Measuring resilience properties of household livelihoods and food security outcomes in the risky environments of Ethiopia

Medición del grado de resiliencia de los sustentos de los hogares y de la seguridad alimentaria en ambientes de riesgo etíopes

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Abstract

The purpose of this case study, conducted in Amhara region of Ethiopia, is to contribute to efforts to measuring and assessing resilience properties of household livelihoods constructed in the risky environments. It provides new insights for assessing livelihood vulnerability and designing resilience building programs in areas of protracted food crisis. Based on resilience theory as applied to social-ecological systems with an application of Modern Portfolio Theory, we adapted and measure the four properties of resilience to livelihood systems and tested the expected relationships between system properties as predicted by resilience theory. Household livelihood systems exhibited the expected pattern of increasing connectivity with increasing wealth (food income). Similarly, household resilience to food insecurity improves with increasing diversity of livelihood options and diversity declines with increasing connectivity of the system. This study demonstrates the use of a set of metrics for assessing resilience properties of household livelihoods based on key driving factors.

Keywords: livelihood resilience, Resilience Theory, Portfolio Theory, food security, Ethiopia.

Resumen

Con este estudio de caso, realizado en la región de Amhara (Etiopía), se pretende contribuir a los esfuerzos para medir y evaluar el grado de resistencia de los sustentos económicos de los hogares construidos en ambientes de riesgo. Así, se proporcionan nuevos conocimientos para evaluar la vulnerabilidad de los medios de subsistencia y diseñar programas de fortalecimiento de la resiliencia en áreas de crisis alimentaria prolongada. Basándonos en la teoría de la resiliencia aplicada a los sistemas socioecológicos, y aplicando la teoría moderna de carteras, adaptamos y medimos las cuatro propiedades de la resiliencia a los sistemas de medios de subsistencia y probamos las relaciones esperadas entre las propiedades predichas por la teoría de la resiliencia. Los sistemas de sustento de los hogares exhibieron el patrón esperado de conectividad creciente con el aumento de la riqueza (ingresos alimentarios). Del mismo modo, la resistencia de los hogares a la inseguridad alimentaria mejora con el aumento de la diversidad de opciones de medios de subsistencia y la disminución de la diversidad a partir del incremento de la conectividad del sistema. Este estudio muestra el uso de un conjunto de métricas con el fin de evaluar las propiedades de resiliencia de los sustentos del hogar basado en factores clave de conducción.

Palabras clave: resiliencia de los sustentos diarios, teoría de la resiliencia, teoría de carteras, seguridad alimentaria, Etiopía.

1
Introduction

The term «resilience» as a concept distinct to other stability concepts was first introduced by C. S. Holling in his influential paper «Resilience and Stability of Ecological Systems» referring to the capacity of a system, or amount of disturbance a system can absorb (Holling 1973) without shifting into an alternate state (Walker *et al.* 2006) or a regime shift (Carpenter *et al.* 2005). Recently the concept of resilience has been proposed to exploring the relative persistence of different states in complex dynamic systems, including food and livelihood systems (Frankenberger *et al.* 2012; Fraser *et al.* 2005; Manyena 2006; Pingali *et al.* 2005). This study was designed to explore resilience properties of livelihood systems, at household level, constructed in one of the risky environments of Amhara region in Ethiopia where recurring climate shocks undermine household livelihoods and food security. Based on the concept of ecosystem resilience, commonly defined as the capacity of a system to experience change while retaining essentially the same function, structure, feedbacks, and therefore identity (Walker *et al.* 2006), we follow similar resilience characterization as applied to our system of concern, where a livelihood system can be thought to be resilient if it can meet food security and other non-food security objectives and still maintain its essential functions following a disturbance (Fraser *et al.* 2005; Le Vallě *et al.* 2007; Tincani 2012). In this regard, we gauge resilience as both a measurable property of complex adaptive systems as well as an outcome in the context of food security. The latter is based on the conventional consumption vulnerability approach in which the concept of resilience is understood as the opposite of vulnerability, referring to the probability of a household to maintain wellbeing beyond a certain normative threshold. Although the term «resilience» has become an important operational concept in chronically vulnerable or food insecure areas of the world (Frankenberger *et al.* 2012; Fraser *et al.* 2005; Pingali *et al.* 2005), the application of the concept in policy-driven assessments has been limited by a lack of robust metrics to measure resilience as an emergent property of complex social systems such as household livelihoods. In this paper, we apply Modern Portfolio Theory (MPT) analysis approach to understanding resilience properties of household livelihood systems including measuring an outcome variable, *i.e.,* household resilience to food insecurity.

2
Resilience and livelihood systems

2.1. Defining the system: resilience of what? To what?

The concept of «resilience» makes sense particularly when applied to a system. A system is a group of interacting components, operating together for a common purpose, capable of reacting as a whole to external stimuli (Spedding 1988). A system behaves as a whole in response to stimuli to any of its components. In this study, the concept of «resilience» is applied to household livelihoods. A household livelihood system is defined as a set of the tangible and intangible assets a household can access including all the things that they do to acquire and sustain assets and resources towards achieving positive wellbeing outcomes within the broader environmental and institutional context in which a household is situated.

Household livelihoods often consist of more than just one activity and the portfolio structure and configuration may vary from household to household. A set of food and income sources of a household along with its food security outcomes represent the system of the study concern, *i.e.,* household livelihood system. Our unit of analysis is therefore the «household unit» —that is an organized economic unit consists of the household head and its members who together contributes to the household economy—. This household definition is consistent with the definition of a system (Alinovi *et al.* 2009) as a set of connected components that make up a unified group and operate together for a common purpose. Households can therefore be viewed as the most suitable entry point for the analysis of livelihood systems (Alinovi *et al.* 2009). Of the many livelihood outcomes of concern to rural households, we focus on the food income obtained from different sources as our measure of wellbeing. Household food income is affected by factors both internal and external to the system. However, we focus our assessment on climate related risks, mainly seasonal variability of rainfall and related shocks, to calculate expected average household portfolio returns and its variation and to understand resilience properties of the livelihood system at household level.

2.2. Resilience properties of systems as applied to household livelihoods

In the field of ecology, the term «resilience» is considered as an emergent property often ascribed to complex systems. There are well established evidences in the field regarding at least the four key properties of system's resilience. First, resilience comes from accumulated capital (wealth), which provides sources for renewal and represents the inherent potential of a system that is available for change. In the case of ecosystems, this stored wealth refers to the biomass stored within an ecosystem (Carpenter *et al.* 2001). As an ecosystem accumulates biomass and is aggregated among fewer units, and in turn species diversity declines (Gunderson *et al.* 2006). This progression makes the system more susceptible to shock. However, in social systems (Fraser *et al.* 2005), wealth has a very different meaning that social or financial wealth help communities adapt to changes. In this paper, wealth of the system is measured by expected average livelihood portfolio return using MPT as the proportion of food income obtained from portfolio of livelihood activities as percent of the minimum food needs (2,100 kilocalories per person/day).

The second key source of resilience that lies within a system captures the connectivity of the system, describing the interdependence of different elements within an ecosystem (Holling 2001). For socio-ecological systems, it has also been termed as the degree to which the system is capable of self-organization, rather than being shaped by external factors originated from the broader context within which a particular system is operating (Carpenter *et al.* 2001). Fraser *et al.* (2005) suggested that MPT could help to capture the interdependence of different elements of the livelihood system measured by the variance and covariance structure between livelihood activities. MPT is uniquely suitable to gauge this property of the livelihood system as its measure of portfolio variation accounts both the variation of individual livelihood activities as well as the covariance between any two activities within the whole household livelihood portfolio. Increasingly positive covariance between portfolio activities as well as increasing variation in portfolio return as a whole would indicate a higher degrees of connectivity of the system (Fraser *et al.* 2005). Positive covariance could be observed among those households who specialize on few profitable activities at the cost of resilience that would maintain stability of portfolio returns by investing on diversified activities. This is because of trade-offs between high expected returns and the expected variance of those returns in the face of inherent uncertainty in most risky environments. Considering both, the expected returns and the expected variance of returns may therefore provide a more complete understanding of the economic functioning of particular portfolio activities (Abson *et al.* 2013).

The third key property of a resilient system is, therefore, the diversity and variety that exists within functional groups, such as biodiversity in critical ecosystem functions, and cultural and political diversity in social groups (Fraser *et al.* 2005). Both vulnerability and resilience research communities (Adger 2000; Berkes & Seixas 2005; Bohle 1993; Braun *et al.* 2005; Perz 2005) agreed that diversity is the key property of resilient social-ecological systems. Diversity provides a way of assessing the capacity of the system to adapt to external forces as diverse systems are better able to tolerate a wide range of environmental conditions than simple systems (Holling

2001). In social systems as applied to livelihood, many scholars (Frankenberger *et al.* 2012; Fraser *et al.* 2005; Niehof 2010; Tincani 2012) have suggested Shannon's index to measure diversity of entitlements to better reflect the process described for ecosystems.

The fourth resilience property captures the adaptive capacity of the system, describing how vulnerable the system is, based on its capacity to reorganize its elements into a new form, which is less exposed to a given shock (Holling 2001). In ecosystems, adaptive capacity is characterized by the opportunities for innovation which arise after a disturbance. For socio-ecological systems, it refers to the capacity for learning and adaptation occurring within the system (Carpenter *et al.* 2001). In the case of livelihood systems, this can be understood as the opportunities to undertake new or different livelihood strategies (Fraser *et al.* 2005; Tincani 2012). In some studies of global change, the concept of adaptive capacity (Bohensky & Lynam 2005; Luers *et al.* 2003) is differentiated from the concept of adaptation. The latter is considered as inherent property of the system to deal with shock while the former often defined as the extent to which the expected vulnerability of the system that could be reduced due to coping and adaptation interventions. In this paper, we prefer to use the term «response capacity», referring to the amount of food income that a household could expand through various coping mechanisms during periods of shock.

3
The empirical context

3.1. Livelihood context

Located in northwestern Ethiopia, Amhara regional state is one of the nine administrative regions in Ethiopia where the study area, Tach Gayint district, is located. The region encompasses 106 administrative districts and more than half of them are characterized as drought prone and food insecure areas. Tach Gayint District is one of the region's top priority areas characterized by risky environments exposed to recurrent food emergencies. The district, with the total area of 995 square kilometres, is located 200 kilometres north east of Bahir Dar City, the regional capital. With a 2 % population growth rate, projected population of the district for the 2015 is 112,762 (BoFED 2015). Almost all residents in the district belong to the Amhara ethnic group and about 98 % of the population lives in rural areas where rain-fed mixed farming is the main activity. Two livelihood zones, namely Abay Beshilo Basin (ABB) and Abay Tekeze Watershed (ATW) (Figure 1), both with a very long history of relief assistance predominantly characterize the district (TGWA 2014).

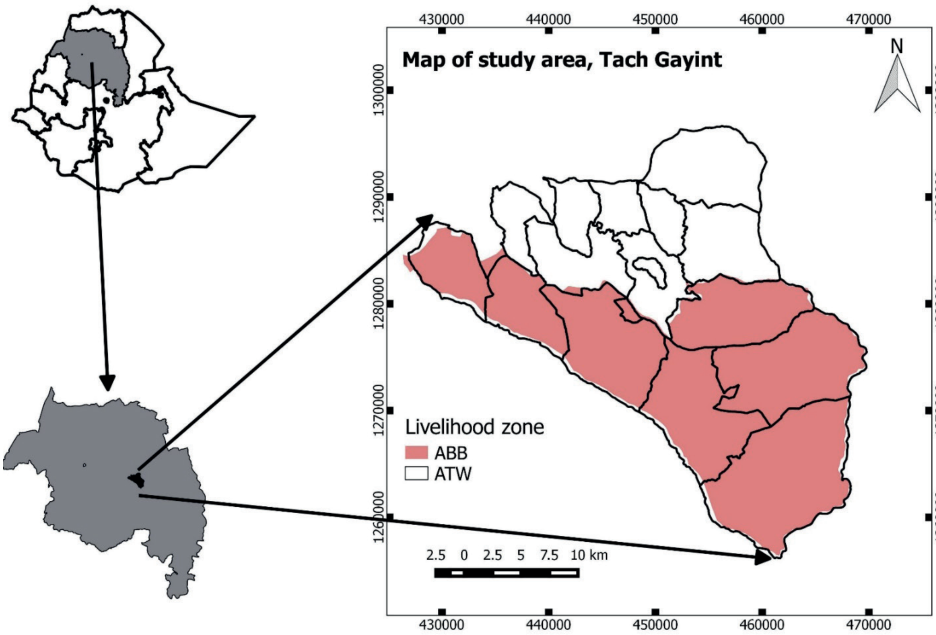

Figure 1
Map of the study area

These livelihood zones serve as a stratum to select five *kebeles* (the smallest administrative units in Ethiopia) as primary sampling units (see section 4.4): ATW livelihood zone characterized by mid-land and highland agroecology, and ABB livelihood zone, predominantly characterized by lowland agroecology. Barley, wheat, beans and peas are the major crops in the highlands while sorghum, maize and haricot beans are widely cultivated in the lowland *kebeles.* Both livelihood zones suffer from chronic food insecurity due to a combination of various factors including erratic rains, small landholdings, and highly degraded farmlands.

3.2. Shock context

The major shocks occurring in Tach Gayint district are mainly climatic shocks with soil erosion and deforestation as the major environmental problems challenging the overall development of the district (DRMFSS 2012). Climatic shocks such as drought, flood, hail-storm, and frost are the common climate related problems affecting the district household livelihoods. The most important climatic shock is drought, characterized by unusually dry conditions during the growing season with poor rainfall distribution, affecting agricultural production in the district. Table 1 shows the specific nature of drought related to the start and end of rain including irregular and unusual rainfall patterns affecting crop production as well as availability of pasture for livestock. Communities reported that climatic shocks such as droughts are a recurring feature of the district causing production shortfalls in at least every three years.

Type of weather shock	Period of occurrence	Frequency of occurrence
Drought (late onset)	After June 30	
Drought (early secession)	Before August 30	
Drought (unusual rainfall)	October and November	Once in every two years
Drought (erratic rainfall: rains in May but stops in June)	May to June	
Frost *(wurch)* combined with strong wind	September to October	Once in every three years
Flood	July to August	Once in every four years
Hail storm *(beredo)*	June to August	Once in every three years

Table 1
Type of weather shock affecting the study area and its temporal aspects
Source: own survey (2015).

Recently, the worst global *El Niño* phase affected the 2015 wet season resulted in up to a 50 % reduction of crop production in the district (Amhara DPFSPCO 2015). The Standard Precipitation Index (SPI) calculated using historical record of precipitation of data available for the district between 1997 and 2015 is shown by Figure 2. In order to account episodes of agricultural drought in the district, the SPI values were calculated for the cropping season (June, July and August). The district experiences at least four drought episodes over the last 20 years with the severe drought in 2015. Drought induced food emergencies are recurrent problems causing half of the population trapped in a state of chronic poverty subject to beneficiaries of the biggest social protection program in Ethiopia.

With the above empirical context of the study area, this study should be understood with the following spatial and temporal aspects. First, the study area is located in one of the drought-prone and chronically food insecure areas of the country. The area experiences one drought episode in every two or three years (DRMFSS 2012). Almost half of the district population has a food gap of more than six months every year regardless of normality of seasonal climate and the same proportion of population subject to benefiting regular food transfer programs of the country (TGWA 2014). Deep rooted poverty trap predominantly characterize the study area and household resilience should be understood in the context of recurrent drought and protracted food crisis.

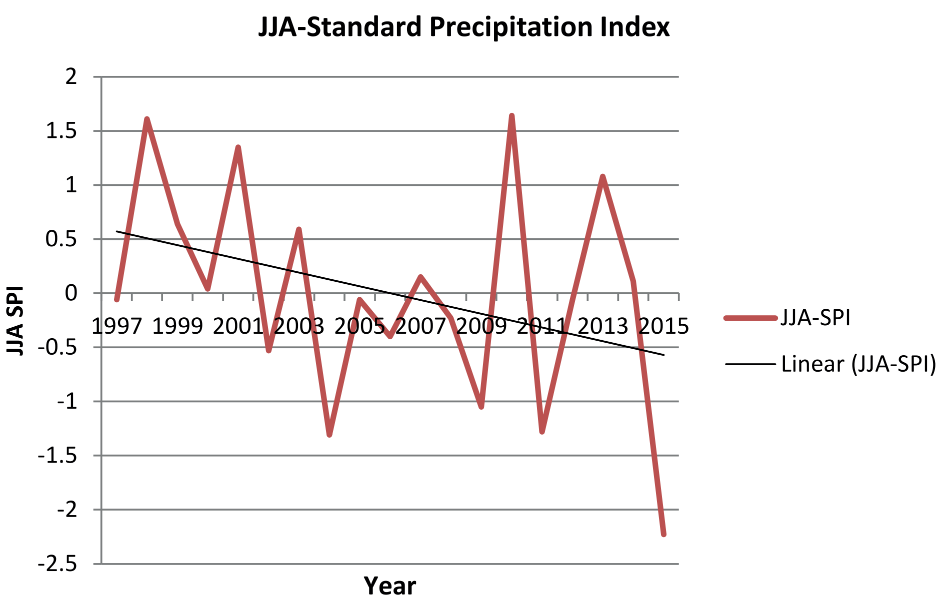

Figure 2
Standard Precipitation Index for Wet Season (Tach Gayint District)

Second, intra-annual and inter-annual variation in availability of food is an important temporal aspect of food security to understand household resilience. Seasonal hunger often occurs during September to November just before the harvest period in December. In this study, only the inter-annual food security dynamics was considered to understand household resilience using methodological approach of MPT as the former require repeated surveys during harvest and hungry season in order to capture the dynamics of seasonal hunger. Hence household resilience should be understood in the context of inter-annual food insecurity dynamics rather than in the context of seasonal hunger. Finally this study has been designed to generate new insights for developing a set of metrics that can be used to measure and assess resilience properties of household livelihoods constructed in areas of recurrent food crisis rather than generalising the results to all livelihoods and shock contexts.

4
Method

4.1. Modern Portfolio Theory (MPT): analysis approach

The finance literature in its emphasis on resource allocation and multiple investment options offers valuable insights into household livelihood strategy as a portfolio of activities. Rural household livelihood portfolios with multiple ways of portfolio configuration structure and objective could represent a social-ecological system of concern for resilience assessment. Modern Portfolio Theory (MPT), developed in the 1950s, provides a set of metrics with a systems-based analysis approach (Markowitz 1952) to examining the whole portfolio of activities.

Its concepts are also applicable to household livelihoods because resources are invested into multiple activities. As a result, MPT, with its underlying principle of minimizing risk for a given level of returns, can provide an analytical framework for examining a livelihood system as a whole (Fraser *et al.* 2005). Therefore, household's expected livelihood portfolio returns are used as a measure of wealth and its variance as the standard deviation of expected returns, which includes not only the variation in return of individual livelihood activity but also the covariance between portfolio activities, is used in this paper as a measure of connectivity of the livelihood system.

For the analysis of livelihood activity portfolios the following assumptions are made following the works of (Witt & Waibel 2009) who applied MPT to farming systems in Cameroon with the objective of understanding the system's sensitivity to climate risk. First, households behave in a rational way, *i.e.,* productive assets are allocated among the different activities in order to maximize returns for a given level of risk or minimize risk for a given level of returns. Second, the relative weight of each activity in the portfolio is represented by the share of labor allocated to the activity a household is engaged in, as livelihood activities in the study area are characterized by high labor intensity. Third, labor is completely distributed among the different activities in the portfolio of a given household. The returns to labor for each activity are computed as the maximum possible income if all labor would be assigned to the respective activity. Households in the study area are often vulnerable to climate related risks where the portfolio analysis can be done subject to probabilities of identifiable climatic states of the world based on subjective perception of households in the last ten years. The following section outline details of the methods as applied to the measurement of resilience properties.

4.2. Measuring resilience properties

Based on resilience properties described in section 2.2 at conceptual level following resilience characterization in the field of ecology, hereafter referred to as resilience theory, we applied a set of metrics developed in various fields of study to measure resilience properties of household livelihood systems. Primarily, these include portfolio analysis approach from financial literature and household economy analysis (HEA) approach from food and livelihood security literature. Measurements for the four key resilience properties including resilience itself are described below.

4.2.1. Measuring wealth of the system

Wealth of the livelihood system in this paper is measured by the expected average food income that a household obtains from various entitlement channels. We employed Household Economy Approach (HEA)[1] to accounting the food and income obtained from different sources (Seaman *et al.* 2014) as percent of the minimum food needs. The ways in which the household acquires the food income include own crop and livestock production, self-employment and labor exchange activities as well as participation in food-for-work programs. In order to capture the expected average livelihood portfolio income and its variability, we employed Modern Portfolio Theory (MPT). The stochastic distribution of returns for each activity results from the food income variations between years with different climatic states of nature as the set of $S = (1, 2\ldots s)$. However, despite the many possible states of the climatic condition, we limit the possible states of the climate into three states: $s = (1, 2, 3)$ representing «bad year», «normal year» and «good year», respectively. Hence, we could be able to establish a subjective probability distribution for the stochastic outcomes based on household's shock experience in the last ten years. We then estimate the expected mean food income using MPT for both individual livelihood activity and the whole household livelihood portfolio. Expected mean food income as percent of the minimum food needs for individual livelihood activity is estimated using Equation 1.

$$\boldsymbol{E[FI_i] = \sum_{s=1}^{s} P_s \,.\, R_{i,\ s}}$$

Equation 1

Where $E(FI_i)$ is the expected food income from activity *i*; P_s is the probability of state *s* occurring for *s = («bad year», «normal year», or «good year»)*; $R_{i,\,s}$ is the returns (in food income as percent of the minimum food needs) to labor for activity *i*, computed as the maximum possible food income if all labor would be assigned to the respective activity. We then estimated the expected mean food income for the whole household livelihood portfolio using Equation 2, representing wealth of the livelihood system at household level, where $E(FI_{port})$ is the expected average portfolio food income and W_i is the relative weight of each activity in the portfolio, represented by the share of labor allocated to activity *i.*

$$\boldsymbol{E(FI_{port}) = \sum_{i=1}^{n} W_i \,.\, E(FI_i)}$$

Equation 2

1 Household Economy Approach (HEA) was developed in the early 1990s by Save the Children-UK in order to improve the ability to predict short-term changes in access to food. It is a livelihoods-based framework for categorization and quantification of people's sources of food and income, and their expenditure patterns, using a common currency. In other words, all food and income sources must be converted into their calorific equivalencies, *i.e.*, the calories in food consumed, plus the calories that could hypothetically be purchased if all cash income was used to buy grain, and then compared to the internationally accepted standard of 2,100 kilocalories per person per day.

4.2.2. Measuring connectivity

Connectivity was observed by examining the variation in return among individual livelihood activities as well as covariance between livelihood activities within the whole household livelihood portfolio, which captured the interdependence present between the four different entitlement channels. Higher variation in return among individual livelihood activities and increasingly positive covariance between activities signals high interdependence and thus higher connectivity, whereas lower variation and negative covariance signals low interdependence and thus lower connectivity (Tincani 2012). Variation in returns for individual activities and covariance between each pair of sources was calculated using Equation 3 and 4 and considering both parameters we calculate the variation for the whole portfolio to represent connectivity using Equation 5.

Hence, the expected average variability of the food income for individual livelihood activity was calculated using Equation 3, where *SD* (FI_i) is expected average variability of the food income from activity *i.*

$$SD(FI_i) = \sqrt{\sum_{s=1}^{s} P_s \,.\, (R_{i,\ s} - E[FI_i])^2}$$

Equation 3

In addition, the covariance between any two individual activities (*i* and *j*) within a household livelihood portfolio was calculated using Equation 4.

$$COV[FI_i, FI_j] = \sum_{s=1}^{s} P_s \,.\, (R_{i,\ s} - E[FI_i]) \,.\, (R_{j,\ s} - E[FI_j]) \ for\ all\ i \neq j \in n$$

Equation 4

Based on Equation 3 and 4, the expected average variation of food income for the whole household livelihood portfolio, representing connectivity, was calculated using Equation 5.

$$SD(FI_{port}) = \sqrt{\sum_{i=1}^{n} w_i^2 SD_i^2 + \sum_{i=1}^{n} \sum_{i=1}^{n} w_i\, w_j cov(FI_i\, , FI_j)}$$

Equation 5

Where $SD(FI_{port})$ is standard deviation of household portfolio food income; SD_i is expected average variability of the food income from individual activity *i* and $COV(FI_i, FI_j)$ is the covariance between any two individual activities (*i* and *j*) within a household livelihood portfolio.

4.2.3. Measuring diversity

Diversity as a property of resilient livelihoods captures the degree of concentration of portfolio of food entitlements through which the household achieved its food security. The diversity of food entitlements was measured via the weighted proportion of food income obtained through each of the household's entitlement channels during the study period. Diversity was calculated using Shannon's diversity index (Equation 6).

$$SHI = \sum_{i=1}^{N} p_i * lnp_i$$

Equation 6

where *SHI* is Shannon's diversity Index, *N* is the number of food entitlement channels, *p* is the proportion of each food income that a household obtains from each food entitlement channels indexed by *i,* and lnp_i is natural logarithms of each proportions of food income indexed by *i*.

4.2.4. Measuring response capacity

In response to shocks, households tend to expand the food income through various temporary coping mechanisms, which include private and public transfers as well as through increasing sales of livestock and labor. Food income expandability potential of household's during shock were captured in the survey questionnaire outlining how much of food income could a household often expand from the potential sources based on their experience in the previous shocks they encounter. It is assumed that households could expand the food income through such positive coping options independent of the shock, *i.e.,* the extra food income expanded by a certain household represents mean zero shock portfolio return which should be accounted as part of response capacity to move the system to a less vulnerable position. We first calculate levels of food income at $t + 1$ when there is shock and, when there is no shock, we use Equation 7, where $E(FI_{port})$ is the expected average portfolio food income obtained from Equation 2, CC_{hi} is the coping capacity defined as the proportion of food income that a household could expand during periods of shock from various coping mechanisms relative to the expected average portfolio food income, and CV_{hi} is coefficient of variation calculated using equations 2 and 5.

$$E(FI_{port})(1 + CC_{hi})\ X \begin{pmatrix} 1\ if\ there\ is\ no\ shock \\ \\ 1 - CV_{hi}\ if\ there\ is\ shock \end{pmatrix}$$

Equation 7

Since coping mechanisms are only used when there is shock, we define response capacity (*RC*) as the percentage points improved in food security position due to coping relative to the minimum survival threshold (*z*1)[2] as compared to the relative position without coping at $t + 1$ when there is shock. Given *a* and *b,* it represents the food income at $t + 1$, where there is shock with coping and without coping, respectively (derived from Equation 7). We measure response capacity of household $i(RC_{hi})$ using Equation 8.

$$RC_{hi} = \left(\frac{a-b}{z1}\right)$$

Equation 8

Unlike household response capacity which is activated in response to shock, adaptive capacity is inherent to the system. The latter is already captured in the wellbeing function used to measure household resilience to food insecurity (see section 4.2.5). However, in order to check the robustness of our measure of resilience, we construct adaptive capacity index based on the factors which includes access to basic services, social safety net, assets and risk management strategies. This is the capacity to manage resilience which the United Nations Food and Agriculture Organization (UN/FAO) termed it as resilience capacity. We employed FAO-RIMA[3] methodology to construct the index.

4.2.5. Measuring resilience to food insecurity

Following conventional vulnerability studies, resilience is defined as the probability that a household will be meeting or exceeding the normative well-being threshold representing the total income required to meet the minimum food and non-food needs. We consider the latest livelihood protection threshold (*z*2)[4] value set by Ethiopian Government Early Warning System for the study district-which is 140 % as percent of the minimum food needs. We compute the probabilities based on the distribution of the household average portfolio food income $E(FI_i)$ and its variance $SD(FI_i)$ obtained from MPT, using equations 2 and 5. Assuming natural logarithms of the expected average household portfolio food income, standard deviation of portfolio food income as well as the normative well-being threshold values as normally distributed in Equation 9 denoted by $lnE(FIport)$, $lnSD(FIport)$ and ln_{z2} respectively and letting (ø) denote the cumulative density function of the standard normal distribution, the estimated probability (*Pr*) that a household will be meeting or exceeding the normative well-being threshold representing resilience denoted by $R_{i,\ t+1}$ is given by:

2 Survival threshold represents the total food income required to cover 100 % of minimum food energy needs (*i.e.,* 2,100 kilocalories per person per day, which is the internationally accepted standard).

3 Food and Agriculture Organization (FAO) of the United Nations developed a model for Resilience Index Measurement and Analysis (RIMA), hereafter referred to as FAO-RIMA model. The model adopted two-stage Factor Analysis with Bartlett's prediction technique. In the first step resilience pillars were estimated through Factor Analysis of observable variables and Resilience Capacity Index (RCI) was then estimated through Factor Analysis of the pillars (the document information is available on www.fao.org/publications).

4 Livelihood protection threshold represents the total food income required to cover both the minimum food needs and non food needs such as regular purchases of seeds, fertilizers, veterinary drugs, etc., which can sustain livelihoods.

$$R_{i,\ t+1} = Pr\,(ln_{E(FIport)} \geq ln_{z2}) = \Phi\left(\frac{ln_{E(FIport)} - ln_z}{ln_{SD(FIport)}}\right)$$

Equation 9

4.3. Determining thresholds and pathological states

The long-term study of ecosystems confirmed that the changes in systems' structures and functions subject to internal dynamics and external shocks follows a predictable cyclical pattern which constitute the adaptive cycle. This adaptive cycle first entails the slow build-up of wealth in the absence of disturbance, and then the reorganization of elements following a disturbance, followed by a renewed accumulation of wealth (Holling 2001). Many systems appear to move through these phases, including social systems.

The properties of systems at a particular stage of the adaptive cycle is determined by wealth of the system and the degree of connectivity between system components and the resulting resilience of the system to change. Assuming that each of the three properties in the adaptive cycle is given two nominal levels either low or high (Allison & Hobbs 2004), it shows possible combinations of the three properties that characterize the adaptive cycle. The first four combinations of the three adaptive cycle properties represent normal flow of conditions (Table 2) and resilience is high in the first phase of the fore-loop (growth phase) and in the second phase of the back-loop (reorganization phase).

	Four adaptive cycle phases			
Key properties	**Reorganization**	**Conservation**	**Growth**	**Release**
Wealth	High	High	Low	Low
Connectivity	Low	High	Low	High
Resilience	High	Low	High	Low

Table 2
Level of key properties and normal characteristics of the four phases of the cycle
Source: Allison & Hobbs (2004).

The other four combinations represent a deviation from normal flows which are often known as pathological states (Table 3). Following Allison & Hobbs (2004), the description of the four pathological states as applied to our system of concern is outlined as follows.

	Adaptive cycle properties		
Pathological state	**Wealth**	**Connectivity**	**Resilience**
Poverty trap	Low	Low	Low
Rigidity trap	High	High	High
Lock-in trap	Low	High	High
Structural trap	High	Low	Low

Table 3
Level of the three adaptive cycle properties and Pathological states
Source: Allison & Hobbs (2004).

The first pathological state, poverty trap, is the predominant state expected to characterize household livelihoods constructed in the study area predominantly distinguished as chronically poor district. This pathological state is characterized by all three properties having low values, creating impoverished systems that exist in a recurring state of crisis. The second pathological state, rigidity trap, may apply to our system of concern characterizing those households that tend to specialize on few livelihood activities and managed to maintain stability of expected portfolio returns despite higher sensitivity to risk. The third pathological state, lock-in trap, refers to the situation where technology effectively redefines the system and prevents the whole system from crossing critical thresholds. This pathological state may be the least expected state to characterize our system of concern. Finally, structural trap characterized by various forms of entitlement constraints that prevents access to available wealth sources, rendering the system caught in a back-loop of recurrent reorganization.

In this paper, the method for classifying household livelihoods for each of the three variables (Wealth, Connectivity and Resilience) into levels of high and low is based on the following. First, wealth of the system represented by household livelihood portfolio food income is classified into high and low levels based on livelihood protection threshold set by Ethiopian government Early Warning System for the study area (140 % as percent of the minimum food needs). It is also possible to use minimum survival threshold, which is 100 % as percent of the minimum food needs, but we prefer the former as it reflects both the food and non-food needs. Hence Households whose expected portfolio food income are greater than this threshold are classified at high wealth level and low wealth level if otherwise. Second, in terms of connectivity, the average expected standard deviation associated with the level of portfolio food income equivalent to the livelihood protection threshold is used to classify household livelihoods into similar categories. Finally, for the third variable, resilience, which is defined, in our case, as the probability that a household will be meeting or exceeding the normative well-being threshold, were categorized into high and low resilience levels based on the normative probability threshold value of 0.5 or 50 %.

For simplicity those households with a characteristic of the four combinations of the three variables representing any of the normal states of the adaptive cycle will be classified as a state of no-trap and the remaining households will be classified into the four pathological states based on the relationship they exhibit between the three variables as described in Table 3.

4.4. Field survey design and data collection

The main data source for this study is the field survey that was conducted between the November 15 and the December 29, 2015. The contents of the survey modules relevant for this study include household demographic characteristics, livelihood assets, shock/risk profiles as well as household production and income sources. Planning and implementation of the survey field work for data collection followed several stages.

First, as part of the preparation stage, desktop study to understand the overall setting of the study area (geography demography, socio-economic as well as risk profile of the target district) was done. This background information was obtained from Amhara Region Bureau of Finance and Economic Development (BoFED). Based on the 2007 census projected by BoFED for 2015 on the population size of the district, the desired sampling size were determined. Current list of *kebeles* arranged by livelihood zones were also obtained from the same source. A total of five *kebeles* were randomly selected as primary sampling units from both strata (ATW and ABB Livelihood zones of the district).

Second, initial visit to the study area were made to contact and introduce the study to the local officials of the district who are often considered as gatekeepers. During the initial visit, research assistances were identified. These include 5 supervisors and 15 enumerators who have good knowledge of the five sample *kebeles.* Full lists of villages in each *kebele* were also obtained and three villages per *kebele* were randomly selected, as secondary sampling units, making up a total of 15 villages. However, due to absence of full list of households (HHs) in each village, it was decided to conduct household listing in the 15 villages for the purpose of constructing appropriate sampling frame.

Hence as a third step, the lists of all households found in 15 sample villages were done by 15 enumerators for about 3 days where a minimum of 149 and maximum of 255 households were registered per village. Twenty households per village were randomly selected from the list, as final sampling units, to come up with the required sample size (300 HHs) for the study. Finally, following training of enumerators, the household questionnaire was administered to sample households and each enumerator managed to complete five household interviews per day. While conducting interviews, focus group discussion in each sample of *kebeles* was made to collect qualitative data at community level which includes disaster history, seasonal calendar of livelihood activities and hazards.

For the collection of data on yields and income flows from household livelihood portfolio activities (such as crop, livestock, off-farm and non-farm employment activities) and subjective probabilities for stochastic outcomes, a visual impact method was applied. Households were first asked to report how often out of the past ten years (covering the period 2005-2014) they had encountered a bad, normal or good year.

The criteria for defining each state were clearly presented to respondents. The criteria were set based on how good production year was in terms of availability of rains, harvest and pasture conditions. For instance, a bad year was defined as a production year with poor or no rains, poor or no harvest and poor or no pasture, while a good year was represented by good rains, good harvest and good pasture. A production year that does not reflect either of the two descriptions but a typical year with usual production conditions was considered as a normal year. The study reference year, the 2014 production year, was considered as a normal year. The fact that the reference year was the last 12 months' prior the survey made it possible for households to recognize deviations in production conditions from what is considered to be a normal year.

Having a clear understanding about the above criteria, households were given 10 bean grains or stones and asked to allocate them among the three rectangles, representing each state. The relative number of grains or stones in each state of the world represents the subjective probability of facing a certain climatic event. Referring to this probability distribution, several questions followed concerning the average yield and income levels for the livelihood activities carried out by the household in each state of the world. The data that was generated through this exercise was used to derive probability density functions for each activity as well as the whole livelihood portfolio.

In addition, referring to the study reference year (2014), which is considered as part of the normal state, households were asked to report the amount of labor hours devoted for each livelihood activity. The reported labor hours were used as a weighting factor for calculating expected average returns and standard deviation of returns for the whole household portfolio of livelihood activities.

5
Result and discussion

5.1. Summary of resilience properties

In order to summarize measures of resilience properties, we classify households into three distinct livelihood strategy groups who have similar patterns. We use non-hierarchical cluster analysis technique using k-means, based on the proportion of income each livelihood activities contributes to the total household food income as percent of the minimum food needs. Accordingly, sample households were categorized into crop farming groups (who obtain most of the food and income from crop farming); mixed farming groups (those who depend on both crop and livestock), and non-agricultural livelihood groups (primarily dependent on off-farm and non-farm employment opportunities).

The proportion of sample households who were classified as crop farming, mixed farming and non-agricultural groups accounts the 57 %, 34 %, and 9 % respectively. Figure 3 depicts the proportion of food income each entitlement channels contribute to the household. More than three-fourth of the food income proceed from crops where as both of the remaining livelihood groups have relatively more diversified sources of food income.

The two reference lines *z*1 and *z*2 are survival and livelihood protection thresholds defined above. In this paper, resilience is considered as the probability that a household will be meeting or exceeding the normative well-being threshold representing the total income required sustaining local livelihoods. The normative well-being threshold value is different across regions and zones. We consider the latest threshold value set by Ethiopian Government Early Warning System for the study district-which is (140 %) expressed as percent of the minimum food needs. Based on the distribution of expected average household food income and its variability obtained from the MPT analysis, we compute the probability of households to maintain food income beyond the threshold.

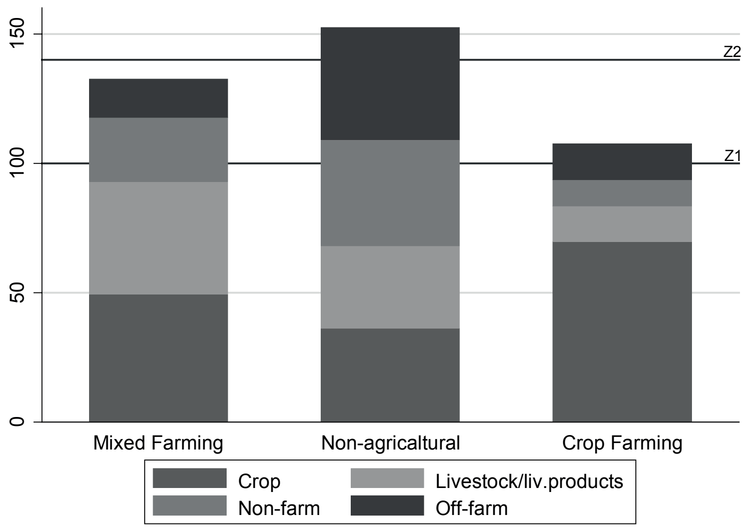

Figure 3
Average contribution of food income entitlement channels by livelihood groups

The probability that an average household will have to maintain food income beyond the threshold is 0.40 (Table 4), which is on average below the minimum probability (0.5) threshold that marks resilience status of households. Crop-based livelihood groups have relatively lower resilience level as compared to other livelihood groups. The average expected portfolio food income per household (a measure of wealth) and associated average standard deviation (a measure of connectivity), computed as percent of the minimum food needs, ranges between a minimum of (mean = 85 %, SD = 24 %) and a maximum of (mean = 117 %, SD = 31 %) for crop farming and non-agricultural livelihood strategy groups, respectively.

	Livelihood strategy group			
Resilience attributes	**All**	**Mixed-farming**	**Non-agricultural**	**Crop-farming**
Wealth	94.85	105.79	117.02	85.12
Connectivity	25.61	26.37	30.68	24.43
Household resilience to food insecurity	0.40	0.42	0.43	0.38
Diversity (Shannon's Diversity Index)	0.60	0.81	0.91	0.42
Response capacity	0.29	0.28	0.33	0.28
Adaptive-Capacity Index	−0.0009	0.10	0.12	−0.08

Table 4
Mean values for key resilience properties of livelihood systems by livelihood strategy group
Source: own survey (2015).

Similarly, higher diversity as well as shock response and adaptive capacity were exhibited among non-agricultural livelihood groups. With higher diversity, mixed-farming and non-agricultural groups could be able to maintain minimum covariance between individual livelihood activities. Households with higher wealth and connectivity as well as higher diversity and response capacity tend to have the highest resilience.

5.2. Testing relations between resilience properties

This section focuses on testing relation among resilience properties of the livelihood system based on resilience theory described above. We use two-way scatter plot to explore relationships between resilience properties including levels of household resilience plotted against each component. Relation between resilience properties tend to vary by levels of wealth. Hence, we classify household's food security levels into higher and lower levels using the threshold value defined above based on the distribution of expected average portfolio food income obtained from MPT.

Firstly, resilience theory would predict that wealth of the system growths with increasing connectivity. In our case as applied to social system, household livelihood systems in the study area show the same pattern as predicted at both lower and higher levels of food security. Similarly, with increasing wealth and connectivity household resilience to food insecurity increases (top-left and top-right side of Figure 4).

However, at higher level of wealth resilience theory would predict that with increasing connectivity of the system diversity declines and intern these relationship causes resilience to decline. As applied to livelihood systems, although livelihood diversity declines with increasing connectivity (bottom-right side of Figure 4) which is significant at 5 %, household resilience to food insecurity does not decline as predicted (bottom-left side of Figure 4). This may be because of at least two reasons. First, the study area is predominantly characterized as chronically poor district and households categorized as high wealth level are only relatively wealthy. Hence these households may tend to diversify their livelihoods sufficiently enough to maintain their resilience to food insecurity. In fact, most households exhibited the expected pattern of increasing diversity with increasing levels of resilience at both lower and higher levels of food security. This confirms the critical role of diversity of entitlement channels to maintain household resilience.

Many studies in Ethiopia (Berhanu *et al.* 2007; Block & Webb 2001; Canali & Slaviero 2010; Carter *et al.* 2004; Dercon 2002; Dercon & Hoddinott 2005; Holden *et al.* 2004; Lemi 2005; Vaitla *et al.* 2012), in the context of food insecurity, confirm the critical role of livelihood diversification to deal with shocks and household resilience. This is not surprising as these studies focus on risky environments characterized by recurrent food crisis due to climate shocks as well as structural poverty. Second, the stage at which the system is at within an adaptive cycle also determines the relationship between resilience properties. For example, resilience theory predicts increasing resilience at growth stage and declining resilience at conservation stage with increasing wealth and connectivity. Hence none of sample household livelihoods exhibits the characteristics of conservation stage (see section 4.3 for normal and pathological states of household livelihoods along the adaptive cycle).

In terms of adaptive capacity, we distinguish response capacity of system participants as they deliberately act to manage resilience trajectories of the system particularly in times of crisis from existing inherent capacity of the system. In characterizing vulnerability (Luers *et al.* 2003), we define the concept of «adaptive capacity» as the capacity of the system to move to a less vulnerable condition in the face of risk; we termed this capacity as response

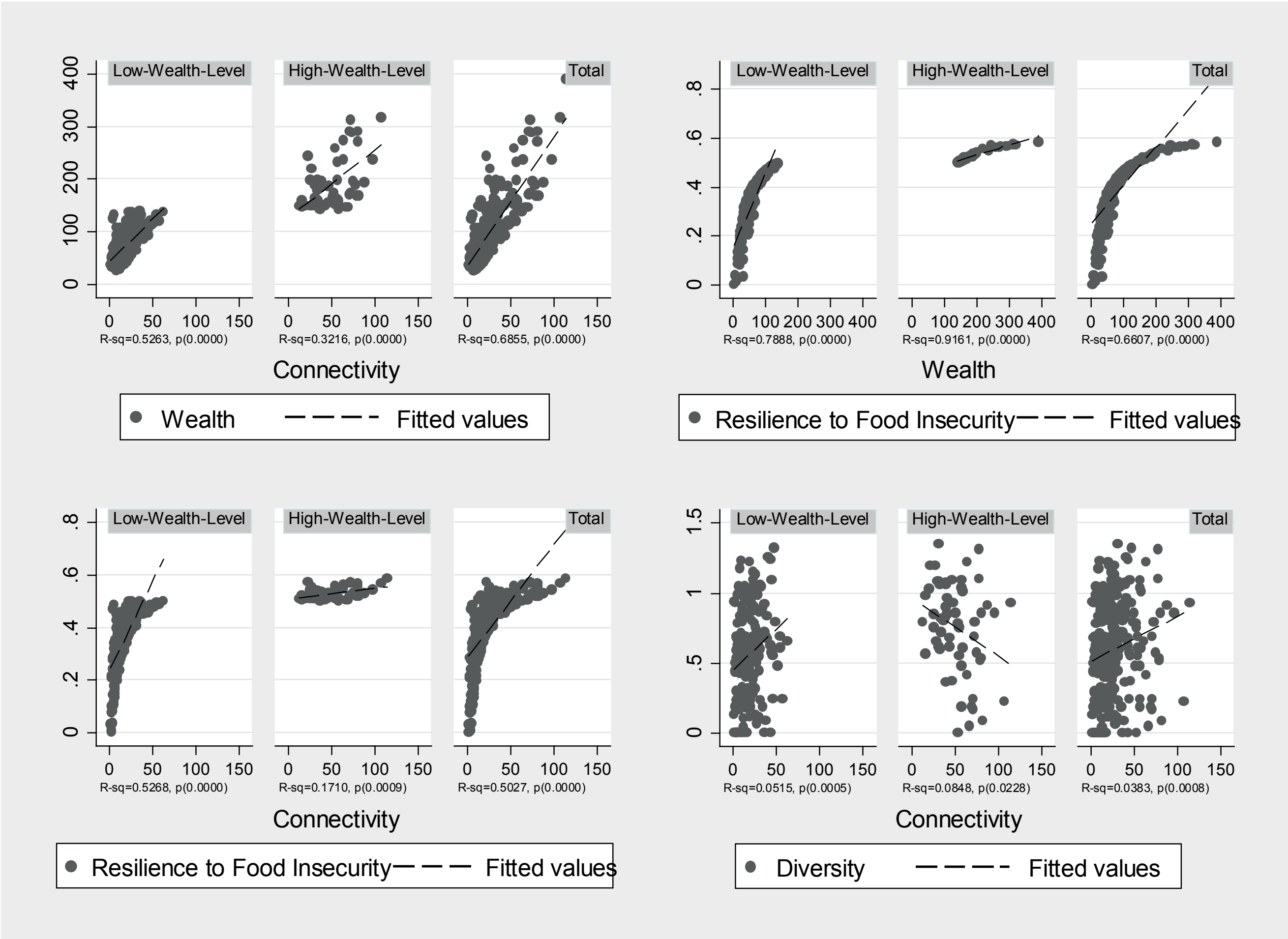

Figure 4
Scatter plots for wealth, connectivity, diversity and household resilience to food insecurity

capacity and use the term «adaptive capacity» to represent the existing inherent capacity of the system of concern. Although, in our resilience characterization, the latter is already captured in our measure of wellbeing function based on the distribution of expected average portfolio food income and its variation obtained from MPT, we develop a separate measure using FAO-RIMA model. This is because our definition of adaptive capacity of the system is very similar to FAO's concept of resilience capacity.

Hence, as independent property of resilience, we define response capacity as the extent to which a system can modify its circumstances to move to a less vulnerable condition due to household coping. Households of the study area employed various coping mechanisms to meet the food and non-food gaps in response to shocks. We asked during the survey the number of days households could cover their food and non-food expenditure from a list of common positive coping mechanisms during times of shortage. We converted the number of days as percent of the minimum food needs based on HEA. If, for example, a household reported a total of three months that they could cover from a list of coping mechanisms, the average contribution of coping to the household food needs as percent of the minimum food needs could be computed by dividing 3 months by 12 months multiplied by 100.

Since this capacity is only used during periods of shock, we measure response capacity as the percentage points improved in food security positions of household's due to coping relative to the minimum survival threshold as compared to the relative position without coping. Resilience theory would predict that household resilience to food insecurity decreases with declining response capacity at both lower and higher levels of wealth. Figure 5 confirms this hypothesis as predicted by resilience theory despite the relationship is found not significant. This relationship is not surprising as we include only what is often considered to be positive coping mechanisms unlike those coping mechanisms such as selling of productive assets which undermines the resilience of household livelihoods as a whole. This is very interesting if future studies explore further the relationship between negative coping behavior of households and resilience properties of their livelihoods.

Similarly, the other aspect of inherent part of system's capacity, which we termed as «adaptive capacity», also shows a positive correlation with household resilience to food insecurity. Adaptive capacity index was constructed following a similar statistical technique used by FAO-RIMA model in constructing resilience capacity index. This aspect of capacity is already part of our wellbeing function, which is used to construct household resilience to food insecurity and it is not surprising to have a significant relation with our measure of resilience at 1 % level of significance. However, FAO's measure of resilience capacity index as a multidimensional concept could confirm the robustness of our measure of household resilience to food insecurity.

5.3. Household resilience profile and pathological states

From the four pathological states defined in section 4.3 based on resilience theory, only two undesirable pathological states of poverty trap and rigidity trap found to be characterizing household livelihoods in the study area. In livelihood systems, poverty trap can be observed if households achieve lower food security levels at lower connectivity with lower resilience, *i.e.,* lower probability to maintain food security beyond the minimum livelihood protection threshold. In contrast, rigidity trap can be observed if households achieve higher levels of food security at higher connectivity with higher resilience. Small proportion of households (14 %) exhibited the pattern of rigidity trap.

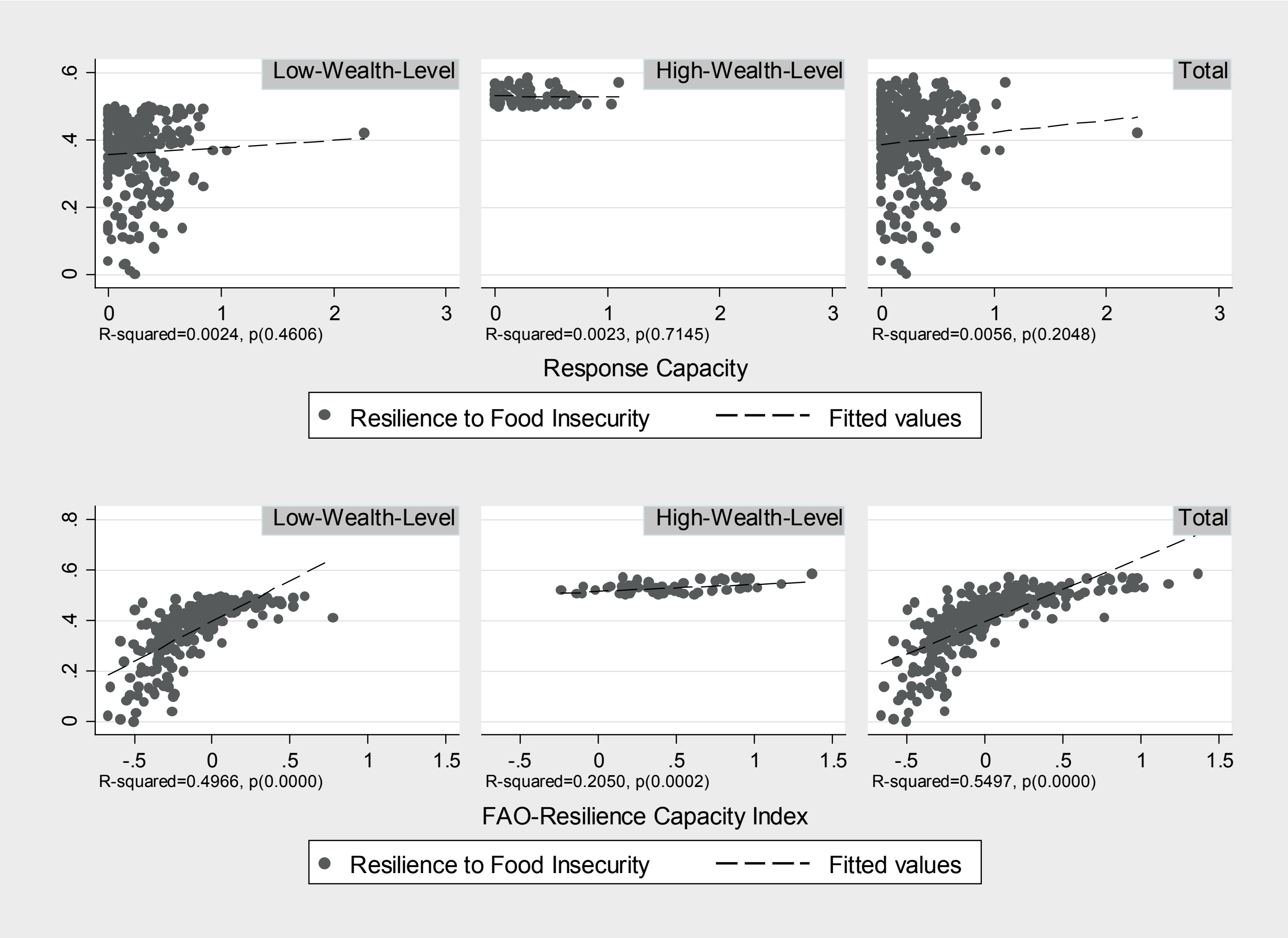

Figure 5
Scatter plots for response capacity, adaptive capacity and resilience to food insecurity

As the study area is one of the risky environments in Ethiopia, more than 70 % of sample households have exhibited the characteristics of undesirable pathological state of poverty trap and only 21 % of all sample households have found to be food secure and resilient. However, this proportions varied by livelihood strategy groups. Most of the households under non-agricultural livelihood strategy groups are found to be outside of undesirable pathological state and more than one-third of them found to be food secure and resilient. This is mainly because these livelihood groups tend to diversify their livelihoods outside of agriculture. For example, the 70 % of these livelihood groups are categorized as higher levels of portfolio diversification (Table 5). Similarly, these households also have relatively higher levels of response capacity as well as the capacity to manage resilience. Hence this confirms that livelihood diversification is a key strategy to building household resilience to food insecurity in the risky environments of Ethiopia characterized by chronically food insecure and other similar features with our study area.

	Livelihood strategy group			
Resilience attributes	**All**	**Mixed-farming**	**Non-agricultural**	**Crop-farming**
Pathological-state				
Poverty-trap	72.85	70.00	50.00	77.84
Rigidity-trap	14.43	17.00	20.83	11.98
No-trap	12.71	13.00	29.17	10.18
Food-security-status				
Chronic	63.23	53.00	41.67	72.46
Transitory	15.81	21.00	25.00	11.38
Food secure	20.96	26.00	33.33	16.17
Connectivity-status				
Low	79.38	79.00	62.50	82.04
High	20.62	21.00	37.50	17.96
Resilience-status				
Non-resilient	79.04	74.00	66.67	83.83
Resilient	20.96	26.00	33.33	16.17
Portfolio-diversification				
Low diversity	34.02	3.00	16.67	55.09
Moderate diversity	34.02	42.00	12.50	32.34
High diversity	31.96	55.00	70.83	12.57
Response-capacity				
Low	33.33	34.00	29.17	33.53
Moderate	33.33	34.00	25.00	34.13
High	33.33	32.00	45.83	32.34
Resilience-capacity index				
Low	33.33	18.00	20.83	44.31
Moderate	33.33	37.00	29.17	31.74
High	33.33	45.00	50.00	23.95

Table 5
Household resilience profile by livelihood strategy group
Source: own survey (2015).

5.4. Implications of the study

One of the primary concern of both humanitarian and development communities has been the issue of methodology for measuring and assessing resilience. However there has been a considerable methodological development for measuring similar complex concepts such as famine vulnerability and several assessment and analysis tools developed to advance famine early warning and monitoring systems for early disaster response and recovery purposes. One of such methodologies includes HEA originally developed by Save the Children-UK. The approach was adopted by Ethiopian Early Warning Institution in 2005 as a standard tool to predicting famine and local food shortages.

Building on this approach for collecting information related to portfolio of household food income sources and risk assessments, we demonstrated the application of MPT for measuring resilience properties of livelihood systems and assessing household resilience to food security shocks. As a complex concept, no single measure will be able to capture completely the multiple dimensions of resilience. However, build on conventional vulnerability assessments combined with the application of MPT analytic measures, our study demonstrated the use of a set of metrics that can help analyze and explain resilience properties of livelihood systems at household levels. The approach could be replicated at larger scales for example at livelihood zone and regional levels by making use of livelihood and shock monitoring databases. We believe the methodology could be used to advance existing famine early warning and vulnerability analysis tools to better inform both emergency response and development interventions.

There are at least four reasons that the proposed metrics are relevant for both humanitarian and development communities involved in resilience building interventions in areas of risky areas characterized by recurrent food crisis. Firstly, understanding resilience of complex systems like livelihoods is the key principle for both humanitarian and development communities. In this regard, the proposed methodology provides a set of metrics to analyze four essential aspects of resilience independently, which are already developed in various fields and sufficiently generic to apply to various scales. For example, it could be used for design of resilience building programs and targeting both in terms of geography and livelihood strategy groups. It is particularly insightful for policy makers as the proposed approach views rural households in the risky environments as rational economic units rather than victims of food emergencies. Second, because the metrics uses standardized measure of units (as percent of the minimum food needs), it is easily comparable between and within systems and allows prioritizing development and emergency resources for targeted interventions. Third, the metric would allow making use of existing HEA-based early warning and monitoring databases for modeling the resilience implications of future environmental or development scenarios. Finally, as an emerging field of study, the concept of «resilience» is being increasingly applied to social systems and there are multiple frameworks developed by various organizations and institutions for assessing resilience particularly in the context of protracted food crisis in most African countries prone to climate shocks. Since the proposed metric is not confined to a particular conceptual framework, it could be applied to test and compare the appropriateness of such frameworks and paves the way for the development of a more comprehensive framework for assessing resilience of rural households.

6
Concluding remarks

This study has proposed a set of metrics for measuring the properties of resilience of livelihood systems at household level. Based on resilience theory (Holling 2001) as applied to social-ecological systems, we adapted the four properties of resilience to livelihood systems and we measure wealth, connectivity, diversity, and adaptive capacity using methodological approaches of Modern Portfolio Theory. We also tested the expected relationships between resilience properties as predicted by resilience theory. Most of the sample households exhibit the expected patterns of increasing wealth, connectivity and diversity with increasing resilience of the system, particularly among sample households at lower level of wealth. At higher levels of wealth, sample households also exhibit the expected pattern of declining diversity with increasing connectivity as these households tend specialize on those few activities with higher return. As typical part of resilience, adaptive/response capacity plays a critical role to maintain household resilience towards a positive food security outcome.

The fact that the study area is one of the priority risky areas characterized by drought prone chronically food insecure districts in Ethiopia causes only the 21 % of the sample households could be considered as resilient. Considerable proportion of sample households (73 %) shows properties of poverty trap-where unviable livelihood system may persist at higher diversity and remain in the trap and continue to achieve negative livelihood outcome (food insecurity). Based on the portfolio analysis result designed to explore the relationship among resilience properties, we recommend interventions designed to expand opportunities of diversification that could improve household resilience to maintain food security beyond the minimum wellbeing threshold. In addition, interventions designed to expand coping options of households in response to shock including safety net programs could have a positive role towards household resilience to food insecurity.

Finally, we recommend further research to explore the potential of Modern Portfolio Theory to measure household resilience trajectories combined with HEA, which is livelihood based early warning instrument to predict food emergency needs, employed in most African and Asian countries. This is particularly important to advance food security and early warning systems in determining not only emergency needs but also development needs which facilitates targeting and the design of resilience building programs in Africa.

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