Impact of climate and environmental risks on food security in Vietnamese rural areas: multidimensional analysis and endogeneity issues.

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Abstract

Vietnam is a country with a high environmental and climate risks and agriculture remains the key sector that employs rural households. In this study, we analyze the association between two types of risks (environmental and climate) and food security of rural households. Food security is understood in all its four dimensions (availability, accessibility, diversity and stability) through composite index. In addition, we deal with endogeneity concern of some risk variables (deforestation and pollution), which could hinder these links, using control function method by Wooldridge (2015). Our identification strategy is implemented with data from the three latter VHLSS waves (2010 to 2014) and high resolution georeferenced data for risks variables. Results show that climate and environmental risks are among the main factors that slowed down Vietnamese rural households' ability to achieve a better nutritional status in all its dimensions and the magnitude and significance of this link depends on the nature of the risk on the one hand and the dimension of food security considered on the other. Then, political intervention is needed to make rural households more resilient to these risks factors.

Keywords: Climate change, Environment, Risk, Food security, Vietnam

JEL classifications: D24, O12, Q12, Q54

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1 Introduction

The current climate context is still alarming and the assessment of its damages remains a necessity. According to the latest IPCC report, 2018 ”Global warming is likely to reach the critical threshold of 1.5°C between 2030 and 2052 if the temperature continues to grow at its current rate.”. In addition, studies on the nexus between economics and climate change have shown that climate has an effect on socio-economic variables such as income (Adger, 1999), inequalities (Bui et al., 2014), poverty (Gentle and Maraseni, 2012), etc. This damage is most evident in developing countries which lack the means to cope with it or mitigate its effects . The projections by Parry et al. (1999) showed that the number of people at risk of starvation due to climate change would reach 80 million by 2080. Like climate risk, environmental risk is also considered as a source of inequality and vulnerability for certain categories of people and geographical areas. Assessing its damages is therefore an emergency for policy makers. In this analysis, our goal is to evaluate the effect of two types of risk (climate and environmental) on food security status of rural households in Vietnam.

Vietnam is one the best example for assessing the causal link between these two types of risks and food security. This country ranks among the top five most vulnerable countries according to Climate Change Knowledge Portal (CCKP) of World Bank[1] with frequent occurrence of natural disasters (floods, typhoons and drought) and an increase in average temperatures that have already reached nearly two degrees in some regions. Vietnam climate projections are rather pessimistic about its future damage. Yu et al. (2013) predicted an increase in the average temperature of 2.5°C in 2070 and sea level of 33 cm in 2050. This exposure to climate risk is most evident in the Mekong regions Delta and coastal areas (Dasgupta et al., 2007). Also, Vietnam is emblematic for its potential exposure to climate variability: more than 3000 km of coastline are subject to an accelerated erosion. This country has been subject to a wide spectrum of natural disasters and ranked respectively as the 4th, 5th and 6th in terms of number of people exposed to the occurrence of floods, drought and other similar climatic events (UNISDR[2], 2009). The agricultural sector is the first sector identified as being most affected by global warming and environmental degradation.

In Vietnam, agricultural sector has undergone a major change and constitutes the main source of income for rural households which are generally victims of climatic hazards. In 1986, the Vietnamese government has committed itself to a goal of poverty reduction with the implementation of the ”DOI Moi” reform. It has facilitated the country’s economic

[1]Source: the CCKP website.

[2]United Nations Office for Disaster Risk Reduction

transition from a planned economy to a market economy. The reform has been very successful in reducing poverty (from 60% in 1990 to 13.5% in 2014 (World Bank Data, 2016)), improving the living conditions of households and social stability in the country. Despite its small contribution to GDP, agricultural sector employ the majority of the country's active workforce (43%) mainly located in rural areas. The vulnerability of this group is directly link to any shock which affect agricultural sector. In addition, there are still gaps to be filled because the country's current poverty rate of 13.5% remains significant and inequalities still exist between social groups (rural vs urban, ethnic groups (Kinh and others), poor and rich). The poverty situation of these groups limits their access to certain quality of food items (Thang and Popkin, 2004). Also, the nutritional status of Vietnamese remains critical. The GHI (Global Hunger Index) is still high: out of 119 countries, Vietnam ranks 64th among countries which suffers from malnutrition and starvation. In Southeast Asia, specifically in China and Vietnam, the nutrition transition from 2005 to 2015 resulted in energy-dense food consumption on the one hand, in urban quality on the other hand and had little benefit for households living in rural areas (Nguyen et al., 2018). Thus, improving food security in all its dimensions in rural area is crucial for Vietnamese policies (National Nutrition Strategy for 2011-2020, with a vision toward 2030). The establishment of such policy should not neglect the climate and environmental risk that are a reality in the country and increasingly threatens agricultural sector productivity (Diallo et al., 2019) which is the key driver of food security.

In this study, we highlight the causal effect of environmental and climatic risks on people well-being. Well-being is approached differently than income, more precisely, well-being is apprehended by the status of food security of households from a multidimensional approach. By answering this problematic, this study is in line with the literature on the assessment of climate change damage and the determinants of food security. Our paper aims to contribute to existing litterature in different ways. First, our approach is multidimensional. Since food security is a multidimensional concept (Schmidhuber and Tubiello, 2007), we take into account all the dimensions of food security proposed by FAO (availability, accessibility, diversity and stability). The simultaneous analysis of each dimension makes it possible to understand the effect of climatic damage on each component and thus allows us to identify the components most affected by climatic hazards and environmental risk. However, most studies are limited to analyzing the effect of climate change on food production or productivity, which is only one dimension among many (Yu et al., 2010; Trinh, 2018). These studies are only partial analyses of the relationship between food security and climatic conditions. We take advantage of the wealth of our database to take into account all dimensions of food security. Secondly, we take advantage with availability of multiple indicators about climate and environment risks data. All the literature on food security analysis in Vietnam has focused more on the income-nutrition relationship

(Dien et al. (2004), Molini (2006), Mishra and Ray (2009) and Thi et al. (2018)), without taking into account the environmental and climatic aspect. To our knowledge, ther is no study exists on the analysis of the causal relationship between climate, environmental risks and food security in Vietnam. Finally, we also contribute methodologically by addressing endogeneity issue between some of our environmental risk variables and food security. The innovative control function (CF) method proposed by Wooldridge (2015) is advantageous for dealing with this concern. The CF estimator tackles the endogeneity by adding an additional variable to the regression, generating a more precise and efficient estimator than the instrument variable (IV) estimator.

Our results show that the fact of living in risk areas affects negatively nutritional status of rural households. The magnitude and significance of this link depend on the nature of the risk on the one hand and the dimension of food security considered on the other. These results can serve as political instruments to the Vietnamese government in the implementation of its National Nutrition Strategies for 2011-2020. To make rural households more resilient to climate and environmental risks, their dependence on the agricultural sector should be reduced by creating new income-generating opportunities. Moreover, relaxation of liquidity constraints may be possible through the development of microfinance activities in rural areas or social protection through weather index insurance for agriculture (Barnett and Mahul, 2007). Government must boost mechanisms to combat climate change by setting up more modern irrigation and drainage systems or seasonal weather services to anticipate temperature and precipitation shocks. Also, policies against deforestation and pollution should be encouraged.

The remaining of the paper is organized as follows: Section 2 presents the literature related to the link between environmental, climate, people well-being and food security. Section 3 details data used. Sections 4, 5 and 6 present respectively the conceptual framework, econometric model and main results. We conclude and make some policies recommendation in section 7.

2 Litterature review

In this section, we first review the literature on the link between environmental, climate risks and well-being. This will allow to understand the different channels by which these two types of risks could impact the welfare of households. Secondly, the multidimensional concept and determinants of food security are analyzed. Finally, the link between our risk variables and each dimension of food security is highlighted in figure 1.

2.1 What do we know about the link between environmental risk, climate risk and people's well-being ?

The relationship between environment and development economics is not new in the literature. This link was first highlighted by Grossman and Krueger (1991) and was followed by several other papers (Grossman and Krueger (1996), Shafik and Bandyopadhyay (1992), Selden and Song (1994), Panayotou et al. (1993) and Cropper and Griffiths (1994)). The common point of most of these studies is the u-inverted relationship between environmental degradation and the level of development of countries, commonly referred to Environmental Kuznets Curve (EKC). Indeed, in the early stages of development or economic growth of a country, environment quality is deteriorated because of industrialization process that facilitates pollutants emission or deforestation from factories installation. Awareness of this degradation is neglected at this stage as people are motivated to search for jobs and accumulate wealth rather than to a healthy environment (Dasgupta et al., 2002). Once the minimum income is reached, environment becomes more and more considered useful asset in the preference basket of people and policy makers.

Environmental degradation manifests in several ways: air pollution through the emission of pollutants, water pollution, deforestation, soil erosion, etc. In developing countries where environmental regulation is not a priority anyway and the important role of the agricultural sector in household income portfolio, environmental degradation could lead to adverse effects on people well-being and lead to poverty trap situation.

Environmental risk is unequally distributed around the world and even households within a country are not vulnerable in the same way. Over the last decade, activists, academics, and policy makers have paid close attention to "environmental equity" or the notion that potential sources associated to environment risk may be concentrated among minorities, some ethnic groups and poor. At the global level, poor countries are most exposed to environmental and climate risks (Barbier (2010) and Sloan and Sayer (2015)). Indeed, the impact of extreme environmental events differs between countries, regions and individuals; the damage they suffer depends on their degree of exposure and their ability to adapt with it (Clark et al., 1998). In developing countries, the literature shows a positive relationship between both of climate and environmental risks and poverty (Narloch and Bangalore, 2018).

In addition, case studies within a country show that most provinces and districts experiencing environmental degradation are areas with relatively high rates of poverty (Winsemius et al., 2015). Acemoglu et al. (2001) argue that the risk of settler disease and mortality during the colonial era, whose main cause was local climatic conditions, explains the economic development of certain regions of the world. Then, climate condition or environmental risks could conditioned the long run development of countries or their sustainable development.

At household level, rich households are less exposed to climate and environment risk than poor households (Wodon et al., 2014). In fact, by the principle of "vote by feet" from Tiebout (1956), rich households settle in areas which are least exposed to environment degradation and correspond to their preferences. Houses prices in these areas increase due to environment quality and this increase limits access of them to poor people. Thus, poor households are settle in localities exposed to more climate and environment risks and poor amenities.

However, there is a considerable number of studies done by other researchers who find different results. The impact of climate risk on people well-being would depend on the nature of the risk considered. Arouri et al. (2015) find that the occurrence of cyclones, floods and droughts negatively impact household income with different magnitudes. For example, the effect of cyclones was relatively small compared to the effect of floods and drought. Also, poor households are more exposed to drought and temperature variability because their income is generally based on the agricultural sector whose production is linked to these types of climate hazards contrary to rich households that are more affected by floods because their physical assets are more at risk (Hallegatte et al., 2016). Pasanen et al. (2017) find a strong link between poverty and domestic pollution and air quality while the connection between non-domestic pollution, soil erosion and poverty is quite weak.

2.2 Food security link to climate change and environmental risk

According to World Food Summit, 1996 "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life". This definition shows the multidimensional nature of food security concept. FAO identifies four main dimensions to understanding food security. The first dimension is availability which means sufficient and quality food production available to households. This dimension refers to an adequate supply of a healthy diet except that it does not take into account the ability (Sen, 1981) of people to appropriate it. So, the second dimension, which is accessibility, is on the demand side. In addition to the first dimension, it takes into account households' access to sufficient food that is linked to the resources or opportunities they have. The third component is the diversity in the basket of food consumption and the use of these goods. Indeed, a balanced diet is necessary to have an adequate nutritional state. Moreover, the use of these food products, which would reflect its effectiveness, depends on the quality of the environment around the household (water quality, air quality ...). The last component reflects the stability of the three components mentioned. To ensure food security, households must have access to sufficient, healthy and diversified food at all

times.
The Sustainable Livelihood Framework approach divides food security (FSI) determinants into five broad categories (Ashley et al., 1999): human capital (HC), social capital (SC), physical capital (PC), financial capital (FC) and natural capital (NC).

$$FSI = f(HC, SC, CP, FC, NC) \quad (1)$$

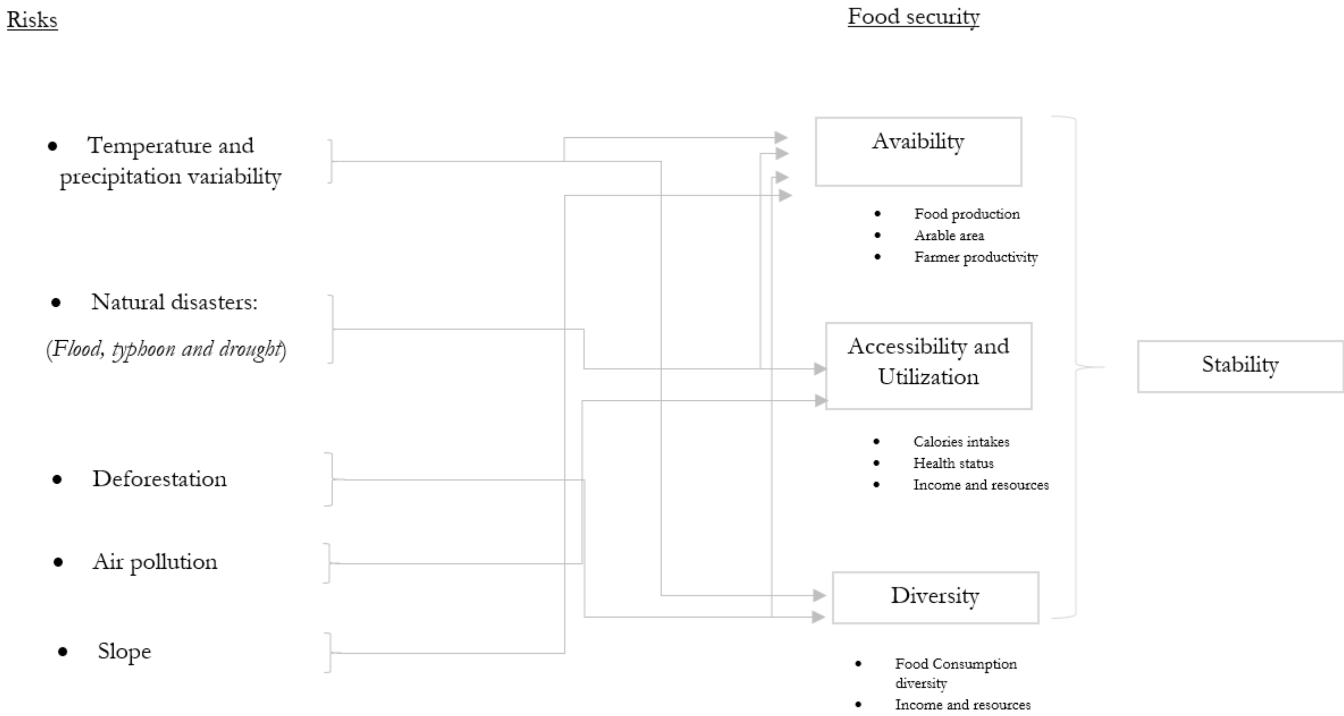
Human capital are skills that together enable people to have different means of livelihoods. At the household level, it can be understood by the household size, health status, education level, etc. Social capital is defined as social resources (social network, membership to an association, level of trust ...) which facilitates cooperation, access to certain goods and services and therefore reduces transaction costs. Physical capital includes public goods or the basic infrastructure available to people who make their subsistence activities easy by improving their productivity (road traffic, adequate supply of water and electricity, access to information, etc.). Financial capital refers to the financial means that allow individuals to smooth their income and consumption. These financial resources can be stocks (savings) or flows (cash transfer, remittances, subsidies ...). Natural capital is the term used to refer to natural resource stocks from which resource flows and services for livelihoods are derived. The resources constituting natural capital vary considerably, ranging from intangible public goods such as the atmosphere (temperature, precipitation ...) and biodiversity to divisible assets directly used for production (trees, land, etc.). Our analysis is essentially based on the last category (natural capital) controlling for some variables of other. Climate and environmental risk variables are used to define natural capital.
We distinguish eight risk variables related to climate and environment[3]. These risk variables can affect food security in many ways. Figure 1 below summarizes the channels through which climate and environmental risks could impact each dimension of food security:

- **Temperature and precipitation variability:**

  There is no doubt that agricultural output is strongly linked to climatic conditions. Mendelsohn et al. (1994) found a nonlinear effect of temperature and precipitation on agricultural production in USA. Schlenker and Roberts (2009) found that beyond the respective thresholds of 29°, 30° and 32°, the temperature generates major damage on wheat, soybean and cotton yields respectively. Climate Shocks also can affect the technical efficiency of farmers and then reduce agriculture productivity (Diallo et al., 2019).

[3]These variables are close to those used by Narloch and Bangalore (2018) with different sources. See section about data for more details

Figure 1: Food security, environmental and climates risks association



- **Natural disasters**

  The occurrence of natural disasters aggravates the poverty situation of rural households (Arouri et al., 2015). Typhoons lead to the destruction of assets; Floods and drought negatively impact farm income which is the main component in the household income portfolio in rural areas. Moreover, since income is the key determinant of diversity and accessibility, variability in temperature, precipitation and natural disasters have an indirect impact on the accessibility dimension and the diversity dimension. Also the quite important periods of drought increase the duration of agricultural production season and thus acts on the supply and the price of food goods.

- **Air pollution**

  About air pollution, chronic exposure to it is associated with adverse health effects like metabolic dysfunction and increase morbidity and mortality (McMichael et al. (2008) and Pope III et al. (2009)). Thus, utilization dimension is affected. Otherwise, bad health due to air pollution affect negatively workers productivity and diminish their income while income is a main determinant of accessing to good quality food.

- **Deforestation**

  The effect of deforestation on food security is ambiguous. On the one hand, deforestation leads to a decline in ecological services and thus to the nutritional possibilities of rural and poor households. On the other hand, deforestation is a substitution for an income shock for poor households. Therefore, it can be considered as additional resources and thus facilitates access to food. In addition, deforestation reflects the extensification of agricultural sector by increasing the total area of arable land. So it could favor the local offer and thus have a positive effect on food availability.

- **Slope**

  High slope can put agricultural yield at risk. Areas with steep slopes are much more exposed to surface runoff and soil erosion - especially areas affected by heavy rainfall and loss of forest cover (Sidle and Ochiai (2006); Vezina et al. (2006)). Therefore, farming in these areas requires a significant investment in terms of labor, capital. Hence, agricultural productivity is threatened in these areas.

Stability dimension resulting from the other three dimensions is necessarily linked to all climate and environmental risk variables. The transmission channels explained above are not exhaustive. There may be other more complex channels that link climate and environmental risk to food security.

Through figure 1, we highlight the dependence of each dimension of food security with the degree of exposure to climatic hazards and environmental risk. The separate analysis of the impact of risk variables considered is complex because they are strongly correlated. We include these variables simultaneously in econometric estimation.

3 Data

We combine three categories of data in this analysis: socioeconomic data, climate and environmental risk data. Climate and environmental risks data are close to those used by Narloch and Bangalore (2018) from different sources.

3.1 Socioeconomic data

The socio-economic data are from Vietnam Household Living Standard Survey (VHLSS) lead by General Statistics Office of Vietnam (GSO) with the support of World Bank. Initiated since 2002, VHLSS's main objective is to collect data at household and commune levels in order to define and evaluate national policies or programs that include poverty analysis and inequalities between gender, socio-groups and regions in Vietnam. The survey questionnaire is administered every two years at two levels.

On the one hand, we have a questionnaire administered at household level. It collects data on sociodemographic characteristics of individuals within a household (sex, age, level of education,...). Moreover, for each household, we have information on different sources of income (agricultural, non-agricultural, services,...) and their use (consumption, health, education ...). The calculation of our measure of food security is deduced from agriculture section and the use of household income section specifically their consumption expenditure[4].

On the other hand, the questionnaire at municipal level is administered to local authorities of each municipality. It collects information on infrastructure (schools, roads, markets, ...) and economic conditions (work opportunities, agricultural production,...) within municipality. Through this questionnaire, we also have information on the occurrence of extreme events by category (typhoons, floods, cyclones ...)

All of these questionnaires collect data from 9000 representative households each year. This allows us to build our database from the last three VHLSS surveys (2010-2012-2014). In this study, we are interested in households living in rural areas. They are vulnerable to climatic shocks and environmental risk because their resources depend heavily on them and they lack of adaptation strategies. In total we have 8666 households that are selected over the three study periods. We recall that our database is not balanced, so that a household can be or not be followed more than once during the analysis period.

3.2 Risks data

We distinguish eight risk variables that concern both climate and environment risks. All of these variables are well suited to study households exposure to climate and environmental risk. Table 1 below describes these variables and their sources.

4 Conceptual framework

4.1 PCA to compute Food Security Index

The measure of food security is complex because of its multidimensional nature. This complexity usually leads researchers to limit its analysis to a single dimension among the four dimensions identified above. To take account four dimension together, Principal Component Analysis (PCA) approach has advantages. PCA is a statistical tool that summarizes the inertia contained in several correlated variables in a single indicator called composite indicator (Dunteman, 1994). This method was used by Abafita and Kim (2014) to analyze the impact of rainfall shocks on food security in Ethiopia. We use the same approach to construct an Food Security Index (FSI) that encompasses the first three dimensions (availability, accessibility and diversity):

$$PC_m = a_{m1}.X_1 + a_{m2} + ... + a_{mp}.X_p; \tag{2}$$

[4] All monetary values are deflated by 2010 Consumer Price Index

Table 1: Risks data description and sources

Variables	Description	Source
Climate risk		
Temperature variability	For one year, we compute temperature variability as deviation of average temperature for this year to their five last year average, in a given commune.	Moderate-Resolution Imaging Spectroradiometer (MODIS)
Precipitation variability	For one year, we compute precipitation variability as difference of average precipitation for this year to their five last year average, in a given commune	Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)
Natural disasters (*Flood, drought and typhoon*)	binary variable (=1 if this type of Natural disaster occured during the past two year)	VHLSS (Commune)
Environnemental risk		
Air pollution	Annual concentration of PM2.5 particles (g / m3).	NASA's Moderate Resolution Imaging Spectroradiometer (MODIS), Multi-angle Imaging SpectroRadiometer (MISR), and the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS).
Deforestation	For a given year, deforestation is defined as a minimum loss of 20% or more of the vegetation cover compared to deforestation in 2000. Using Landstat data, the authors have spatialised the dynamics of the vegetation cover in terms of gain, expansion and loss at a spatial resolution of 30 km.	Hansen et al (2013).
Slope	The average slope of a second arc about 30 m to Ecuador. It is measured in%	NASA Shuttle Radar Topography Mission Global 1 arc second V003

Where a_{mp} represents the weight associated with the component m and dimension p of food security. Table 2 shows variables used to represent each dimension. To construct food security index, we only include the first three dimensions (avaibility, accessibility and diversity). Stability dimension is analyzed differently. To understand stability dimension, we make a longitudinal analysis by study the persistence and transition of FSI and their tertile dimension. Table 3 present the descriptive statistics and component loading of PCA results. Initially, the number of components was five and we use the Kaiser[5] criterium to choose the best components. Then, we select two component with egein value more than one. FSI corresponds to first component ($PC1$) because this component got the maximum information (35% of total inertia) of correlated variables more than the second component.

About first component, all variables used are positively associated with it witch correspond to our expectation. $Production\ value$ and $agriculture\ surface$ are strongly correlated with FSI which correspond respectively to 0.69 and 0.68 as weights. Otherwise, having large agriculture surface and agriculture production value are positively associated with per capita calories intake, production and dietary diversity. However, the contributions of both variables of production and consumption diversities are quite low. This means that FSI is less dependent on these two variables. Still, there is a positive correlation

[5]Criterium of Kaiser (1960) allows to select only component with egeinvalue superior to 1

Table 2: Variables used for PCA

Dimensions	Variables
Avaibility	Value of agricultural production by type of crop (rice, starchy, vegetables, industrial crops and fruits) and total agriculture surface.
Accessibility	Per capita calories intakes per day (PCCI)
Diversity	Production and dietary diversity index

Note: some variables such as agricultural area, agriculture production value and PCCI were normalized with a logarithmic transformation. See the appendix for PCCI calculation method. To compute the productive and dietary diversity index, we use the Simpson and Shanon indices. The indicators are more detailed also in Appendix.

between FSI and two diversity indicators. FSI is recalculated using the min-max[6] method and follows a normal distribution.

The second component is different from the first one. In this component, we observe

Table 3: Summary statistics and component loadings of food security index

Variable	Mean	Std. Dev.	Component loading (PC1)	Component loading (PC2)
Agriculture surface	8.102532	1.109043	0.6810	-0.1481
Production value	9.541603	1.172828	0.6944	0.0103
PCCI	8.458136	.3545511	0.2315	0.3894
Production diversity	0.2628631	.2263587	0.0151	-0.5672
Dietary diversity	0.5627853	.1267999	0.0171	0.7104
Eigenvalue			**1.75**	**1.28**
Percentage of variance explained			**0.35**	**0.26**

a clear representation of households who practice diversity in their production and those who consume several goods at a time. While the agricultural production value has a small contribution. Also, this axis shows that diversification in production is opposed to diversification in consumption. Also, a significant consumption of calories is followed by a diversification in the consumption basket. As can be seen, this component does not reflect the structure of a food security indicator. Our analysis focuses on the first component because not only does it capture the largest information but also all the variables used

[6]This method consist to range variable between 0 and 1 by transform it as:

$$FSI_{norm} = \frac{FSI - Min(FSI)}{Max(FSI) - min(FSI)} \tag{3}$$

for PCA are associated with the right sign.

Despite its advantages, PCA has some limitations. First of all the share of information retained in our food security index is only 35%, which means that 65% of the information is lost and will not be exploited. Also, the low weights associated with diversity dimension are not justified. Normally, the weight associated with each dimension should be expected to be positive and important as all four dimensions contribute to food security (Abafita and Kim, 2014). To circumvent these concerns, we conduct robustness analyzes by assessing the effect of climate and environmental risks on each dimension of food security in addition to the effect on the overall FSI.

4.2 Stability dimension

For FSI and each of its dimensions, we break down our sample into three groups according to the tertile to which household belongs. Thus, for a given year, households are classified from the most vulnerable (first tertile) to the least vulnerable (last tertile) according to their food security status. This way to analyse stability dimension is similar to the approach used by Bigsten et al. (2003), Qureshi (2007) and Demeke et al. (2011). Also, the decomposition into tertile allows to take into account the inequalities between different groups of households in terms of nutrition. This inequality could be explained by chronic exposure to climate hazards and living in a risky environment.

Table 4 is transition matrix that gives the evolution of each tertile of FSI indicator and each of its dimensions over the 2010-2014 period. There is a high degree of instability in the nutritional status of households in our sample. This instability is manifested by the movement of households from one tertile to another over the three years (2010 2012 2014) period of this analysis.

For example, about the global indicator FSI, we observe around 75% of individuals who initially belonged to the first tertile who remained stable in their group. 21% of them went to the second tertile and only 4% saw their nutritional status improved (last tertile). In addition, 27% of households in third tertile in 2010 have moved to a lower status. Otherwise, we remark that small producer stay always small and big producer remain big in term of agriculture production value over 2010-2014. Thus, there is exist a trap in agriculture production among small and big producers in Vietnam. About PCCI, more than 50 percent of each quintile sample transit to other quintile: 35% of second tertile (T2) in 2010 move to inferior tertile (T1) and 27% move to superior tertile (T3) and only 39% stay to initial status (T2).

Also, diversity in consumption behaviour is non stable. For each tertile, the probability to move in another tertile in 2012 or 2014 is very important: From T1 group, 53.12% stay in less secure status; from T2 group, 27% move back to less secure status and 34% move forward.

Table 4: Food security factor score evolution between 2010 and 2014

FSI	**1**	**2**	**3**	**Total**
1	**74.89**	20.84	4.27	100.00
2	24.67	**57.33**	18.00	100.00
3	5.10	21.69	**73.21**	100.00
Food production				
1	**69.92**	23.87	6.22	100.00
2	23.17	**57.75**	19.08	100.00
3	4.51	19.23	**76.26**	100.00
PCCI				
1	**55.27**	26.77	17.96	100.00
2	34.69	**38.84**	26.46	100.00
3	21.47	33.43	**45.10**	100.00
Diversity				
1	**53.12**	31.00	15.88	100.00
2	27.19	**38.58**	34.23	100.00
3	14.67	32.66	**52.66**	100.00

5 Econometric model

5.1 Endogeneity issues

Causal analysis of weather shocks, environment risks and food security is very complex because of endogeneity issues. Among risk variables, we treat endogeneity of two variables (deforestation and air pollution) that we suspect to be endogenous because the others are relatively more exogenous. There are two potential sources of endogeneity in this analysis.

The first one is the inverse causality between food security and environmental risk since the pressure of people on environment services especially in rural areas is not negligible. Fisher (2004) shows that forests prevent poverty by smoothing income, and may also help to improve the living standards of households. So deforestation itself explains household income and therefore their access to good food. Also, extensive agriculture practice, which is the main determinant of food availability, contributes to environment degradation through deforestation. Moreover, by the principle of vote by feet of Tiebout (1956), the choice of people's location is a function of their income and therefore of the importance they attach to environment quality. This choice creates a distortion in the price of housing. The poor, who generally suffer from food insecurity, tend to settle in polluted areas because they are cheaper relative to the rich. Thus, there is self-selection between food-insecure people and their environmental vulnerability because residing in a polluted area is a function of the individual's level of well-being. In Vietnam, farmers could also contribute

to air pollution by rice straw burning. To prepare farm land for next season, producers burn rice straw according two methods: i) piling the residues after hand harvesting; ii) burning the residues without piling, after machine harvesting. Lasko and Vadrevu (2018) findings suggest that pile burning method and non-pile burning method contribute respectively to 180 Gg and 130 Gg of PM2.5 emissions in Vietnam for year 2015.
The second cause of endogeneity is the omitted variable bias. However, taking into account several climatic and environmental risks indicators in the analysis reduces this bias.

To tackle endogeneity concern, we use control function approach from Wooldridge (2015). CF approach is two steps estimation strategy used to solve endogeneity issues in linear and non-linear models. Fisrt step consists to regress each endogenous variables on instruments variables and other exogenous variables (reduced form). In the second step, residuals from reduced form are integrate in final equation (structural form) as additional explanatory variables. By doing this, orthogonality condition for endogeneity variables and error term is respected. Consider the model:

$$y_1 = \sigma_1.z_1 + \alpha_1.y_2 + \epsilon_1; \tag{4}$$

where z_1 is a subvector of exogenous variables z that also includes a constant, and σ_1 and α_1 are parameters to be estimated. The exogeneity of z is given by the orthogonality restriction:

$$E(z'\epsilon_1) = 0 \tag{5}$$

The first step in the CF approach consist to estimate a reduced-form equation of endogenous explanatory variable y_2:

$$y_2 = \pi_2.z + v_2 \tag{6}$$

$$E(z'v_2) = 0 \tag{7}$$

where π_2 are parameters to be estimated. Endogeneity of y_2 arises if there is correlation between ϵ_1 and v_2. The linear projection of ϵ_1 on v_2 in error form is:

$$\epsilon_1 = \phi_1.v_2 + e_1 \tag{8}$$

By definition, $E(v_2e_1) = 0$ and $E(z'e_1) = 0$ because ϵ_1 and v_2 are both uncorrelated with z. In the second step, the residuals obtained from the reduced form estimation are used as an additional explanatory variable in the structural model regression:

$$y_1 = \sigma_1.z_1 + \alpha_1.y_2 + \phi_1.v_2 + e_1 \tag{9}$$

However, v_2 is not observable. We can rewrite $v_2 = y_2 - \pi_2.z$ and consistently estimate π_2 by OLS and replace v_2 with $\hat{v_2}$ the OLS residuals from the first-stage regression of y_2 on z_2. Simple substitution gives:

$$y_1 = \sigma_1.z_1 + \alpha_1.y_2 + c.\hat{v_2} + e_1 \tag{10}$$

Equation (10) is CF estimates, because the inclusion of the residuals $\hat{v_2}$ "**controls**" for the endogeneity of y_2 in the original equation. If the coefficient of $\hat{v_2}$ on the generalized residual is significantly different from zero in the structural model, the explanatory variable of interest, y_2 , is endogenous.

This method is similar to 2LS standard method because both have the same kinds of identification conditions and lead to the same results when endogenous variables appear linear. However, CF approach is better than 2LS when there is a non linearity in endogenous variables[7].

Instruments choice

Our instruments are spatial. To explain deforestation and air pollution of an area, we use respectively the average of deforestation and atmospheric pollution for four bordering areas. These variables have the good properties of an instrument. First, the deforestation and pollution levels of a given municipality are strongly correlated with those of their neighbors. Also, in a given commune, the nutritional status of an individual is weakly correlated with the levels of pollution and deforestation recorded by neighboring localities. Thus, the conditions of rank and exclusivity that a good instrument must fulfill are respected.

5.2 Food security change between households and over time

We use two types of models to estimate the impact of environmental and climate risk on food security. The first is the **"pooled cross section"** to analyze the effect of each risk considered on the difference in nutritional status between households. And "**panel model**" to assess the effect of each risk on the change in nutritional status of households over the three survey periods. The econometric equations are summary as follow:

[7] These advantages are at the asymptotic level and the respect of the conditions of a good instrument i.e exogenous and rank condition

- Reduced forms:

$$deforestation_{j,t} = a_0 + b_0.neighb.deforest_{j,t} + \sum_{i,j,k,t} d_{k0}.Z_{i,j,k,t} + u1_{jt} \tag{11}$$

$$pollution_{j,t} = a_1 + b_1.neighb.poll_{j,t} + \sum_{i,j,k,t} d_{k1}.Z_{i,j,k,t} + u2_{jt} \tag{12}$$

- Structural form:

$$Y_{i,j,t} = \alpha_0 + \sum_{r,j,t} \alpha_{1,r}.NC_{r,j,t} + \sum_{i,j,k,t} \alpha_{2,k}.Z_{i,j,k,t} + year_t + \phi_1.u1_{jt} + \phi_2.u2_{jt} + \epsilon_{ijt} \tag{13}$$

Reduced forms includes the instrumentation equations 11 and 12 of $deforestation$ and $pollution$ variables. Where deforestation and pollution of a commune j are respectively explained by that of their neighbors: $neighb.deforest$ and $neighb.poll$. In structural equation 13, $Y_{i,j,t}$ represents the global indicator FSI and its three components (Food production, PCCI and consumption diversity) for household i live in commune j at time t. NC is the natural capital that represents all eight climate and environmental variables at commune level j: $Temperature$, $Precipitation$[8], $Flood$, $Typhoon$, $Drought$, $Airpollution$, $Deforestation$ and $Slope$. $year$ is a dummy for each period (2010 2012 2014) of our panel data . These temporal dummies catch here the common shocks (e.g. price shocks, macroeconomic policy) to our entire sample. This reduces the possibility that some unobserved variant variables could be correlated with our risk variables. And $u1_{jt}$ and $u2_{jt}$ are residuals from reduced form and non correlated with error term $\epsilon_{i,j,t}$.

5.3 Food security stability: difference between households and evolution over time

As we have shown in the section above, the global indicator of food security FSI and each of its components are unstable over the study period. This instability results in the movement of an individual from one group of tertiles to another. For each component, we identify three groups of individuals according to the tertile of belonging: T1: less food secure, T2: Medium food secure and T3: High food secure. This classification being ordered, we use an ordered probit model. The principle of ordered probit is to identify factors that are associated with the probability that a household belongs to a better tertile (from less food secure(1) to high food secure (3) status) according to the FSI indicator

[8]For one year, temperature and precipitation measure respectively annual temperature and precipitation deviation to their five last year average.

and each of its dimensions. The reduced form is that defined by equations 11 and 12. Consider Q^*, the latent variable that classifies individuals according to their nutritional status. So we have tertiles ($q1$, $q2$ et $q3$) for FSI global index and each of its dimensions (Food production, PCCI and consumption diversity) and explained by same explanatory variables used in previous models.

$$Q^* = \alpha_0 + \sum_{r,j,t} \beta_{1,r}.NC_{r,j,t} + \sum_{i,j,k,t} \beta_{3,k}.Z_{i,j,k,t} + year_t + u1_{jt} + u2_{jt} + \epsilon_{ijt}, \tag{14}$$

The structural form is defined as:

$$Prob(Qit = q) = \Phi(NC_{r,j,t}, Z_{i,j,k,t}, year_t, u1_{jt}, u2_{jt}) \tag{15}$$

with q=1, 2, 3.

In this model, the dependent variable is the probability that household belongs to tertile q. ϕ is the distribution function of residual term ϵ_{ijt} from equation 15; ϵ_{ijt} is assumed to follow a reduced centered normal distribution . With pooled cross section, this estimation makes it possible to understand the difference in nutritional status between the different groups of quintile. The panel estimation allows to identify the factors that facilitate or hinder the transition from one group to another over time.

6 Results

Table 5 presents descriptive statistic about climate, environment and household characteristics variables. We observe that the occurrence of natural disasters is regular phenomenon in Vietnam. About 15%, 16% and 11% of Vietnam commune are respectively affected by $flood$, *typhoon* and *drought*. Descriptive statistics show an increasing pathway of temperature (0.27°C) and diminishing in precipitation level (-0.028mm). Otherwise deforestation, pollution and geographic structure are very heterogeneous. Area deforested varies from 0 to 14.35 ha. The level of minimal value of PM2.5 concentration is 4.14 $\mu g/m3$ while maximal value is 44.34 $\mu g/m3$ which correspond to 40 $\mu g/m3$ as extend. Also the standard deviation of area slope is very high (15%) with %1.71 and 57.98% as minimum and maximum value.
These figures allow to understand the potential climate and environmental risk that faced Vietnamese households. As we showed in section 1.2, these risks could affect people well-being by many ways.

Table 6, results from pooled cross section estimation, help to identify the ways that live in a risk area could affect household nutritional status. In column 1, the dependent variable is food security indicator from the PCA analysis. Among three natural disaster variables, only the occurrence of floods negatively affects food security. Indeed, an occurrence of flood would lead to a decrease of food security indicator by 0.02 unit. This result is statistically significant at a

Table 5: Descriptive statistics of explanatory variables

Variable	Mean	Std. Dev.	Min	Max
flood	.15	.36	0	1
typhoon	.16	.37	0	1
drought	.11	.31	0	1
temperature deviation	.27	1.81	-18.69	32.88
precipitation deviation	-.03	1.32	-11.92	4.89
deforestation	.14	.50	0	14.35
PM2.5	24.26	11.97	4.15	44.34
slope	14.32	14.16	1.71	57.98
gender	1.17	.37	1	2
age	48.57	13.47	16	99
education	1.48	1.28	0	9
HH_size	4.11	1.57	1	15

Notes: Temperature and precipitation are measured as deviation to last five years average level.

threshold of 1%. Even if the marginal impact of the typhon and drought is not significant, the negative sign of the coefficients corresponds to our expectation. This link is more highlighted by the columns (2), (3), (4) and (5).). In column (2), the occurrence of floods and typhoon have a negative and significant impact on the value of agricultural production while the effect of drought is not significant. This non-significance of drought can be explained by the importance of irrigation (more than 40%) used as a strategy for adapting to climate change in agricultural production in Vietnam. However, mitigation systems for other types of disasters such as drainage for flood and dike systems for typhoons are not sufficiently developed. In column (3), none of natural disasters have a significant effect on the number of calorie per capita consumed. This result is not surprising, as there are surely substituability mechanisms in household consumption patterns. They also choose to consume foods that are cheaper compared to foods that are priced higher because of climate shocks. This assertion is confirmed by columns (4) and (5). Diversity indicators in consumption are negatively affected by the occurrence of the three types of natural disasters considered: Flood (-0.03), Typhoon (-0.02), and Drought (-0.03). So we can say that to cope with the occurrence of natural disasters, households tend to less diversify their consumption basket.

Moreover, a temperature or precipitation shock causes a decrease in the global indicator. A deviation of 1 °C (1000mm) from the temperature (precipitation) compared to its trend of the last five years corresponds to a decrease of the FSI by 0.003 (0.008), for a significance threshold of 1 %. Analysis for each dimension of food security does not say the opposite.

Temperature shocks have negative effects on each of the dimensions: Production value (-4 %), PCCI (-0.7 %), Simpson index (-0.001) and Shanon index (-0.005). Similarly for the deviation

Table 6: Food security, weather shocks and environment risk: Pooled cross section estimation

VARIABLES	(1) FSI	(2) Production value	(3) PCCI	(4) Simpson index	(5) Shanon index
Flood	-0.0197***	-0.198***	-0.0155	-0.0140***	-0.0349***
	(0.00288)	(0.0281)	(0.0128)	(0.00313)	(0.00617)
Typhoon	-0.00311	-0.0416*	-0.0116	-0.00961**	-0.0199**
	(0.00217)	(0.0225)	(0.0103)	(0.00369)	(0.00752)
Drought	-0.00355	-0.0247	0.00227	-0.0140***	-0.0295***
	(0.00415)	(0.0420)	(0.0125)	(0.00408)	(0.00871)
Temperature	-0.00339***	-0.0412***	-0.00660**	-0.00174**	-0.00529***
	(0.000726)	(0.00761)	(0.00295)	(0.000809)	(0.00151)
Precipitation	-8.05e-06**	-8.92e-05**	-2.80e-05**	3.18e-06	-6.62e-07
	(3.32e-06)	(3.50e-05)	(1.28e-05)	(3.40e-06)	(7.37e-06)
deforestation	-0.000783	-0.0232	-0.0208***	-0.00362	-0.00929
	(0.00302)	(0.0289)	(0.00613)	(0.00379)	(0.00768)
PM2.5	-0.00294***	-0.0236***	-0.000945***	-0.000869***	-0.00256***
	(0.000108)	(0.00127)	(0.000308)	(0.000108)	(0.000230)
slope	-0.000290**	-0.00867***	-0.00113**	-0.00168***	-0.00367***
	(0.000140)	(0.00129)	(0.000444)	(0.000153)	(0.000326)
gender	-0.0307***	-0.304***	-0.0728***	0.00207	0.0105
	(0.00372)	(0.0379)	(0.00928)	(0.00344)	(0.00701)
age	-0.000442***	-0.00370***	-0.00416***	-0.000127	-0.000421**
	(0.000124)	(0.00122)	(0.000366)	(0.000105)	(0.000200)
education	0.00113	-0.00133	0.0282***	0.00963***	0.0179***
	(0.00119)	(0.0132)	(0.00420)	(0.00130)	(0.00271)
HH size	0.0139***	0.158***	-0.0141***	-0.00834***	-0.0167***
	(0.000713)	(0.00870)	(0.00219)	(0.000831)	(0.00181)
ethnicity	-0.0204***	-0.131***	0.0485***	0.0500***	0.0999***
	(0.00390)	(0.0415)	(0.0146)	(0.00447)	(0.00942)
2012	-0.0110***	-0.0754*	-0.0597***	-0.00244	-0.0159**
	(0.00368)	(0.0386)	(0.00928)	(0.00352)	(0.00664)
2014	-0.0104***	-0.00689	-0.0791***	0.0194***	0.0361***
	(0.00310)	(0.0329)	(0.0110)	(0.00398)	(0.00768)
Constant	0.558***	10.29***	8.823***	0.600***	1.308***
	(0.00940)	(0.1000)	(0.0241)	(0.00884)	(0.0187)
Observations	11,952	11,952	11,952	11,952	11,952
R-squared	0.179	0.130	0.063	0.174	0.180

Notes: this table indicates coefficients estimated from ‘Pooled’ Cross-section model using Ordinary Least Squares. ∗0.10, ∗∗0.05, ∗∗∗0.01 significance level. Values in parentheses indicate standard errors corrected for cluster correlation at the commune level.

of precipitation levels except that the effect on the diversity dimension is not significant.

As shown in the section above, the effect of deforestation on food security is ambiguous because its function is to smooth income (consumption) on the one hand and to reduce ecological services on the other. The results from Table 6 show that it only impacts the accessibility dimension that is captured here by PCCI variable, the effect on the other dimensions and the overall indicator not being significant. Pollution has negative effects on the overall FSI indicator and all of these dimensions. These effects are statistically significant at the 1% level. We will provide a thorough interpretation of the results of these two variables after taking into account the endogeneity problem they present.

The average slope of agricultural land plays a very important role in the development of agricultural practices which are the main key factors of food security. There is a negative effect of high slope agricultural areas on the overall indicator of food security and on each of its dimensions. A high slope necessarily requires additional efforts to increase the agricultural yield which conditions the value of agricultural production. In addition, self-consumption plays an important role in the consumption basket of rural households. So, a shock on the agricultural yield would lead to a decrease in terms of the number of calories consumed. As the household income is affected because of the value of agricultural production, the latter is restricted to having access to several foodstuffs, so the diversity dimension is also negatively affected.

Regarding sociodemographic characteristics, we observe that households with chief woman are relatively less food secure than men. However, there is no significant difference in terms of dietary diversification between men and women. If the difference existed, it would be positive, which would indicate that women tend to diversify their food basket more than men. Education of head household plays a positive role in the diversification of consumption and the number of calories consumed by the household. The effect of household size on food security is heterogeneous. First of all, size can be considered as a labor factor for an agricultural household and thus contribute to the improvement of agricultural production. This is observed in column (2) where one more individual in the household has a positive effect on the value of agricultural production (16%). However, household size is not favorable to accessibility and diversity dimensions. This result is consistent with the accessibility indicator we use: PCCI. Indeed, the larger the household size, the lower the food intake of an individual in this household. Similarly, for the diversity dimension, the size of the household restricts the probability of diversification of the consumption basket. It would be more expensive for a large household to diversify their diet because it will require a significant amount of each food for it to be sufficiently consumed by each member of the household. Column (1) shows that the positive effect of size on the value of agricultural production outweighs its negative effects on the other dimensions. This translates into a positive total effect on the food security indicator.

Kinh group have more access to food and diversify their consumption basket relatively to minority ethnic groups.

6.1 Endogeneity issues

Deforestation and air pollution are subject to endogeneity issues for many reasons explained above. Tables 7 and 8 show the results from control function approach to take into account this concern. Reduced forms estimation are summarized in table 7. Results from estimation of reduced form (11) and (12) are shown respectively in column 1 and 2. Two instruments (neighbor level of deforestation and pollution) are very relevant, statistically significant at 1% and impact positively endogenous variables. One Km2 increase in commune neighbor deforestation increase 0.65 its deforestation level and one $\mu g/m3$ increase in PM2.5 concentration around commune increase its PM2.5 by 1 $\mu g/m3$. Table 8 shows the results after taking into account for endogenity issues about deforestation and air pollution variables. For deforestation, this correction allows to extract income effect in its global effect observed in table 13. Marginal impact of deforestation in PCCI has been multiplied by 3. The diminishing of vegetation cover from 1 km2 decreases per capita calories intakes by 6.7%. Similarly, the marginal impact of deforestation on diversity in consumption is significant and the magnitude has multiplied by 10 (from -0.0036 in table 13 to 0.024 in table 8).

Regarding air pollution, the effects do not really change after correcting for endogenous. However, we can not conclude that there is not a problem of endogeneity. As can be seen in Table 6, the association between the pollution variable and its instrument is almost perfect. This means that there is no significant difference between the PM2.5 concentration of an area and that of its neighbors. Another instrument could better analyze the endogeneity of this variable. For now, we do not have one.

To assess the change of FSI and its dimensions over time, we use panel random effect estimation. Among our explanatory variables, there are variables that do not vary a lot(deforestation) and even non-variant (slope). Thus, the estimation with the fixed-effect model will not make it possible to know the effect of these variables. Results from table A4 confirm that risk variables explain the difference in food security status between households and its changing over the three periods considered (2010, 2012 and 2014). There is no important difference with pooling cross section analysis (cf. table 8) in terms of sign and magnitudes of risk variables.

6.2 Food security stability change between households and over time

Table 9 presents the result of the estimation of equation 15 with the ordered probit model. Remember that the dependent variable is the probability to belong to a given tertile group. For each dimension, T1 is defined as the group of the least secure, T2 moderately secure and T 3 most secure. In the table, we do not have the marginal impacts directly. However, the sign of the coefficient is the same as that of the marginal impacts. Thus, we will interpret the impact of the risk variables in terms of sign and their statistical significance. Among our risk variables, it is noted that the occurrence of floods, temperature deviations, air pollution, and large slopes reduce the probability of an individual to have a better state of food security (cf. column 1). These variables are significant at the 1% level. Nutritional inequalities are deep in areas with

Table 7: Estimation of reduced forms equations

VARIABLES	(1) deforestation	(2) PM 2.5
neighb.deforest	0.650***	
	(0.110)	
neighb.poll		0.999***
		(0.000766)
Flood	0.0293*	-0.0687**
	(0.0165)	(0.0276)
Typhoon	0.0147	-0.00399
	(0.0177)	(0.0232)
Drought	-0.0309**	-0.0547
	(0.0128)	(0.0500)
Temperature	0.00639	-0.00572
	(0.00467)	(0.00522)
Precipitation	-2.07e-05	9.95e-06
	(3.37e-05)	(2.44e-05)
slope	0.00542***	-0.00194**
	(0.00105)	(0.000790)
gender	0.00794	0.0157
	(0.0101)	(0.0132)
age	-0.000800*	-0.000935**
	(0.000441)	(0.000354)
education	-0.00609**	-0.00102
	(0.00264)	(0.00397)
HH size	-0.000564	-3.73e-05
	(0.00258)	(0.00400)
ethnicity	0.0670***	-0.0608***
	(0.0247)	(0.0201)
2012.year	-0.000317	-0.0162
	(0.0164)	(0.0145)
2014.year	-0.00266	-0.00761
	(0.0141)	(0.0147)
Constant	-0.0200	0.0898**
	(0.0403)	(0.0353)
Observations	11,952	11,952
R-squared	0.214	0.999

Notes: this table indicates coefficients estimated from reduced equations by 'Pooled' Cross-section model using control function approach. *0.10, **0.05, ***0.01 significance level. Values in parentheses indicate standard errors corrected for cluster correlation at the commune level.

Table 8: Food security, weather shocks and environment risk: IV+ Pooled cross section estimation

VARIABLES	(1) FSI	(2) Production value	(3) PCCI	(4) Simpson index	(5) Shanon index
Flood	-0.0202***	-0.201***	-0.0137	-0.0131***	-0.0329***
	(0.00290)	(0.0288)	(0.0130)	(0.00305)	(0.00599)
Typhoon	-0.00329	-0.0424*	-0.0111	-0.00932**	-0.0192**
	(0.00200)	(0.0216)	(0.0104)	(0.00365)	(0.00748)
Drought	-0.00311	-0.0228	0.000429	-0.0148***	-0.0314***
	(0.00431)	(0.0445)	(0.0127)	(0.00400)	(0.00835)
Temperature	-0.00355***	-0.0419***	-0.00602*	-0.00146*	-0.00467***
	(0.000759)	(0.00784)	(0.00318)	(0.000830)	(0.00154)
Precipitation	-8.09e-06**	-8.92e-05**	-2.74e-05**	3.35e-06	-3.04e-07
	(3.20e-06)	(3.46e-05)	(1.29e-05)	(3.43e-06)	(7.43e-06)
deforestation	0.0102	0.0237	-0.0665***	-0.0245**	-0.0552***
	(0.00780)	(0.0845)	(0.0240)	(0.00979)	(0.0187)
PM2.5	-0.00291***	-0.0235***	-0.00110***	-0.000928***	-0.00268***
	(0.000104)	(0.00122)	(0.000329)	(0.000114)	(0.000242)
slope	-0.000392**	-0.00910***	-0.000705	-0.00148***	-0.00325***
	(0.000147)	(0.00132)	(0.000464)	(0.000186)	(0.000376)
gender	-0.0308***	-0.304***	-0.0725***	0.00221	0.0108
	(0.00376)	(0.0381)	(0.00934)	(0.00341)	(0.00691)
age	-0.000430***	-0.00365***	-0.00421***	-0.000151	-0.000472**
	(0.000125)	(0.00121)	(0.000380)	(0.000104)	(0.000195)
education	0.00122	-0.000923	0.0280***	0.00949***	0.0176***
	(0.00118)	(0.0132)	(0.00417)	(0.00129)	(0.00268)
HH size	0.0139***	0.158***	-0.0141***	-0.00836***	-0.0168***
	(0.000725)	(0.00881)	(0.00219)	(0.000834)	(0.00182)
ethnicity	-0.0210***	-0.134***	0.0509***	0.0511***	0.102***
	(0.00398)	(0.0420)	(0.0145)	(0.00447)	(0.00932)
u1	-0.0131	-0.0556	0.0540**	0.0247**	0.0543***
	(0.00802)	(0.0888)	(0.0258)	(0.00970)	(0.0190)
u2	0.00786**	0.0546	0.0135*	-0.00461	-0.0129
	(0.00349)	(0.0367)	(0.00721)	(0.00407)	(0.00885)
2012.year	-0.0112***	-0.0760*	-0.0595***	-0.00229	-0.0155**
	(0.00374)	(0.0389)	(0.00921)	(0.00352)	(0.00667)
2014.year	-0.0104***	-0.00680	-0.0792***	0.0193***	0.0360***
	(0.00314)	(0.0333)	(0.0111)	(0.00393)	(0.00751)
Constant	0.557***	10.29***	8.827***	0.601***	1.312***
	(0.00933)	(0.0999)	(0.0245)	(0.00877)	(0.0186)
Observations	11,952	11,952	11,952	11,952	11,952
R-squared	0.180	0.130	0.064	0.175	0.181

Notes: this table indicates coefficients estimated from structural forms by 'Pooled' Cross-section model using control function approach. *0.10, **0.05, ***0.01 significance level. Values in parentheses indicate standard errors corrected for cluster correlation at the commune level.

Table 9: Stability of food security, weather shocks and environment risk: IV+ ordered probit estimation

VARIABLES	(1) FSI	(2) Production Value	(3) PCCI	(4) Simpson index	(5) Shanon index
Flood	-0.251***	-0.225***	-0.0433	-0.121***	-0.172***
	(0.0273)	(0.0255)	(0.0360)	(0.0372)	(0.0314)
Typhoon	-0.0333	-0.0362	-0.0568*	-0.102***	-0.104***
	(0.0232)	(0.0241)	(0.0345)	(0.0373)	(0.0347)
Drought	-0.0149	-0.0266	-0.0221	-0.119***	-0.129***
	(0.0501)	(0.0457)	(0.0416)	(0.0330)	(0.0366)
Temperature	-0.0345***	-0.0524***	-0.0276***	-0.0118	-0.0155
	(0.00958)	(0.00843)	(0.00976)	(0.0109)	(0.0109)
Precipitation	-5.31e-05	-9.02e-05**	-0.000121***	7.04e-05**	3.36e-05
	(4.05e-05)	(3.88e-05)	(4.46e-05)	(3.21e-05)	(2.96e-05)
Deforestation	0.0688	-0.0159	-0.234***	-0.170***	-0.185***
	(0.116)	(0.0906)	(0.0630)	(0.0647)	(0.0708)
PM2.5	-0.0311***	-0.0223***	-0.00326***	-0.00805***	-0.0116***
	(0.00145)	(0.00129)	(0.000918)	(0.00111)	(0.00104)
Slope	-0.00359**	-0.0110***	-0.00275*	-0.0143***	-0.0149***
	(0.00173)	(0.00140)	(0.00153)	(0.00185)	(0.00165)
gender	-0.326***	-0.297***	-0.199***	0.0154	0.0383
	(0.0345)	(0.0359)	(0.0354)	(0.0302)	(0.0285)
age	-0.00205	-3.02e-05	-0.0134***	-0.00199**	-0.00190**
	(0.00160)	(0.00135)	(0.00123)	(0.000987)	(0.000902)
education	0.0111	0.00310	0.0761***	0.0897***	0.0767***
	(0.0121)	(0.0127)	(0.0104)	(0.0122)	(0.0118)
HH size	0.147***	0.170***	-0.0580***	-0.0617***	-0.0690***
	(0.0106)	(0.0119)	(0.00533)	(0.00768)	(0.00728)
ethnicity	-0.330***	-0.257***	0.150***	0.423***	0.420***
	(0.0433)	(0.0388)	(0.0384)	(0.0485)	(0.0443)
u1	-0.129	-0.0294	0.183***	0.164***	0.176**
	(0.118)	(0.0871)	(0.0625)	(0.0621)	(0.0776)
u2	0.0924**	0.0682	0.0316	-0.0373	-0.0510
	(0.0368)	(0.0430)	(0.0198)	(0.0486)	(0.0514)
2012.year	-0.119***	-0.109***	-0.244***	-0.00105	-0.0656
	(0.0361)	(0.0340)	(0.0319)	(0.0374)	(0.0407)
2014.year	-0.169***	-0.0453	-0.298***	0.183***	0.157***
	(0.0318)	(0.0312)	(0.0325)	(0.0393)	(0.0430)
/cut1	-1.505***	-1.096***	-1.699***	-0.809***	-0.971***
	(0.131)	(0.117)	(0.0789)	(0.0801)	(0.0766)
/cut2	-0.509***	-0.161	-0.803***	0.170**	0.0210
	(0.130)	(0.123)	(0.0811)	(0.0822)	(0.0769)
Observations	11,952	11,952	11,952	11,952	11,952
Pseudo R-squared	0.0687	0.0687	0.0687	0.0687	0.0687
Wald Chi2(17)	4268	4268	4268	4268	4268

Notes: this table indicates coefficients estimated from structural forms by ordered probit model with 3 categories (always-insecured (T1), vulnerable (T2) and always secured (T3),) using control function approach. *0.10, **0.05, ***0.01 significance level. Values in parentheses indicate standard errors corrected for cluster correlation at the commune level.

high climatic and environmental risks. The other risk variables are not significant. The analysis of the different dimensions does not say the opposite. In Column 2, the dependent variable is the probability that a household belongs to a tertile group according to the value of its agricultural production. In addition to the factors that were significant for the first column, significant rainfall deviations impact negatively the likelihood that a household will be in a better and stable nutritional status. In column 3, we are interested in the accessibility dimension that is reflected in this model by the inequality in households consumption. The results show that our risk variables, apart from the occurrence of typhoons and droughts, reduce the probability of a household being in the group of households that have more access to sufficient food in terms of per capita calories intakes. Finally, in columns 4 and 5, we see the same results for stability in the diversification of consumption. Here, all natural disaster variables are statistically significant at the 1% level with negative effects on the likelihood that an individual will further diversify his consumption basket. Only the deviation of the average temperature level is not significant even if its sign corresponds to our expectation.

In panel analysis, the objective is to take into account the temporal dimension of our data, which will allow us not only to compare the groups of households with each other but also to monitor the evolution of the nutritional status of each household over time. Table A5 confirms the results found in cross section. It can therefore be said that climatic and environmental risks increase nutritional inequalities among individuals and affect the stability of the nutritional status of rural households over time.

All these results are in phase with our expectations, i.e living in a risky area increases the instability of the nutritional status of households. This result is true for all dimensions of food security. In fact, households with better nutritional status in any year are very vulnerable to climate and environmental risks in the following years. The last tertile group (T3) may see their nutritional status deteriorated at the occurrence of climatic shocks or because they live in an area that presents a high risk in terms of deforestation, pollution or even unfavorable to agricultural practice (high slope of land). Similarly, for households with poor nutritional status, there is a risk of trapping this situation.

7 Conclusion and policies recommendations

Vietnam is a country with a high environmental and climate risk and agriculture remains the key sector that employs rural households. In this study, we analyze the association between two risks (environmental and climate) and food security of rural households. Food security is understood in all four dimensions (availability, accessibility, diversity and stability) through composit index. In addition, we deal with endogeneity concern of some risk variables (deforestation and pollution), which could hinder this link, using control function method by Wooldridge (2015).
Our results show that living in risky areas affects negatively nutritional status of rural households. The magnitude and significance of this link depends on the nature of the risk on the one hand and the dimension of food security considered on the other.
Among three natural disasters considered, only flood impact negatively global food security in-

dex (FSI). While, Flood and typhoon have negative effect on agriculture production value; three natural disasters are detrimental for diversity dimension and none of these disasters have an effect on accessibility dimension. About temperature and precipitation deviations, both of these variable have negative effect on FSI and each of its components excepted diversity dimension which is only affected by temperature deviation. Also, availability dimension is most affected than other by these two weather shocks. The effect of deforestation must be interpreted with caution because deforestation could increase food production by extensification process but also diminished ecological services and limit their access to households. Our findings confirm this ambiguity. We find that deforestation affects negatively accessibility and diversity dimensions but have no effect on production value. Air pollution significantly explains all components of food security. The main channel that would explain this link would potentially be the health status of people living in a polluted area that would necessarily affect their productivity (avaibility dimension) and their ability to consume (accessibility). Unfortunately the accessibility dimension is not perfectly measured because we do not have information on the amount of calories actually consumed per household but rather on the amount of food purchased in the household. We therefore make the assumption that all the quantity purchased is actually consumed. Higher slope tends also to deteriorate household food security status. This is true for all component of food security but the magnitude effect is more important for avaibility dimension. Finaly, these risks variables have negative effects on the stability of global food security index and all of its components (avaibility, accessibility and diversity). We can note the PM2.5 concentration and higher slope effects are persitents on all food security components considered.

Climate and environmental risk are among the main factors that slow down Vietnamese rural households' ability to achieve a better nutritional status in all its dimensions (availability, accessibility, diversity and stability). Then, political intervention is needed to make rural households more resilient to these risk factors. First, Think about the diversification of the income portfolio of rural households with the aim of reducing their dependence on the income of agriculture, which is conditioned by weather shocks. To facilitate access to foods, it will be necessary to create opportunities for them to relax their liquidity constraint which limits their access to various quality foods. Relaxation of liquidity constraints may be possible through the development of microfinance activities in rural areas or social protection through Weather index insurance for agriculture (Barnett and Mahul, 2007). And government must boost mechanisms to fight climate change by setting up more modern irrigation and drainage systems. Or seasonal weather services to anticipate temperature and precipitation shocks.The fight against deforestation and pollution are also to be encouraged. Moreover, in the implementation of policies to improve agricultural yield, a favor is given to farmers whose farms are in areas with unfavorable geographical characteristics (a fairly high average slope). Indeed, households residing in areas where the average slope of farmland is quite high, must make more effort than others to have better productivity. Also, Access to modern inputs remains a necessity for rural households.

However, our analysis has some limitations. The data we use are not purely nutritional and therefore limit the measurement of the different dimensions of food security. Also, due to a lack of data, we do not test the above-mentioned mechanisms that can mitigate the effect of the risks on the nutritional status of rural Vietnamese households. Future studies could use nutritional survey data and test the effectiveness of the set of policy recommendations to identify the best intervention policies.

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APPENDIX

PCCI calculation

TCI

In our analysis accessibility dimension of food security is measured with Total Calories Intakes (TCI) by household. TCI measures total nutritional intake for each food item consumed by household. For each household, VHLSS provides information about all of food items consumed during the last twelve months. Otherwise one section is dedicated to consumption expenditure during festive periods which are high food consumption period. We are information about quantity and expenditure value by items consumed. Thus we use conversion table from Vietnamese National Institute of Nutrition in 2007 (Table A1) to convert quantity consumed to TCI for each item.

Limits of VHLSS data

VHLSS isn't nutritional survey then there is not easy to make nutritional analysis because of data limit. Some foods items have not information about quantity consumed. Only expenditure value is available. For these last ones, we follow method elaborated by Hoang et al. (2009) and Thi et al. (2018):

- First, we compute the median of one calorie price[9] of food items for which both quantity (and thus the corresponding TCI value) and expenditure value are available.
- Second, for each food item with only expenditure value, TCI is approximate by dividing expenditure value by the median calorie price from the

Another limit of nutritional data from VHLSS is the fact that information about quantity and expenditure of food items are those purchased and not directly consumed by household. The last information is the best to understand accessibility dimension of food security. However, expenditure or quantity purchased for one food item is strongly correlated with the actual consumption of that food. So our approach can be acceptable.

Equivalence scales (ES)

It is difficult to make nutritional status comparison across individuals in our sample since TCI is computed household level while households differ in size and composition (age structure). Thus, for best quantitative analysis is necessary to take into account these elements in TCI calculation. Common practice use equivalence scale to make households comparable by normalizing TCI value at household level by equivalence scales. This method allows to swicth from TCI by

[9]Price of one calorie correspond to the ratio between expenditure value and total calorie intake for this item. This calculation is desegregated by geographic unit and consumption period (festive or non festive)

Table A1: Conversion tablle from National Institute of Nutrition (2007).

item__grp	groupe	item__cod	Food type	gram	fd__kcal
1	Cereal and other starches	101	Ordinary rice	1000	353
1	Cereal and other starches	102	Glutinous rice	1000	355
1	Cereal and other starches	103	Corn/maize	1000	364
1	Cereal and other starches	104	Cassava	1000	156
1	Cereal and other starches	105	Potatoes	1000	108,8
1	Cereal and other starches	106	Bread, wheat, flour	1000	301,5
1	Cereal and other starches	107	Noodle, pho noodle,instant rice soup	1000	358
1	Cereal and other starches	108	Rice noodle	1000	340
1	Cereal and other starches	109	Vermicelli	1000	128,5
2	Meat Fish tofu rich protein	110	Pork	1000	395,6
2	Meat Fish tofu rich protein	111	Beef	1000	123,3
2	Meat Fish tofu rich protein	112	Buffalo s meat	1000	123,3
2	Meat Fish tofu rich protein	113	Chicken	1000	175,9
2	Meat Fish tofu rich protein	114	Duck and other poultry meat	1000	126
2	Meat Fish tofu rich protein	115	Other meat	1000	x
2	Meat Fish tofu rich protein	116	Processed meat	1000	325,9
3	Fats and oils	117	Fat and oil	1000	927
2	Meat Fish tofu rich protein	118	Fresh fish, shrimp	1000	90
2	Meat Fish tofu rich protein	119	Dried and processed fish and shrimp	1000	240,9
2	Meat Fish tofu rich protein	120	Other seafood (crab, snails etc.)	1000	x
2	Meat Fish tofu rich protein	121	Chicken or duck eggs (per one)	50	7,8
2	Meat Fish tofu rich protein	122	Tofu	1000	98
4	Vegetables	123	Peanuts, sesame seeds	1000	544,5
4	Vegetables	124	Beans	1000	314,2
4	Vegetables	125	Fresh peas	1000	73,5
4	Vegetables	126	Water morning glory	1000	21
4	Vegetables	127	Kohlrabi	1000	30
4	Vegetables	128	Cabbage	1000	37
4	Vegetables	129	Tomatoes	1000	37
4	Vegetables	130	Other vegetables	1000	x
5	Fruits	131	Oranges	1000	43
5	Fruits	132	Bananas	1000	83
5	Fruits	133	Mangoes	1000	29
5	Fruits	134	Other fruits	1000	x
8	Food Away From Home	135	Fish sauce and dipping sauce	1000	33,2
8	Food Away From Home	136	Salt	1000	0
8	Food Away From Home	137	Spices,powdered soup	1000	0
8	Food Away From Home	138	Food seasoning	1000	0
6	Sugar and drink	139	Sugar, molasses	1000	390
8	Food Away From Home	140	Cakes, jams, sweets	1000	402,6
7	Milk and other dairy product	141	Condensed milk,powdered milk	1000	354,4
7	Milk and other dairy product	142	Ice creams,yoghurtsa	1000	50
7	Milk and other dairy product	143	Fresh milk	1000	86,8
6	Sugar and drink	144	Liquor	1000	47
6	Sugar and drink	145	Beer	1000	47
6	Sugar and drink	146	Bottled & canned refreshment	1000	47
6	Sugar and drink	147	Instant coffeea	1000	0
6	Sugar and drink	148	Powdered coffee	1000	129
6	Sugar and drink	149	Powdered tea/instant tea	1000	0
6	Sugar and drink	150	Dried tea	1000	0
8	Food Away From Home	153	Outdoor meals	1000	x
8	Food Away From Home	154	Others	1000	x

household to its corresponding value at a person's level called Per Capita Calorie Intake (PCCI). The idea of PCCI is to get comparable numbers among households. Sometimes, PCCI is refered as adult equivalent calorie intake.

There are several methods to compute equivalence scale:

(i) **Household size**: This method consist to normalized consumption or welfare variable collected at household level by household size. It's generally used because of its simplicity.

(ii) **OECD** equivalent scales: The first method limit household demographic characteristics to household size only. While households could differs from gender and age composition. To deal it, OECDE integrate age in ES calculation:

$$ES_{OECDE} = 1 + 0.7 * adult + 0.5 * child \tag{16}$$

adult correspond to the number of adults other than the houshold head (age above to 18) and *child* is the number of children (below to 18) in the household whatever member gender. There is also modified OECDE equivalence scales which differs from the first one by the weight associated to *adult* (0.5) and *child* (0.3).

(iii) Method by Aguiar and Hurst (2013): to compute ES, the authors purpose to take into account gender, age and household localisation (urban vs rural). This method consist to estimate separately ES according to geographical localisation and VHLSS wave: First, the following regression model is estimùated separately by area of residence (urban vs rural):

$$log(TCI_i) = \gamma_0 + \gamma_1 gender_i + \gamma_2 Adult_i + \gamma_3 Child_{a,g,i} + \epsilon_i \tag{17}$$

where TCI_i is total household i calorie intake, $gender_i$ is the gender of the head of the household ($gender$ equal to 0 ih HH is male and 1 otherwise), $adult_i$ is the number adult other than household head in the household other than the head, and $child_{a,g,i}$ counts the numbers of children by gender (g) and age categories (a: 0-2; 3-5; 6-13; and 14-17) in household i.

Second, TCI_i for singleton households (i.e Household Head only which correspond to adult equivalent.) is predicted and correspond to ES_i:

$$ES_i = \begin{cases} e^{\gamma_0} & \text{if } HH \text{ gender is male} \\ e^{\gamma_0 + \gamma_1} & \text{if } HH \text{ gender is female} \end{cases} \tag{18}$$

In this sutdy, we use the last method from Aguiar and Hurst (2013) to generate household equivalence scale because of its complete relatively to others. This way to compute households ES is the same used by Santaeulàlia-Llopis and Zheng (2017) and Thi et al. (2018).

Per capita calorie intake (PCCI) or adult equivalent calorie intake, is then computed as the ratio of household total calorie intake and household equivalence scale. We find that, on average, a rural vietnamese household consumes about 4985 kcal per day over 2010-2014 period. This value is consistent and similar to other studies: Thi et al. (2018) (3631 kcal); FAO, 2015 (2713 kcal) and Nguyen and Winters (2011) (3212 kcal). The difference is marginal and can be explained by PCCI calculation method used in each study.

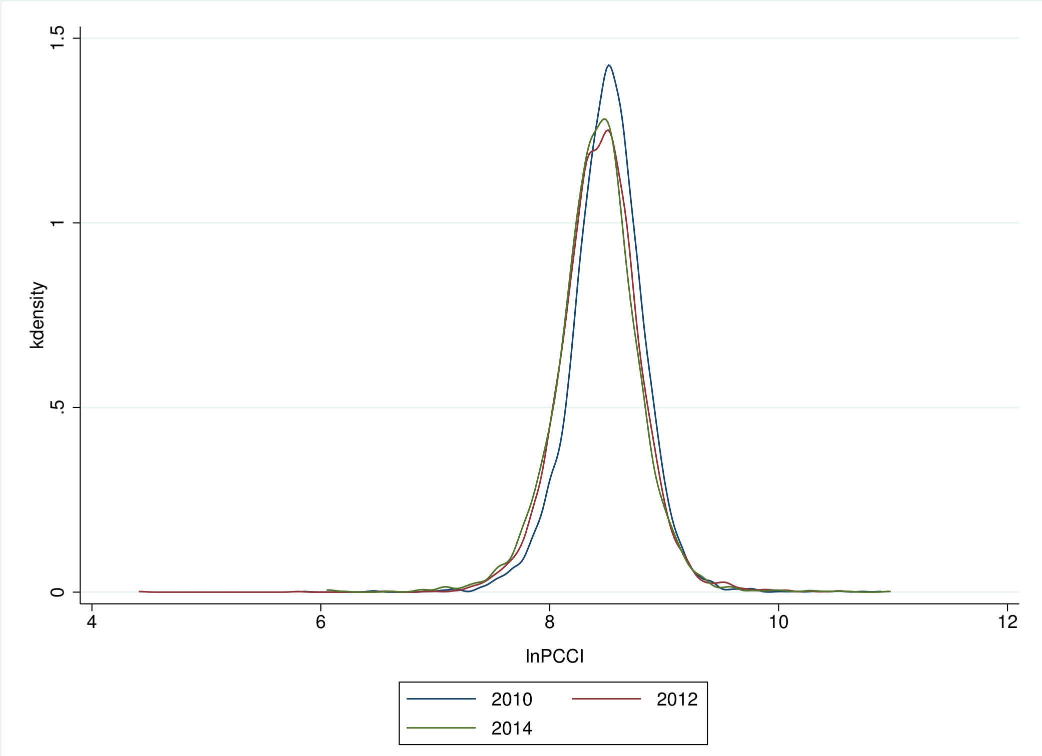

Figure A1: Kernel distribution of PCCI logarithm

Diversity index

In literature, diversity dimension of food security is assessed using diversity index. Diversity index must allow to catch the variety of food items consumed by household. Generally, the number of food items or food groups in the household is used to compute diversity index. However, this way to compute diversity index doesn't capture the degree of concentration in households food basket. Since, nutrient levels vary between food items and food groups, the weight of each food groups in total calories intake by household must be considered. To take into account this aspect, we follow Nguyen and Winters (2011) by using two type of dietary and production diversity index:

$$Simpson.index = 1 - \sum_i w_i^2 \tag{19}$$

where i identifies the food groups. We distinguish eight food groups[10]: *(i) Cereal and other starches, (ii) Meat, fish, tofu, rich protein, (iii) Fats and oils, (iv) Vegetables, (v) Fruits, (vi) Milk and other dairy products, (vii) Sugar and beverages, and (viii) Food away from home.* w_i is calorie share of food group i. Simpson's index ranges from zero (no diversified) to one (more diversified). Otherwise, Shannon' index measures the concentration degree of food groups, and

[10]For production diversity index, we identify 4 cultures: (i) Rice, (ii) Staple non food, (iii) Industrial crops and (iv) Fruits crops.

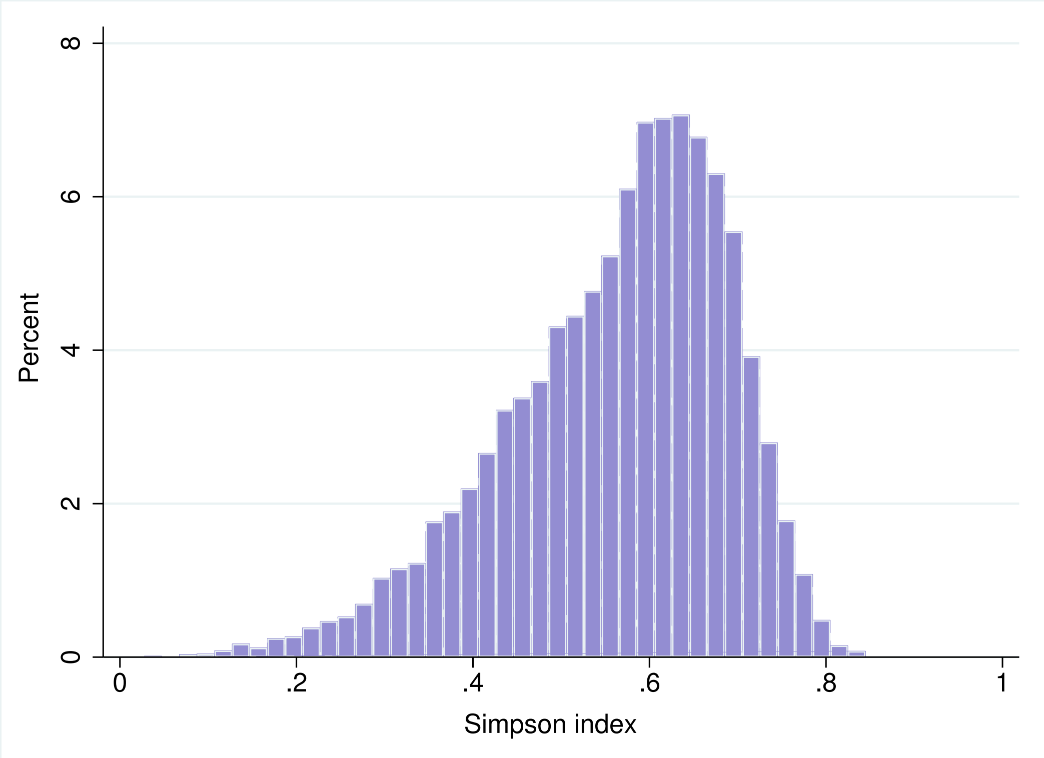

Figure A2: Simpson index distribution from VHLSS (2010-2014))

is measured as:

$$Shannon.index = -\sum_{i} w_i log(w_i) \tag{20}$$

It takes on values from zero to the value of log of the highest number of food groups.

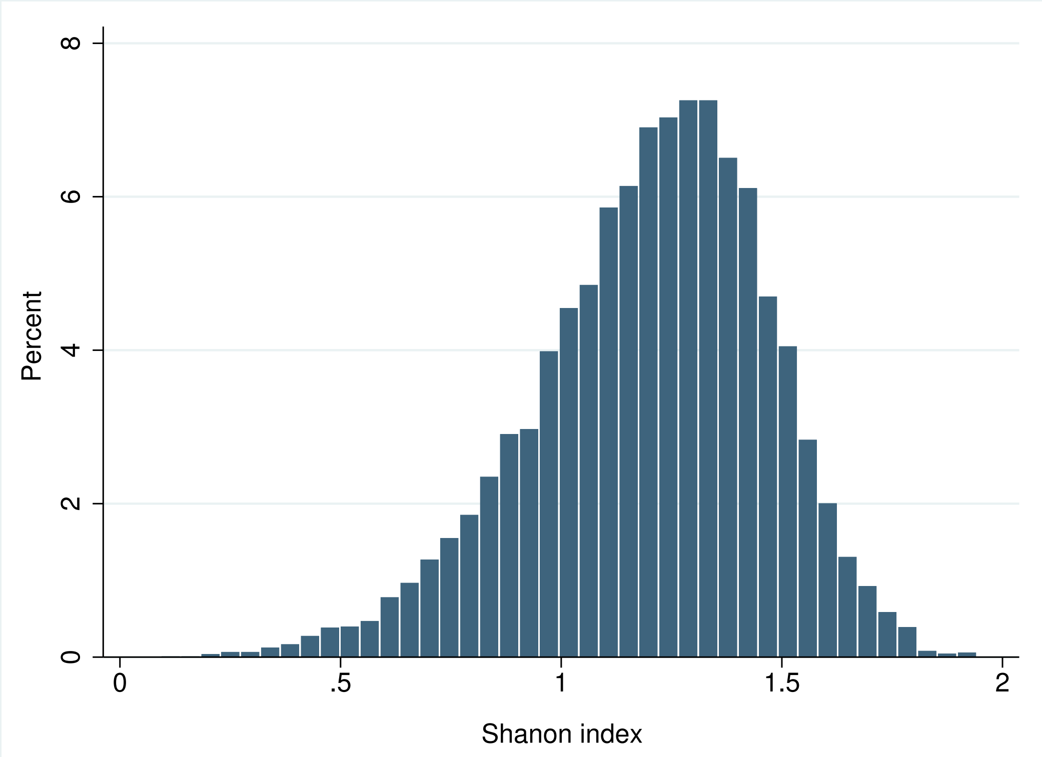

Figure A3: Shanon index distribution from VHLSS (2010-2014)

PCA method

Table A2: Correlation matrix of PCA variables

	Agriculture surface	Prod. value	PCCI	Prod. diversity	Dietary diversity
Agriculture surface	1.0000				
Prod value	0.7085	1.0000			
PCCI	0.0868	0.1611	1.0000		
Prod diversity	0.0254	-0.0004	-0.0091	1.0000	
Dietary diversity	-0.0959	0.0631	0.1619	-0.2131	1.0000

Table A3: Inertie of each PCA component

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	1.75006	.470278	0.3500	0.3500
Comp2	1.27978	.316272	0.2560	0.6060
Comp3	.963513	.22965	0.1927	0.7987
Comp4	.733863	.461085	0.1468	0.9454
Comp5	.272778	.	0.0546	1.0000

Estimation results

Table A4: Food security, weather shocks and environment risk: IV+ Panel with random effects

VARIABLES	(1) FSI	(2) Production value	(3) PCCI	(4) Simpson index	(5) Shanon index
Flood	-0.0136***	-0.120***	-0.0169	-0.0105***	-0.0267***
	(0.00242)	(0.0199)	(0.0119)	(0.00290)	(0.00557)
Typhoon	-0.00325**	-0.0401***	-0.0126	-0.00867**	-0.0168**
	(0.00133)	(0.0131)	(0.00969)	(0.00353)	(0.00737)
Drought	-0.00263	-0.0238	0.00163	-0.0127***	-0.0266***
	(0.00309)	(0.0303)	(0.0132)	(0.00347)	(0.00729)
Temperature	-0.00126**	-0.0193***	-0.00452	-0.000882	-0.00319**
	(0.000500)	(0.00508)	(0.00304)	(0.000720)	(0.00133)
Precipitation	-4.77e-06**	-6.81e-05***	-2.32e-05**	1.97e-06	-2.71e-06
	(2.18e-06)	(2.34e-05)	(1.15e-05)	(3.87e-06)	(8.11e-06)
deforestation	-0.00325	-0.0892*	-0.0444**	-0.0200***	-0.0478***
	(0.00510)	(0.0519)	(0.0185)	(0.00752)	(0.0145)
PM2.5	-0.00283***	-0.0225***	-0.00103***	-0.000877***	-0.00257***
	(0.000105)	(0.00120)	(0.000298)	(0.000118)	(0.000251)
slope	-0.000176	-0.00763***	-0.000867**	-0.00160***	-0.00350***
	(0.000147)	(0.00142)	(0.000419)	(0.000162)	(0.000340)
gender	-0.0277***	-0.264***	-0.0710***	0.00155	0.00893
	(0.00377)	(0.0379)	(0.00963)	(0.00332)	(0.00684)
age	-0.000461***	-0.00400***	-0.00425***	-9.52e-05	-0.000361**
	(0.000127)	(0.00131)	(0.000369)	(9.54e-05)	(0.000178)
education	0.000598	-0.00507	0.0277***	0.00951***	0.0178***
	(0.00115)	(0.0123)	(0.00405)	(0.00126)	(0.00261)
HH size	0.0120***	0.143***	-0.0140***	-0.00842***	-0.0170***
	(0.000609)	(0.00840)	(0.00226)	(0.000778)	(0.00171)
ethnicity	-0.0198***	-0.138***	0.0483***	0.0493***	0.0979***
	(0.00376)	(0.0410)	(0.0145)	(0.00413)	(0.00879)
u1	0.00376	0.108*	0.0412	0.0281***	0.0659***
	(0.00578)	(0.0608)	(0.0289)	(0.00994)	(0.0198)
u2	0.0159	0.247**	0.0403	0.00672	-0.00713
	(0.0111)	(0.105)	(0.0674)	(0.0233)	(0.0435)
2012.year	-0.00517**	-0.0116	-0.0561***	-0.000931	-0.0118**
	(0.00244)	(0.0245)	(0.00902)	(0.00311)	(0.00586)
2014.year	-0.00733***	0.0274	-0.0770***	0.0197***	0.0369***
	(0.00208)	(0.0277)	(0.0102)	(0.00357)	(0.00675)
Constant	0.554***	10.23***	8.824***	0.600***	1.310***
	(0.00954)	(0.0972)	(0.0229)	(0.00871)	(0.0190)
Number of hid	8,666	8,666	8,666	8,666	8,666
R-squared					

Notes: this table indicates coefficients estimated from structural forms of control function approach using panel with random effects model. ∗0.10, ∗∗0.05, ∗∗∗0.01 significance level. Values in parentheses indicate standard errors corrected for cluster correlation at the commune level.

Table A5: Stability of food security, weather shocks and environment risk: IV+ panel ordered probit with random effect.

VARIABLES	(1) FSI	(2) Production value	(3) PPCI	(4) Simpson index	(5) Shanon index
Flood	-0.414***	-0.328***	-0.0554	-0.121***	-0.183***
	(0.0479)	(0.0376)	(0.0422)	(0.0441)	(0.0365)
Typhoon	-0.0847**	-0.0910**	-0.0704*	-0.120***	-0.117***
	(0.0379)	(0.0400)	(0.0394)	(0.0464)	(0.0440)
Drought	-0.0212	-0.0507	-0.0166	-0.120***	-0.143***
	(0.0831)	(0.0706)	(0.0524)	(0.0346)	(0.0407)
Temperature	-0.0395**	-0.0719***	-0.0281**	-0.00956	-0.0115
	(0.0173)	(0.0144)	(0.0115)	(0.0127)	(0.0129)
Precipitation	-6.14e-05	-0.000120*	-0.000138***	7.95e-05*	4.24e-05
	(6.18e-05)	(6.33e-05)	(4.76e-05)	(4.24e-05)	(3.72e-05)
deforestation	-0.126	-0.203	-0.234***	-0.156**	-0.205**
	(0.141)	(0.137)	(0.0678)	(0.0739)	(0.0799)
PM2.5	-0.0614***	-0.0446***	-0.00368***	-0.00907***	-0.0137***
	(0.00277)	(0.00251)	(0.00109)	(0.00133)	(0.00124)
slope	-0.00258	-0.0185***	-0.00367**	-0.0182***	-0.0188***
	(0.00301)	(0.00266)	(0.00161)	(0.00195)	(0.00204)
gender	-0.619***	-0.573***	-0.238***	0.0125	0.0381
	(0.0737)	(0.0864)	(0.0449)	(0.0355)	(0.0335)
age	-0.00417	-0.000847	-0.0161***	-0.00159	-0.00165
	(0.00296)	(0.00268)	(0.00143)	(0.00112)	(0.00104)
education	0.0125	0.00346	0.0898***	0.108***	0.0946***
	(0.0220)	(0.0240)	(0.0126)	(0.0136)	(0.0134)
HH_size	0.255***	0.308***	-0.0694***	-0.0762***	-0.0853***
	(0.0199)	(0.0233)	(0.00693)	(0.00839)	(0.00851)
ethnicity	-0.604***	-0.470***	0.172***	0.496***	0.497***
	(0.0820)	(0.0729)	(0.0425)	(0.0561)	(0.0501)
u1_re	0.0857	0.226*	0.248***	0.209**	0.284**
	(0.146)	(0.132)	(0.0929)	(0.0909)	(0.112)
u2_re	0.555**	0.848**	0.00535	0.0427	0.158
	(0.253)	(0.356)	(0.234)	(0.221)	(0.245)
2012.year	-0.176***	-0.144***	-0.286***	0.0122	-0.0625
	(0.0603)	(0.0557)	(0.0365)	(0.0422)	(0.0472)
2014.year	-0.295***	-0.0458	-0.356***	0.228***	0.198***
	(0.0508)	(0.0580)	(0.0363)	(0.0457)	(0.0502)
/cut1	-2.976***	-2.207***	-2.034***	-0.947***	-1.160***
	(0.258)	(0.216)	(0.106)	(0.0987)	(0.0952)
/cut2	-1.016***	-0.329	-0.957***	0.239**	0.0491
	(0.242)	(0.221)	(0.103)	(0.0979)	(0.0925)
sigma2_u	2.953***	3.120***	0.449***	0.464***	0.484***
	(0.222)	(0.179)	(0.0379)	(0.0452)	(0.0389)
Observations	11,952	11,952	11,952	11,952	11,952
Number of hid	8,666	8,666	8,666	8,666	8,666
Log-likelihood	-12163	-12163	-12163	-12163	-12163
Wald Chi2(17)	10602	10602	10602	10602	10602

Notes: this table indicates coefficients estimated from structural forms by panel ordered probit with random effect model using control function approach. ∗0.10, ∗∗0.05, ∗∗∗0.01 significance level. Values in parentheses indicate standard errors corrected for cluster correlation at the commune level.