on the sign of the numerator.

We will define $\varphi_s(r) = -\frac{\partial^2 W(r,\alpha)}{\partial r_s \partial \alpha} \frac{\partial W(r,\alpha)}{\partial r_s}$ and consider three distinct cases:
Case (i) \( \varphi_s(r) = \varphi(r) \) for all \( s = 1, \ldots, S \) and \( \alpha \).

Case (ii) \( \varphi_{s+1}(r) \geq \varphi_s(r) \) for all \( s = 1, \ldots, S - 1 \) and \( \alpha \).

Case (iii) \( \varphi_{s+1}(r) \leq \varphi_s(r) \) for all \( s = 1, \ldots, S - 1 \) and \( \alpha \).

For case (i): Since \( \varphi(r) \) is independent of the state, the numerator of (1) is

\[
-\varphi(r(d^*)) \sum_{s=1}^{S} (f'(d^*) + h'(d^*) \varepsilon_s) \frac{\partial W(r(d^*), \alpha)}{\partial r_s} = 0
\]

by the first order condition. Thus, if \( \varphi_s(r) \) are equalized for all \( s \), then the Arrow-Pratt absolute risk aversion has no effect on crop diversification (i.e., \( \varphi^*_s = 0 \)).

For case (ii): From equation first note that \( \frac{\partial r(d, \varepsilon)}{\partial \varepsilon} = h(d) > 0 \) since \( r(d, \varepsilon) = f(d) + h(d) \varepsilon \).

Define \( r^0 = r(d, \varepsilon^0) \) where \( f'(d^*) + h'(d^*) \varepsilon^0 = 0 \). Also note that there exists a \( \varphi^0 \in \mathbb{R} \) such that \( \varphi_s(d^*) \geq \varphi^0 \) when \( r(d^*, \varepsilon_s) \geq r^0 \) and \( \varphi_s(d^*) \leq \varphi^0 \) when \( r(d^*, \varepsilon_s) \leq r^0 \). For \( \varepsilon_s \geq \varepsilon^0 \), \( f'(d^*) + h'(d^*) \varepsilon_s \leq 0 \) and \( r_s(d^*) = r(d^*, \varepsilon_s) \geq r^0 \).

For \( \varepsilon_s \leq \varepsilon^0 \), \( f'(d^*) + h'(d^*) \varepsilon_s \geq 0 \) and \( r_s(d^*) = r(d^*, \varepsilon_s) \leq r^0 \)

(2) \( \varphi_s(d^*) \geq \varphi^0 \).

Multiplying both sides of equation (2) by \( (f'(d^*) + h'(d^*) \varepsilon_s) \frac{\partial W(r(d^*), \alpha)}{\partial r_s} \) \( \leq 0 \) then yields

(3) \( (f'(d^*) + h'(d^*) \varepsilon_s) \frac{\partial W(r(d^*), \alpha)}{\partial r_s} \varphi_s(d^*) \leq (f'(d^*) + h'(d^*) \varepsilon_s) \frac{\partial W(r(d^*), \alpha)}{\partial r_s} \varphi^0 \) or

(4) \( - (f'(d^*) + h'(d^*) \varepsilon_s) \frac{\partial^2 W(r, \alpha)}{\partial r_s \partial \alpha} \leq (f'(d^*) + h'(d^*) \varepsilon_s) \frac{\partial W(r(d^*), \alpha)}{\partial r_s} \varphi^0 \).

For \( \varepsilon_s \leq \varepsilon^0 \), \( f'(d^*) + h'(d^*) \varepsilon_s \geq 0 \) and \( r_s(d^*) = r(d^*, \varepsilon_s) \leq r^0 \)

(5) \( \varphi_s(d^*) \leq \varphi^0 \).
Multiplying both sides of equation (5) by \((f'(d^*) + h'(d^*))\varepsilon_s\) \(\frac{\partial W(r(d^*),\alpha)}{\partial r_s}\) \(\geq 0\) then yields

\[
(f'(d^*) + h'(d^*))\varepsilon_s \frac{\partial W(r(d^*),\alpha)}{\partial r_s} \varphi_s(d^*) \leq (f'(d^*) + h'(d^*))\varepsilon_s \frac{\partial W(r(d^*),\alpha)}{\partial r_s} \varphi^0 \]  

or

\[
-(f'(d^*) + h'(d^*))\varepsilon_s \frac{\partial^2 W(r,\alpha)}{\partial r_s \partial \alpha} \leq (f'(d^*) + h'(d^*))\varepsilon_s \frac{\partial W(r(d^*),\alpha)}{\partial r_s} \varphi^0.
\]

Equations (4) and (7) are identical for all \(s\), so summing implies

\[
-\sum_{s=1}^{S}(f'(d^*) + h'(d^*))\varepsilon_s \frac{\partial^2 W(r,\alpha)}{\partial r_s \partial \alpha} \leq \varphi^0 \sum_{s=1}^{S}(f'(d^*) + h'(d^*))\varepsilon_s \frac{\partial W(r(d^*),\alpha)}{\partial r_s} = 0 \quad \text{or}
\]

\[
\sum_{s=1}^{S}(f'(d^*) + h'(d^*))\varepsilon_s \frac{\partial^2 W(r,\alpha)}{\partial r_s \partial \alpha} \geq \varphi^0.
\]

Equations (1) and (8) then imply \(\frac{dd^*}{d\alpha} \geq 0\). Thus, if the Arrow-Pratt absolute risk aversion increases, then the crop diversification increases. Also, by the proposition I, if the Arrow-Pratt absolute risk aversion increases, the producer’s expected utility will increase.

Assuming CARA, we have

\[
W(r(d)) = \sum_{s=1}^{S} p_s (1 - e^{-\alpha r_s})
\]

\[
u(r) = 1 - e^{-\alpha}
\]

\[
\frac{-u''(r)}{u'(r)} = -\frac{\alpha^2 e^{-\alpha r}}{\alpha z^{-\alpha r}} = \alpha
\]

\[
\varphi_s(r) = -\frac{e^{-\alpha r_s} - r_s \alpha e^{-\alpha r_s}}{\alpha e^{-\alpha r_s}} = -\frac{1}{\alpha} + r_s
\]

For case (iii): Similar to case (ii).
3. EMPIRICAL FRAMEWORK

This section investigates estimation and identification strategy to map from the two testable hypotheses (Proposition I and II) to the empirical framework separately.

3.1 The Effect of Crop Diversification on Food Security

The first testable hypothesis concerns the impact of household-level crop diversification on food security. The following linear regression with household fixed effect is estimated to analyse the relationship between crop diversification and food security.

\[ Food\ Security_{it} = \beta_0 + \beta_1 Crop\ Diversification_{it} + \beta_2 X_{it} + \theta_t + u_{it} \]

where \( Food\ Security_{it} \) is the level of household food security and \( Crop\ Diversification_{it} \) is an index of crop diversification for a household \( i \) in year \( t \). \( X_{it} \) is a vector of time-varying household-level control variables including demographic characteristics (household size, household head education, dependency ratio, the number of children) and economic condition (assets, income, land holdings). Control variables are selected to control for observables that might affect the household food security, widely used in food security context (Bellmare and Novak, 2016). To control for unobserved heterogeneity within household, I use household fixed effects (\( \theta_t \)). \( u_{it} \) represents an error term. Given that the residuals and the regressors are both correlated within villages, I cluster at village level to correct standard errors (Abadie et al., 2017).
Food Security

The concept of food security is a theoretical construct (Maxwell et al., 2017). In the literature, food security has been approached in three perspectives: availability, access, and utilization (Barrett, 2010). Food availability is not sufficient to ensure food access. Commonly, food availability can be ensured by advances in agricultural production. Food accessibility and utilization are, however, more related to the demand side of food security such as nutritious food, dietary quality, or sanitary of individual or household. (Webb et al., 2006). Thus, food security is required to be measured in multidimensional perspectives in empirical work. Measuring food security considering nutritional abundance and frequency can be done in several ways, each with its own specific aims looking at consumption from different angles, and with different strengths and weaknesses (ODAV-WFP, 2008).  

In this study, I adopt Food Consumption Score (FCS) to measure food security of an individual household because it enables to capture both nutrition intake and frequency. FCS is a score indicator merging dietary diversity, food frequency, and relative nutritional importance of different food groups calculated based on the frequency of consumption of different food groups consumed by anyone in the household over the past week before survey (ODAV-WFP 2008). The food groups are categorized: (i) meats and fish, (2) dairy products, (3) pulses, (4) staple, (5) fruit, (6) vegetables, (7) sugars, and (8) oils/fats in the order by high weight. In this study, I modified FCS as excluding two groups of food, sugar and oils/fats, due to the lack of data. Table 3 describes food group (\(i\)) and imposed weight (\(w_j\)) with justification. FCS is measured as

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2 In humanitarian emergencies and development context, four measurements are often used: FCS, HDDS, rCSI, and HHS (Maxwell et al., 2017).
3 The FCS is weighted based on World Food Program(WFP)’s perception of nutrient density (ODAV-WFP, 2008).
where \( d_j \) is the days of consumption of food group \( j \) per week and \( w_j \) is the weight of food group \( j \) for all \( j = 1, \ldots, 6 \). The FCS is between 0 to 105. Based on World Food Programme (WFP) internal decision-making, household level food security is considered: acceptable if FCS > 35; borderline if \( 21 \leq \text{FCS} \leq 35 \); poor if FCS < 21.

### Table 1. Food Security Measure: Food Consumption Scores (FCS) (ODAV-WFP 2008)

<table>
<thead>
<tr>
<th>Food Group (( j ))</th>
<th>Weight (( w_j ))</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Meats and Fish</td>
<td>4</td>
<td>Highest quality protein, easily absorbable micronutrients (no phytates), energy dense, fat. Even when consumed in small quantities, improvements to the quality of diet are large.</td>
</tr>
<tr>
<td>2. Dairy Products</td>
<td>4</td>
<td>Highest quality protein, micro-nutrients, vitamin A, energy. However, milk could be consumed only in very small amounts and should then be treated as condiment and therefore re-classification in such cases is needed.</td>
</tr>
<tr>
<td>3. Pulses</td>
<td>3</td>
<td>Energy dense, high amounts of protein but of lower quality (PER less) than meats, micro-nutrients (inhibited by phytates), low fat.</td>
</tr>
<tr>
<td>4. Staple</td>
<td>2</td>
<td>Energy dense/usually eaten in larger quantities, protein content lower and poorer quality than legumes, micro-nutrients.</td>
</tr>
<tr>
<td>5. Fruit</td>
<td>1</td>
<td>Low energy, low protein, no fat, micro-nutrients</td>
</tr>
<tr>
<td>6. Vegetable</td>
<td>1</td>
<td>Low energy, low protein, no fat, micro-nutrients</td>
</tr>
</tbody>
</table>
Crop Diversification

In the literature of agricultural economics, the term of crop diversification represents the management of farm risk incorporating production, marketing, financial environmental responses (Culas and Mahendrarajah, 2005). By the nature of crop diversification concept, various measures of crop diversification have been developed depending on the purpose of studies (Clarke, 1993). In early studies, the incidence of diversification is an elementary approach of crop diversification. Dercon (1996) uses the proportion of inputs allocated to the risky crop while more advanced measures incorporate non-farm sources of income as well as farm production (Culas and Mahendrarajah 2005). This study, however, excludes income variables to measure crop diversification because of high self-subsistence rate in our sample and the potential measurement error in income that is often considered when using data from developing countries. Instead, I use Herfindahl-Hirschman Index (HHI) as measures of crop diversification to represent relative land sizes of farming activities operated in by a given a farm, widely used in crop diversification literature (Magurran, 1988; Malik et al., 2002; Abey et al., 2009; Mukherjee, 2010; Sichoongwe et. al, 2014).

For an individual farm household \(i\), \(HHI_i\) is computed:

\[
HHI_i = 1 - \sum_{k_i} (A_{k_i})^2
\]

where \(k_i = 1, \ldots, K_i\) is crops cultivated by household \(i\) and \(A_{k_i}\) is the share of each crop defined as

\[
A_{k_i} = \frac{L_{k_i}}{\sum_k L_{k_i}}
\]

\(^4\) In the literature of agricultural science, crop diversification (or diversity) generally refers biodiversity or biological diversity to describe the observable variation in a particular plant feature within crop population of the same species (Smale, Bellon, and Pingali, 1998). In this study, crop diversification does not represent biological diversity.
where $L_{k_i}$ is the utilized land area (hectare) for crop $k_i$.\textsuperscript{5}

HHI weights to the farm’s major crops while it is less sensitive to minor secondary crops. HHI takes the value of zero when a farm is completely specialized in one primary crop and should approach one as the variety of crops becomes diverse.

**Endogeneity Issues**

(i) **Measurement Errors**

The measure of food consumption score (FCS) – the popular measure of household food security in empirical works– used as the dependent variable is a proxy for actual household food security. The measure is computed based on household head’s reporting of the household food consumption. It is unlikely to have motivations to misreport the household food consumption because the survey was originally constructed in the purpose of water research\textsuperscript{6} rather than any programs related to possible food aid. Also, any systematic under- or over-reporting of the food consumption was not observed. See Figure 1 in appendix.

The measure of crop diversification might be another concern on measurement error. Given that the harvested quantity of all crops is zero in 46 households out of the 400 total observations, I exclude 46 non-farm households because the population of this study is farm households in developing countries.\textsuperscript{7} Any outliers is not observed in the distribution of varieties of crop, thus no observation is dropped among the rest of 354. See Figure 2 in appendix.

\textsuperscript{5} Depending on literature, HHI is often defined $\sum k_i(A_{k_i})^2$. In this study, I used the modified HHI defined by Malik et al. (2002).

\textsuperscript{6} The motivation of the survey I used in this study is related to water quality and community public health in developing countries (See: sites.duke.edu/ethiopiawaterquality)

\textsuperscript{7} I drop 46 households whose plot size and the volume of cultivated crops are all recorded in 0.
Finally, control variables might induce measurement errors as well. Especially, many households have a reported income or asset of zero. Given that I use the logarithms of income and asset as the control variables, I replace zero values of income and asset with one before taking the natural logarithm function not to lose the observations whose income or asset is equal to zero. There is no single household that takes the values less than 1, and thus all households have the non-negative logarithm income or assets. For the other control variables such as household size, the number of dependents, and household head education level, no systematic under- or over-reporting was founded.

(ii) Reverse Causality

It is possible that, smallholder farmers diverse crops as they secure more food. If this is the case, reverse causality might need to be concerned in the linear regression. In Ethiopia, there are two rainy seasons so called the Meher and the Belg. During the Meher season, over 95 percent primary crops are sowing and seedling in September and harvested in February (IFPRI, 2011). This implies crop-decision making of smallholder farmers mostly occurs near September. The survey is conducted during the month of February in 2013 and 2014 immediately after post-harvest. Households were asked to recall events from the 12 months prior to the survey and in food consumption questions, it asks how many days per week a household consume primary foods on average. Thus, it is unlikely that smallholder households consume food before they choose what to seed and cultivate. It might be possible that households buy and consume food in the retail markets before they begin seeding in September expending their net income. It is, however, hard to think because over 80 percent of households focus on growing food to feed themselves (i.e., self-subsistence farming) in the data that represents they are not grow cash
crops. Also, limited accessibility to commodity markets in rural Ethiopia might disable households to buy food in the months prior to seeding.

(iii) Unobserved Heterogeneity

Another source of statistical endogeneity is unobserved heterogeneity or omitted variables. To eliminate time-invariant unobserved confounders, I use time-invariant household fixed effects. It enables to control for household-specific economic conditions such as production, labor allocation, or input market accessibility. In addition, time-invariant household-specific characteristics, for instance preferences, ratio of gender, or food-consumption routine, is also controlled.

3.2 The Effect of Risk Aversion on Food Security

The second testable prediction described in Proposition II concerns the effect of risk aversion on food security. While this analysis can be also conducted by linear regression with household fixed effect, it might lead to biased and inconsistent estimates because crop diversification plays a role as a mediator between risk aversion and food security. To eliminate the bias by crop diversification, I adapt the identification strategies developed by Acharya et al. (2016). The primary advantage of the method is it allows me to estimate the unbiased average controlled direct effect (ACDE) of a treatment on outcome. In this study, ACDE represents the causal effect of risk aversion on food security when the crop diversification is already taken into account.

Identification

The direct effect is estimated as the controlled direct effect (CDE) of the treatment (risk aversion), which is the direct effect of the treatment when a mediator (crop diversification) is the
same fixed value for all households. By subtracting the average controlled direct effect (ACDE) from the average total effect (i.e. average treatment effect, ATE), the average natural indirect effect (ANIE) through crop diversification is estimated. The ANIE measures the impact of the mediator on how the treatment affects the outcome through a mediator. This is a featured empirical strategy because ANIE is not solely parametrically identified, while ATE and ACDE are identified.\(^8\)

For an individual household, \(i\), let \(R_i\) be the treatment of interest, taking values \(r \in \mathcal{R}\), where \(\mathcal{R}\) is the set of possible treatment values. I define \(D_i\) as the mediator, taking values \(d \in \mathcal{D}\) assuming both \(R_i\) and \(D_i\) are continuous. In our context, \(R_i\) represents risk aversion of a household head and \(M_i\) represents a level of crop diversification at a household level. Two sets of covariates are defined for \(i\): pre-treatment confounders \((X^{pre}_i)\) and intermediate confounders \((X^{int}_i)\). \(X^{pre}_i\) are variables that affect the treatment, and possibly the mediator \((D_i)\) and outcome as well. For instance, socio-economic control variables such as household size, dependency ratio, or household assets are pre-treatment confounders.\(^9\) \(X^{int}_i\) are consequences of the treatment that also affect the mediator and outcome.

Let \(Y_i\) be the outcome variable of food security for a household \(i\) and \(Y_i(r)\) be its potential outcome. Given that we observed a household head’s risk aversion \((R_i)\), we have an observed outcome of \(Y_i(R_i)\). Food security \((Y_i)\) is a function of risk aversion \((r)\) and crop diversification \((d)\) while crop diversification is a function of risk aversion. Thus, for a household \(i\), we have

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\(^8\) Note that ATE and ACDE is parametrically identified under two assumptions: Sequential Unconfoundedness and No Intermediate Interactions (Acharya et al., 2016).

\(^9\) Citation will be added.
\[ Y_i = Y_i(r, d) \]
\[ D_i = D_i(r) \]
and \[ Y_i = Y_i(r, D_i(r)) \]

I then define the average treatment effect (ATE), the average controlled direct effects (ACDE), and the average natural indirect effects (ANIE) as below:

\[
ATE(r, r') = E[Y_i(r) - Y_i(r')] \\
ACDE(r, r', d) = E[Y_i(r, d) - Y_i(r', d)] \\
ANIE_i(r, r') = E[Y_i(r, D_i(r)) - Y_i(r, D_i(r'))]
\]

The average treatment effect is the difference in average between two potential outcomes \(Y_i(r)\) and \(Y_i(r')\). This represents the average treatment effect of risk aversion on food security if we were to change risk aversion from \(r\) to \(r'\) in all households. The average controlled direct effects (ACDE) is the direct effect with the mediator fixed at some value, \(d\), for all households in the population. In our study, this quantity of interest represents the effect of changing risk aversion if I were to fix the level of crop diversification at some level \((m)\). The natural direct effect (ANIE) represents the effect of risk aversion on food security induced only through crop diversification \((D_i(r))\). Figure 1 visualizes the causal chains that we discussed above. The solid lines represent the average total effects (ATE) while the dashes lines only represent the average controlled direct effects (ACDE) of risk aversion not through the crop diversification in the population.
By VanderWeele (2014) and VanderWeele and TchetgenTchetgen (2014), the average total effect (ATE) can be decomposed from the overall effect into the direct effect, indirect effect, and interaction term as:

\[
ATE(r, r') = E[Y_i(r) - Y_i(r')] \\
= E[Y_i(r, d) - Y_i(r', d)] + E[Y_i(r, D_i(r)) - Y_i(r, D_i(r'))] \\
+ E[D_i(r')[CDE_i(r, r', 1) - CDE_i(r, r', 0)]] \\
= ACDE(r, r', 0) + ANIE(r, r') + E[D_i(r')[CDE_i(r, r', 1) - CDE_i(r, r', 0)]]
\]

where the last term in the final equation \(E[D_i(r')[CDE_i(r, r', 1) - CDE_i(r, r', 0)]]\) represents the interaction. Under the constant interactions assumption and the identification assumption\(^\text{10}\), the term of interaction effect is 0, and thus the average natural indirect effect (ANIE) can be

\(^{10}\) Identification assumption includes sequential unconfoundedness and no intermediate interactions (Acharya et. al. 2016).
measured in the difference between the average total effect (ATE) and the average controlled
direct effect (ACDE) (Imai and Yamamoto 2013; Acharya et al. (2016)). As a result, the average
natural indirect effect (ANID) will supply information on how strongly crop diversification plays
a role as a mediator in a causal chain for the effect of risk aversion to food security.

In order to identify ACDE, two assumptions are required (Acharya et al. 2016):

Assumption 1. Sequential Unconfoundedness

\[
\{Y_i(r, d), D_i(r)\} \parallel R_i | X_i^{pre} = x^{pre}
\]

\[
\{Y_i(r, d) \parallel D_i\} | R_i = r, X_i^{pre} = x^{pre}, X_i^{int} = x^{int}
\]

for all possible treatment values \( r \in R \), mediator values \( d \in D \), and covariate values \( x^{pre} \in X \) and \( z \in Z \). In addition, I assume for all the above values:

\[
P(R_i = r | X_i^{pre} = x^{pre}) > 0
\]

\[
P(D_i = d | R_i = r, X_i^{pre} = x, X_i^{int} = x^{int}) > 0
\]

Thus, the ACDE is non-parametrically identified under sequential unconfoundedness (Robins,
1997)

Assumption 2. No Intermediate Interactions

\[
E[Y_i(r, d) - Y_i(r, d') | X_i^{pre} = x^{pre}, R_i = r, X_i^{int} = x^{int}]
\]

\[
= E[Y_i(r, m) - Y_i(r, d') | X_i^{pre} = x^{pre}, R_i = r]
\]
for all values $r \in \mathcal{R}, d, d' \in \mathcal{D}$, and $x^{pre} \in \mathcal{X}$. No intermediate interactions assumption serves to make estimation simpler similar to omitting an interaction term from a regression model.

Acharya et al (2016) define the demediation function:

$$
\gamma(r, d, x^{pre}) = E[Y_i(r, d) - Y_i(r, 0)|X_i^{pre} = x]
$$

I subtract the demediation function from observed outcome (food security) which removes the variation in the outcome due to the causal effect of the mediator (crop diversification):

$$
E[Y_i - \gamma(r, d, x^{pre})|R_i = r, X_i = x] = E[Y_i(r, 0)|X_i^{pre} = x]
$$

The ACDE conditional on $X_i^{pre}$,

$$
E[Y_i(r, 0) - Y_i(0, 0)|X_i^{pre} = x]
$$

is non-parametrically identified as difference in means of the demediated outcome:

$$
E[Y_i - \gamma(r, D_i, x^{pre})|R_i = r, X_i^{pre} = x^{pre}] - E[Y_i - \gamma(0, D_i, x^{pre})|R_i = 0, X_i^{pre} = x^{pre}]
$$

By sequential unconfoundedness, the demediation function is nonparametrically identified as equal to the difference-in-means estimator conditional on causal variables (treatment, mediator, pre-and-posttreatments variables) (Robins, 1994):

$$
\hat{\gamma}(r, d, x^{pre}) = \hat{E}[Y_i|R_i = r, D_i = d, X_i^{pre} = x, X_i^{int} = x^{int}] - \hat{E}[Y_i|R_i = r, D_i = 0, X_i^{pre} = x^{pre}, X_i^{int} = x^{int}]
$$

As a result, the average conditional direct effect of risk aversion to food security, not through crop diversification, can be nonparametrically identified using the estimable demediation function since the identification of the ACDE as holds when replacing $\gamma$ with its estimate. Furthermore, by subtracting identified ACDE from ATE, ANIE is also identified representing the causal indirect effect of risk aversion on food security through crop diversification.
Implementation

This paper implements g-estimation rather than the differences-in-means to estimate ACDE because our treatment of risk aversion is continuous and parametric models help estimate ACDE avoiding instability and high variability issues (Vansteelandt, 2009). I follow the two steps to run the g-estimation to have parametrical identification: estimating the sample version of the demediation function and regressing ACDE using it. First, the baseline regression model with interactions between the mediator and treatment and the pretreatment confounders:

\[
E[Y_i|R_i, D_i, X_i^{pre}, X_i^{int}] = \alpha_0 + \alpha_1 R_i + \alpha_2 D_i + X_i^{preT} \alpha_3 + Z_i^T \alpha_4 + \alpha_5 D_i R_i + \alpha_6 D_i X_i^{pre}
\]

Then, the sample version of the demediation function can be calculated \(^{11}\):

\[
\hat{\gamma}(R_i, D_i, X_i^{pre}; \hat{\alpha}) = \hat{\alpha}_2 D_i + \hat{\alpha}_5 D_i R_i + \hat{\alpha}_6 D_i X_i^{pre}
\]

Secondly, I demediate the outcome,

\[
\bar{Y}_i = Y_i - \hat{\gamma}(R_i, D_i, X_i^{pre}; \hat{\alpha})
\]

From the result above, I can estimate the ACDE of treatment by regressing this demediated outcome on the treatment (risk aversion) and the pretreatment confounders,

\[
E[\bar{Y}_i|R_i, X_i^{pre}] = \beta_0 + \beta_1 R_i + X_i^{preT} \beta_2
\]

where the least squares estimator \( \beta_1 \) is the consistent estimate of ACDE.

---

\(^{11}\) See Archarya et al. (2016) for derivation of the demediation function (page 10).
In our analysis, pretreatment confounders vector $X_i$ consists of all covariates discussed in Table 2 and 3 while posttreatment confounders vector is defined as a null vector. Finally, I run household fixed effect linear regression for two rounds (2013-14) clustering by village. In the interpretation of the estimation, if the null hypothesis is rejected, this means that risk aversion influences food security not through the pathway of crop diversification. If the null hypothesis cannot be rejected, we can conclude risk aversion has no effect on food security when the indirect effect of crop diversification is excluded.

4. DATA AND DESCRIPTIVE STATISTICS

The Ethiopian Rift Valley Household Survey data is a household panel data set from rural Ethiopia. The data set consists of two parts: household survey data and field experiment data. The survey covers from 2013 to 2014 collecting socio-economic characteristics and nutritional status of household members. Twenty villages, located in four woredas (i.e., districts) of the Ziway-Shala lake basin in the Ethiopian Rift Valley, were selected using a stratified method (See Figure 2). The final sample consists of 20 randomly selected households from each of 20 villages and thus, the total sample size of the survey is 400 households. I exclude 46 non-farm households because the population in this study is farm households in developing countries. Thus, the total

---

12 I take the baseline set of covariates from Tanaka et al. (2010) who showed demographic or wealth-related variables are significantly correlated with risk aversion. Following their finding, I assume risk aversion does not affect any demographic variables or wealth variables.
13 This study uses a fixed effect model rather than a random effect model since the treatment of risk aversion is not randomly assigned.
14 The project is entitled “Response to Uncertainty about Climate and Water Availability: Evidence from Ethiopia”, funded by the United States Agency for International Development (USAID). Data source (https://sites.duke.edu/ethiopiawaterquality/)
15 Half of the villages were selected from all 5,936 villages within the study area, and half were randomly selected from a list of 50 sites with known poor water quality following the sampling process comport with a separate study on water quality and health in this region and builds upon prior research (Kravchenko et al. 2014; Rango et al. 2012).
16 I drop 46 households whose plot size and the volume of cultivated crops are all recorded in 0.
observation is 354 and the data is balanced. In each selected household, both the male and female household head were interviewed if applicable. During the month of February each year, data collection occurred immediately after the primary crop (teff and maize) harvest. Households were asked to recall events from the 12 months prior to the survey.

This study uses the 2013 and 2014 rounds of the data for the following reasons: First, the data set contains the field experiment data that is essential information to measure household head’s risk aversion parameter. The field experiment is conducted based on the investment and risk games by Tanaka et al. (2010). Using the primary feature of the games in the risk experiment, the three prospect theory parameters of household heads can be directly measured. In this study, the concavity of the value function parameter is used for a measurement of risk aversion (Tanaka et al., 2010, Liu, 2013). Second, the household survey data includes household food consumption and production of agricultural commodities with plot information. This information is necessary for measuring crop diversification indexes (HHI) and food security (FCS) to answer the research questions of this paper. Table 2 and 3 summarizes the key survey questions and variables used in this study. Third, household samples in the location represent the target population in this study. Ethiopia is one of the poorest, with a per capita income of $660 and a population that is 84% rural (World Bank, 2017). The 13 million smallholder households practice self-subsistence farming under limited access to financial capital. Table 4 presents household food security status in the Ethiopian Rift Valley measured in food consumption score (FCS). Over half of smallholder households are on or below the borderline of food security based on the scale provided by World Food Programme (WFP).

---

17 See Tanaka et al. (2010) for the detailed game design (page 560).
18 The prospect theory parameters are concavity of the value function (σ), the degree of loss aversion (λ), and the probability weighting (α) (Tanaka et al., 2010).
Table 2. Survey questions for key variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Survey question text</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food Security</td>
<td>In the week, how many meals do you eat a group of food?</td>
</tr>
<tr>
<td>Household Size</td>
<td>Number of members listed on detailed roster</td>
</tr>
<tr>
<td>Dependent Size</td>
<td>Number of dependents under 16 on roster to household size</td>
</tr>
<tr>
<td>Household Head Age</td>
<td>What is your age?</td>
</tr>
<tr>
<td>Income</td>
<td>Please estimate the total amount of money your household receives in an average year</td>
</tr>
<tr>
<td>Household Assets</td>
<td>The sum of total value of ten key asset types (e.g. furniture, technology, transportation)</td>
</tr>
<tr>
<td>Total land area (Ha)</td>
<td>Sum of “What is the area of [each] plot you own or rent?”</td>
</tr>
<tr>
<td>Education</td>
<td>What is your highest level of schooling?</td>
</tr>
</tbody>
</table>
### Table 3. Descriptive Statistics, 2013 to 2014 (n = 400)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Food Consumption Score (FCS)</strong></td>
<td>35.15</td>
<td>0.61</td>
<td>77.38</td>
</tr>
<tr>
<td><strong>Household Head’s Risk Aversion</strong></td>
<td>0.69</td>
<td>0.05</td>
<td>1.45</td>
</tr>
<tr>
<td><strong>Crop Diversification Index</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Crop Variety</td>
<td>2.83</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Herfindahl-Hirschman Index</td>
<td>0.44</td>
<td>0</td>
<td>0.85</td>
</tr>
<tr>
<td><strong>Socio-Economic variable</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Children (under 5 year old)</td>
<td>0.67</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Household Size</td>
<td>6.50</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Dependency Ratio</td>
<td>0.44</td>
<td>0</td>
<td>1.33</td>
</tr>
<tr>
<td>Household Head Education</td>
<td>1.40</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Household Assets (log, Birr)</td>
<td>6.29</td>
<td>0</td>
<td>13.37</td>
</tr>
<tr>
<td>Household Income (log, Birr)</td>
<td>7.98</td>
<td>0</td>
<td>14.13</td>
</tr>
<tr>
<td>Land Holdings (ha)</td>
<td>2.26</td>
<td>0.2</td>
<td>77.5</td>
</tr>
</tbody>
</table>

### Table 4. Food Security: Proportion of Household Food Consumption Score (FCS)

(Obs.=400)

<table>
<thead>
<tr>
<th>Food Security Status</th>
<th>FCS</th>
<th>Proportion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>$FCS &lt; 21$</td>
<td>25.6</td>
</tr>
<tr>
<td>Borderline</td>
<td>$21 \leq FCS \leq 35$</td>
<td>24.6</td>
</tr>
<tr>
<td>Acceptable</td>
<td>$35 &lt; FCS$</td>
<td>49.8</td>
</tr>
</tbody>
</table>
5. ESTIMATION RESULT AND DISCUSSION

5.1 Core Results

5.1.1 Crop Diversification and Food Security

Table 5 presents the key results from the household fixed effect of crop diversification on food security being in line with Proposition I. Column (1) and (2) presents results of a simple linear regression. Column (3) and (4) show results from including household fixed effects. The primary results in the table indicate that increases in the level of crop diversification insecure food security under household fixed effects. In Column (3) and (4), I find the negative effect of crop diversification on food security that is stable regardless of control variables and highly significant. Thus, our estimation results from Table 5 provide the original evidence to support the first testable prediction that the higher level of crop diversification leads the less food security (Proposition I).

One can interpret the coefficient of treatment that in average food consumption score of a household decrease about 30 units as the Herfindahl-Hirschman index (HHI) increase one unit (See Column 4). This, however, does not provide intuitive interpretation of the results because the magnitude of coefficient relies on both measures of treatment and outcome variables. For robustness of the coefficient of the treatment, I show the similar results when using the varieties of crop instead of HHI to see how diversifying one more crop influences a household food security score.

5.1.2 Risk Aversion and Food Security

The results in table 6 primarily reports that the direct effect of risk aversion on food security without bias caused by crop diversification is significantly positive. Columns of table 6 shows
results from different models: baseline not including crop diversification in Column (1), the average total effect (ATE) including mediator of crop diversification in Column (2), and the average controlled direct effect (ACDE) in Column (3). By including the mediator of crop diversification in Column (2), I find no evidence that risk aversion is significantly correlated to food security while crop diversification has negative relationship with food security. I, however, observe the positive direct effect of risk aversion on food security (ACDE) after conducting the method by Acharya et. al (2016) to exclude the bias of crop diversification in Column (3). As a measure of risk aversion increases by one unit, the household food consumption score increases over 12 points. Conclusively, the result supports Proposition II that a more risk averse producer will have higher utility on average.19

19 The concept of food security has been used extensively at the household level as a measure of welfare (Pinstrup-Andersen, 2009).
Table 5. Crop Diversification and Food Security

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>Food Security (FCS)</th>
<th>OLS</th>
<th>Fixed Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>[1]</td>
<td>[2]</td>
</tr>
<tr>
<td><strong>Crop Diversification (HHI)</strong></td>
<td>0.23</td>
<td>-3.45</td>
<td>-28.80***</td>
</tr>
<tr>
<td></td>
<td>(2.43)</td>
<td>(2.46)</td>
<td>(5.85)</td>
</tr>
<tr>
<td><strong>Household Fixed Effect</strong></td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Controls</strong></td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Number of Children (under 5)</td>
<td>-0.46</td>
<td>-3.31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.03)</td>
<td>(2.62)</td>
<td></td>
</tr>
<tr>
<td>Household Size</td>
<td>0.60*</td>
<td>2.82**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.31)</td>
<td>(1.21)</td>
<td></td>
</tr>
<tr>
<td>Dependency Ratio</td>
<td>3.78</td>
<td>-13.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3.69)</td>
<td>(9.93)</td>
<td></td>
</tr>
<tr>
<td>Household Head Education</td>
<td>0.77**</td>
<td>1.16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.46)</td>
<td>(1.36)</td>
<td></td>
</tr>
<tr>
<td>Household Assets</td>
<td>1.74***</td>
<td>0.83</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.39)</td>
<td>(0.67)</td>
<td></td>
</tr>
<tr>
<td>Household Income</td>
<td>-0.21</td>
<td>-0.67*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.23)</td>
<td>(0.35)</td>
<td></td>
</tr>
<tr>
<td>Land Holdings (ha)</td>
<td>0.42**</td>
<td>-0.11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.19)</td>
<td>(0.26)</td>
<td></td>
</tr>
<tr>
<td><strong>Constant</strong></td>
<td>35.03***</td>
<td>20.14***</td>
<td>47.89***</td>
</tr>
<tr>
<td></td>
<td>(1.28)</td>
<td>(3.19)</td>
<td>(2.59)</td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td>718</td>
<td>712</td>
<td>718</td>
</tr>
<tr>
<td><strong>R-squared</strong></td>
<td>0.00</td>
<td>0.07</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Notes: In model [2], six observations are missing when including control variable. Standard errors are reported in parentheses. Clustered at the level of the village (n = 20). The variables of income and assets are given in log form. *p < 0.10, **p < 0.05, ***p < 0.01.
### Table 6. Risk Aversion and Food Security

<table>
<thead>
<tr>
<th>Dependent Variable: Food Security (Food Consumption Score)</th>
<th>Baseline</th>
<th>Total Effect (ATE)</th>
<th>Direct Effect (ACDE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[1]</td>
<td>[2]</td>
<td>[3]</td>
</tr>
<tr>
<td>Household Head Risk Aversion</td>
<td>3.45</td>
<td>2.28</td>
<td>12.21***</td>
</tr>
<tr>
<td></td>
<td>(6.58)</td>
<td>(6.11)</td>
<td>(6.06)</td>
</tr>
<tr>
<td>Crop Diversification (HHI)</td>
<td>-</td>
<td>-27.92***</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(5.98)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Children (under 5)</td>
<td>-3.96</td>
<td>-2.99</td>
<td>-0.88</td>
</tr>
<tr>
<td></td>
<td>(2.91)</td>
<td>(2.68)</td>
<td>(2.56)</td>
</tr>
<tr>
<td>Household Size</td>
<td>2.75**</td>
<td>2.69**</td>
<td>5.65***</td>
</tr>
<tr>
<td></td>
<td>(1.38)</td>
<td>(1.21)</td>
<td>(1.22)</td>
</tr>
<tr>
<td>Dependency Ratio</td>
<td>-10.74</td>
<td>-12.63</td>
<td>-13.83</td>
</tr>
<tr>
<td></td>
<td>(10.69)</td>
<td>(9.93)</td>
<td>(10.54)</td>
</tr>
<tr>
<td>Household Head Education</td>
<td>1.28</td>
<td>1.25</td>
<td>4.05***</td>
</tr>
<tr>
<td></td>
<td>(1.45)</td>
<td>(1.38)</td>
<td>(1.24)</td>
</tr>
<tr>
<td>Household Assets</td>
<td>0.69</td>
<td>0.96</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>(0.73)</td>
<td>(0.68)</td>
<td>(0.68)</td>
</tr>
<tr>
<td>Household Income</td>
<td>-0.83**</td>
<td>-0.75**</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>(0.36)</td>
<td>(0.36)</td>
<td>(0.35)</td>
</tr>
<tr>
<td>Land Holdings (ha)</td>
<td>-0.07</td>
<td>-0.08</td>
<td>0.41**</td>
</tr>
<tr>
<td></td>
<td>(0.41)</td>
<td>(0.25)</td>
<td>(0.16)</td>
</tr>
<tr>
<td>Constant</td>
<td>23.15*</td>
<td>34.58***</td>
<td>-2.65</td>
</tr>
<tr>
<td></td>
<td>(11.84)</td>
<td>(11.10)</td>
<td>(10.85)</td>
</tr>
<tr>
<td>Observations</td>
<td>708</td>
<td>708</td>
<td>708</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.04</td>
<td>0.10</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Notes: The estimated coefficients of the interactive covariates and fixed effect are not reported but are available upon request. Standard errors are reported in parentheses. Clustered at the level of the village (n = 20). The variables of income and assets are given in log form. *p < 0.10, **p < 0.05, ***p < 0.01.
6. CONCLUSION

Does cultivating one crop secure more food than cultivating five crops for smallholder farmers in developing countries? How does farmers’ risk aversion affect crop diversification and food security choices at the household level? Risk aversion has been considered a key concept of farmers’ decision making in agricultural production in developing as well as developed countries. Also, the correlation between risk aversion and crop diversification has been widely studied in the view of a farm-level risk management strategy. It is unclear, however, how risk aversion, crop diversity, and food security are linked in a causal chain.

The objective of this article is to investigate (i) the effect of crop diversification on food security and (ii) the direct effect of risk aversion on food security without a bias from crop diversification. In the theoretical section, this article develops the original framework to show the causal chain of risk aversion, crop diversity, and food security. By adapting the theory of the competitive firm under price uncertainty (Sandmo, 1971) and the production under uncertainty (Just and Pope, 1979; Chambers and Quiggin, 2000), I prove two propositions: First, assuming the producer’s risk aversion follows constant absolute risk aversion, if crop diversity increases, the producer’s expected utility decreases. Secondly, if the producer is more risk averse, then the producer will less diverse crops and his expected utility will increase.

In the empirical framework, I investigate the propositions using the identification strategy of causal chains by Acharya et al. (2016). By conducting the unique household survey and experimental data from rural Ethiopia, I estimate (i) the fixed effect of crop diversification on food security and (ii) the direct effect of risk aversion, so-called the average controlled direct effect (ACDE), on food security excluding the indirect effect of crop diversification. Our result shows there exist (i) a negative effect of crop diversification on household food security and (ii) a positive
direct effect of household head risk aversion on household food security. This paper considers Herfindahl-Hirschman Index (HHI) to measure crop diversification. Household food security is measured by food consumption scores (FCS)\textsuperscript{20} and household head’s risk aversion is measured by field experiment (Tanaka et al., 2010).

This paper contributes, first, to the literature in the causal chains of risk aversion, crop diversity, and food security. Second, this article provides the original evidence that crop diversity decreases food security at household level. Our findings provide insight into development-related policy implications. Food security is the primary issue considered by many international non-profit organizations such as FAO, IFPRI, World Bank, and WFP. Not surprisingly there have been controversial discussions with respect to the efficient way to secure food at a household level in developing countries. This article gives an evidence that risk aversion of household measured through field experiments could be a significant solution to understand how households react to food policy associated with food security.

\textsuperscript{20} Food Consumption Score (FCS) measures food security of an individual household in terms of intake-nutrition that is widely used (ODAV-WFP 2008; Maxwell 2017)
References


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Appendix

Figure 1. Distribution of Household Food Consumption Score (FCS)

Figure 2. Distribution of Household Varieties of Crop

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