University of Naples Federico II
Department of Agriculture Sciences

Ph.D. Thesis in Agriculture and Food Sciences

Methodological and Empirical challenges for analysing and enhancing adaptive capacity of smallholder farmers.

Evidences from India and Uganda.

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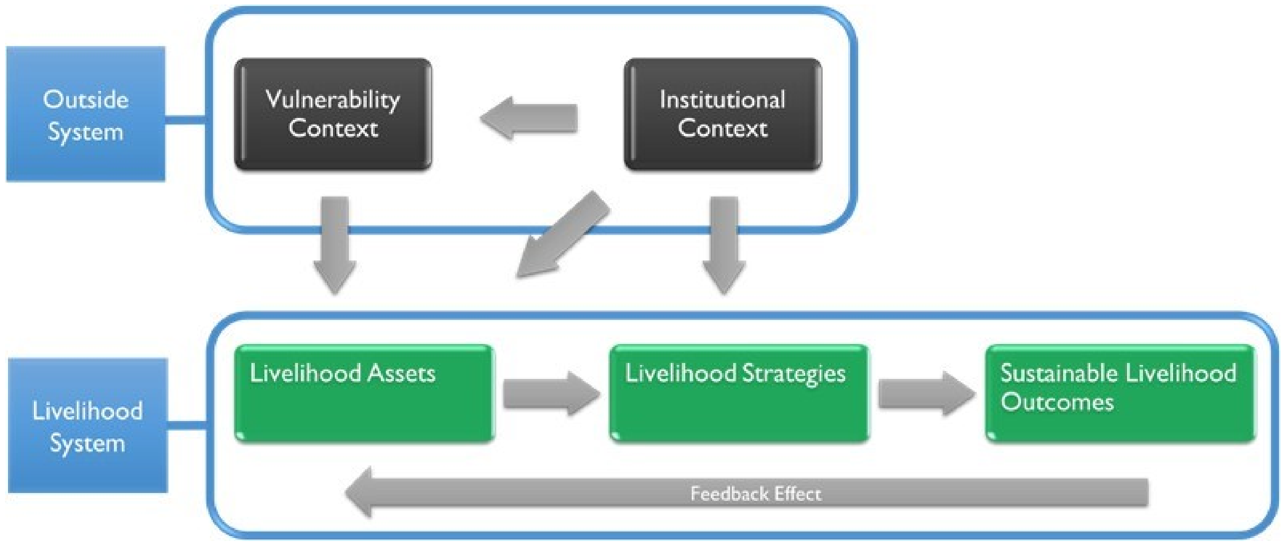
1 INTRODUCTION

A large percentage of households living in developing countries are characterized by high levels of poverty, inadequate institutional adaptation skills, lack of social safety nets and limited access to education and healthcare (Tubiello and Fischer, 2007; Stige et al., 2006; Mirza, 2003; Nicholls et al., 1999; Clark et al., 1998). At the same time, poor households deeply depend on agriculture systems for their livelihoods. Indeed, agriculture meets the basic human needs of food and it represents the main source of income of many rural households, stimulating social cohesion and safeguards cultural traditions and heritage (FAO, 2013; Van Huylenbroeck et al., 2007). Unfortunately, agricultural production systems are undergoing an unprecedented confluence of pressures from an increasing demand for food for a growing population, high competition over dwindling natural resources, loss of biodiversity, emerging pests and diseases, and the adverse effects of climate vagaries. This in turn threatens rural households' livelihoods that often have to cope with the effects of shocks and associated risks on their own (Nguyen et al., 2015).

Consequently, it is important to identified specific household strategies able to guarantee food security, increase income levels and ensure a decent standard of living for rural households living in developing countries, and for which agricultural production remains the main source of income (Lin, 2011). However, to pursue this objective its necessary to understand the context of reference and how livelihood systems adapt to external stressors in order to achieve a wider and informed view of the opportunities for development and their likely impact.

Among the different studies on rural poverty, the Sustainable Rural Livelihoods (SRL) became a predominant international development approach in the 1990s as it was strongly at odds with previous theories. As a matter of facts, the advent of the SRL framework signified a shift away from top-down interventions towards participatory, bottom-up programming (Ashley and Carney, 1999), providing a framework for a holistic interpretation of the dynamics of development (Butler and Mazur, 2007; Small, 2007; Helmore and Singh, 2001). Key in this framework are (1) the emphasis on rural poverty on the basis of the highly rural nature of worldwide poverty, (2) the concept of livelihood as more than income generation and (3) the idea of sustainability as a process, rather than a result (Small, 2007). In that respect, the SRL framework proposes a comprehensive insight that emphasizes the livelihood system of the rural households and the way in which it interrelates with the outside system (Fig.1.1).

Figure 1.1. *The Sustainable Rural Livelihood Framework*



Source: Adapted from Carney et al. (1999) and Scoones (1998).

The framework recognizes households themselves as actors with assets and capabilities, i.e. livelihood assets, which are combined and mobilized in order to implement different livelihood strategies with the aim of pursuing their own livelihood outcomes.

Particularly, the asset base upon which households build their livelihoods comprehends a portfolio of five different types of assets: human, social, natural, physical and financial capitals (Mayunga, 2007; Goodwin, 2003; Ellis, 1999; Scoones, 1998). Human capital (e.g. knowledge and skills) refers to human capacity to understand risk and uptake adaptation strategies. Social capital (e.g. networks, social relations and associations) embraces the social connections and bonds that facilitates coordination and cooperation when pursuing different livelihood strategies. Natural capital (e.g. soil and water) refers to the natural resource stocks and environmental services that gives capacity to sustain the livelihood strategies. Physical capital (e.g. machinery or mechanical or electrical appliances) includes items used to provide flows of goods and/or services. Finally, financial capital (e.g. savings and credits) refers to the economic base to which a household has access and that facilitates economic production. The above-mentioned categories of assets are forecasters of the uptake of specific strategies to accomplish a desirable livelihood outcome.

However, the framework also emphasizes that livelihood systems must interact with the outside system, consisting of the vulnerability context and the institutional context (Scoones, 1998). The concept of vulnerability refers to unpredictable events that can undermine households' assets and hence influence their livelihood strategies (Adato and Meinzen-Dick, 2002). The institutional context refers to a set of formal and informal institutions and organizations that can shape the vulnerability context, the access to the assets and subsequently the choice of livelihood strategies (ibid.).

On the basis of the foregoing, it is evident that livelihood outcomes can be different and vary from one household to another since they depend heavily on multiple and interactive influences. Although, what is important to highlight is that livelihood outcomes are not necessarily the end point, as they can generate a feedback effect on the future state of vulnerability and base asset of households (Randolph et al., 2007).

Since its advent, the SRL framework was adopted by different international development agencies, such as Oxfam, the United Nations Development Program (UNDP), and the UK Department for International Development (DFID) (Small, 2007). Numerous livelihoods approaches, perspectives, methods and frameworks currently exist and differ from each other to a considerable extent (FAO, 2019; Butler and Mazur, 2007; Randolph et al., 2007; De Haan, 2000; Ellis, 2000; Brock, 1999; Scoones, 1998). Consequently, to date, there is no single, definitive conceptualization of the SRL framework (Small, 2007). Furthermore, empirical studies seeking to demonstrate the relationships identified by the framework are still limited to our knowledge. Most of them tend to adopt the framework only partially.

In light of this, this Ph.D. thesis aims to contribute to this area of research with the specific objectives being (1) to contribute to the empirical contextualization of the core concepts of the SRL framework; (2) to widen the comprehension of the linkages identified by the SRL framework from an empirical point of view; and (3) to analyse the ways in which rural households adapt their farming practices to handle external influences and to preserve their livelihoods.

To achieve these objectives, the current study theoretically builds upon the SRL framework and empirically implements different econometric methods. Particularly, this Ph.D. thesis shapes in three papers, as indicated below.

The first paper applies the SRL framework in the context of resilience to climate change. Particularly, objectives of the study are (1) to empirically contextualize the SRL framework in a specific study site; (2) to identify the level of adaptation to the undesirable climatic stresses of rural farmers; (3) to identify the hidden correlations within the different adaptive strategies; and (4) to extend the understanding on the relation between livelihood resources, livelihood strategies and livelihood outcomes from an empirical point of view. In accordance with the objectives, firstly, the state of Bihar, India is considered as study site of the analysis due to its socio-economic and climatic conditions. Secondly, the composite index of resilience-building adaptive strategies (REBAS), developed by Mutabazi et al. (2015), is used to assess adaptation at farm level against changing climatic conditions. Thirdly and finally, an econometric analysis to identify the linkages between the five capitals (viz. human, social, natural, physical and financial capitals), the livelihood strategies (proxied by the REBAS index) and the livelihood outcomes (food security explicitly) is carried out.

The second paper mainly focuses on the role of the institutional context, aiming to identify its effective impact on shaping the relationship between the smallholder's adoption of a specific livelihood strategy, explicitly varietal diversification, and the livelihood outcomes. To achieve this objective, the study is carried out right after the implementation of a development program that took place in Bihar, India from 2010 to 2017. This provides the ideal setting for carrying out the empirical analysis, generating a quasi-experimental framework. Thanks to the program activities it is possible to observe heterogeneities of the responses among households with knowledge and practice on how to diversify the seed portfolio with a counterfactual provided by households' business as usual. Two empirical analyses are performed: the first analysis consists in the identification of the casual effect of the institutional context change on a set of key households' outcomes, the second analysis consists in the assessment of the specific consequentiality of the steps theorized in the SRL framework, linking the livelihood outcomes to the households' adoption of varietal diversification strategies and the institutional context.

The third and final paper contributes to the growing literature on pest management analysing the influence of livelihoods assets on farmers' decisions to control Banana Xanthomonas Wilt (BXW), a disease that is threatening banana production in Uganda since 2001. BXW control strategy is based on the simultaneous implementation of four cultural practices: de-budding, sick plants removal, disinfecting tools and clean planting materials. The theoretical contextualization of the SRL framework on this specific study case offers a wide-ranging understanding of (1) the function performed by banana production within the household livelihood system, (2) the way in which the BXW disease modified it, (3) the role played by the institutional context, and finally, (4) the determinants of adoption of the integrated BXW control package by Ugandan smallholders farmers. Empirically, the double-hurdle class of model is applied in this study with the base assumption that the two adoption decision processes (adoption and intensity of adoption of the cultural practices) are separate.

2 ADAPTIVE STRATEGIES ENHANCE SMALLHOLDERS' LIVELIHOOD RESILIENCE IN BIHAR, INDIA

2.1 INTRODUCTION

Agricultural systems are increasingly threatened by climatic stressors which can influence physiological processes and crop productivity, water use and soil properties, input prices and quantities sold at market (Knox et al., 2012). Sudden changes to the stream of income generated by farming activities may undermine the livelihood of the most vulnerable rural households (Caracciolo et al., 2014). This is a common problem in different parts of the world, but India in particular is one of the countries most exposed to climatic hazards (Maiti et al., 2015). Temperatures are projected to rise by 0.5°C by 2030 (NIC, 2009), while by 2050 rainfall is projected to increase in the autumn season and to decrease in the winter season (Prabhakar and Shaw, 2008; Lal et al., 2001). Climate projections indicate more extreme weather events, such as floods and droughts. Such extreme events can stir up a sweeping decline in agricultural outputs, aggravating problems of rural poverty and food insecurity (Birthal et al., 2014). Moreover, due to its vast size and complex geography, India's climate has large spatial and temporal variations. This generates considerable uncertainty about when, where and how climate change will affect agricultural production in India (Lal, 2011). Considering that about 68% of the Indian population (of over a billion people) is directly or indirectly involved in the agricultural sector, and a population increase of 19% is expected by 2050 (United Nations, 2017), India faces a tough challenge. Indeed, the high dependence on the agricultural sector and the expected population growth combined with the unpredictable effects of weather vagaries could cause a serious food shortage in the near future (Ahmad et al., 2011).

Among the Indian states, Bihar is characterized by a very large proportion of the population (almost nine out of every ten people) whose income is directly or indirectly tied to agricultural activities (Tesfaye et al., 2017). Furthermore, it is one of the most climate-sensitive states in India due to its hydro-meteorological fluctuations. Vagaries of rainfall, recurrent floods and droughts occurring in the same season in the same place are severely threatening the agricultural production of the state (Aryal et al., 2018).

Given this scenario, a better understanding of how farming systems' resilience to the climatic stressors can be fostered is a matter of high priority in Bihar. There is still much uncertainty about which farming strategies are the most appropriate to mitigate these adverse impacts and what are the resources households need to develop to successfully implement such strategies.

The Sustainable Rural Livelihoods (SRL) framework provides a theoretical underpinning for identifying the ways through which livelihood outcomes, viz. resilience at household level, can be influenced by the strategies adopted. These in turn depend on the available household livelihood resources that are often grouped into human, social, natural, physical and financial capitals (Ellis, 2000, Scoones, 1998). Human capital improves the understanding of the risks associated with climate change and the importance of adopting appropriate management strategies; social capital makes it easier to manage contingencies; natural capital supports productive entrepreneurships; physical capital facilitates the adoption of livelihood strategies that improve resilience; financial capital makes it possible to develop adaptation measures and to accelerate recovery after shocks (Mutabazi et al., 2015).

The SRL framework has been long debated in the literature (FAO, 2019; Butler and Mazur, 2007; Randolph et al., 2007; Brock, 1999). Numerous livelihoods approaches, perspectives, methods and frameworks currently exist and differ from each other to a considerable extent (De Haan, 2000; Ellis, 2000; Scoones, 1998). Consequently, to date, there is no single, definitive conceptualization of the SRL framework (Small, 2007). Furthermore, empirical studies seeking to demonstrate the link between livelihood resources, livelihood strategies and sustainable livelihood outcomes from a quantitative point of view are still limited to our knowledge. This may be due to the fact that these concepts are difficult to clearly characterise and, consequently, to quantify. Some studies adopt the framework only partially. For instance, the recent study of Asfaw et al. (2019) focuses the analysis exclusively on the impact of a diversification strategy on household welfare in Sub-Saharan Africa. Mutabazi et al. (2015) instead analyse a broader set of livelihood strategies that farmers have adopted in Tanzania to increase resilience to climate change and the linkages of such strategies to various indicators representing the livelihood resources (human, social, natural, physical and financial capitals). What is missing in the latter study is the important connection between the adoption of the livelihood strategies and the livelihood outcomes.

In light of this, this paper aims to contribute to this area of research with the specific objectives being (1) to empirically contextualize the SRL framework in a specific study site; (2) to identify rural farmers' level of adaptation to the undesirable climatic stresses in the study context; (3) to identify hidden correlations within the different adaptive strategies; and (4) to extend the theoretical understanding of the relationship between livelihood resources, livelihood strategies and livelihood outcomes from an empirical point of view.

In accordance with the first objective, the state of Bihar, India, is considered the study site for the present analysis due to its socio-economic and climatic conditions. Secondly, the composite index of resilience-building adaptive strategies (REBAS) developed by Mutabazi et al. (2015) is used to assess adaptation at the household level against changing climatic conditions. Thirdly and finally, this study conducts an empirical analysis to identify the linkages between the five capitals (viz. human, social, natural, physical and financial capitals), the livelihood strategies (proxied by the REBAS index) and the livelihood outcomes (food security explicitly).

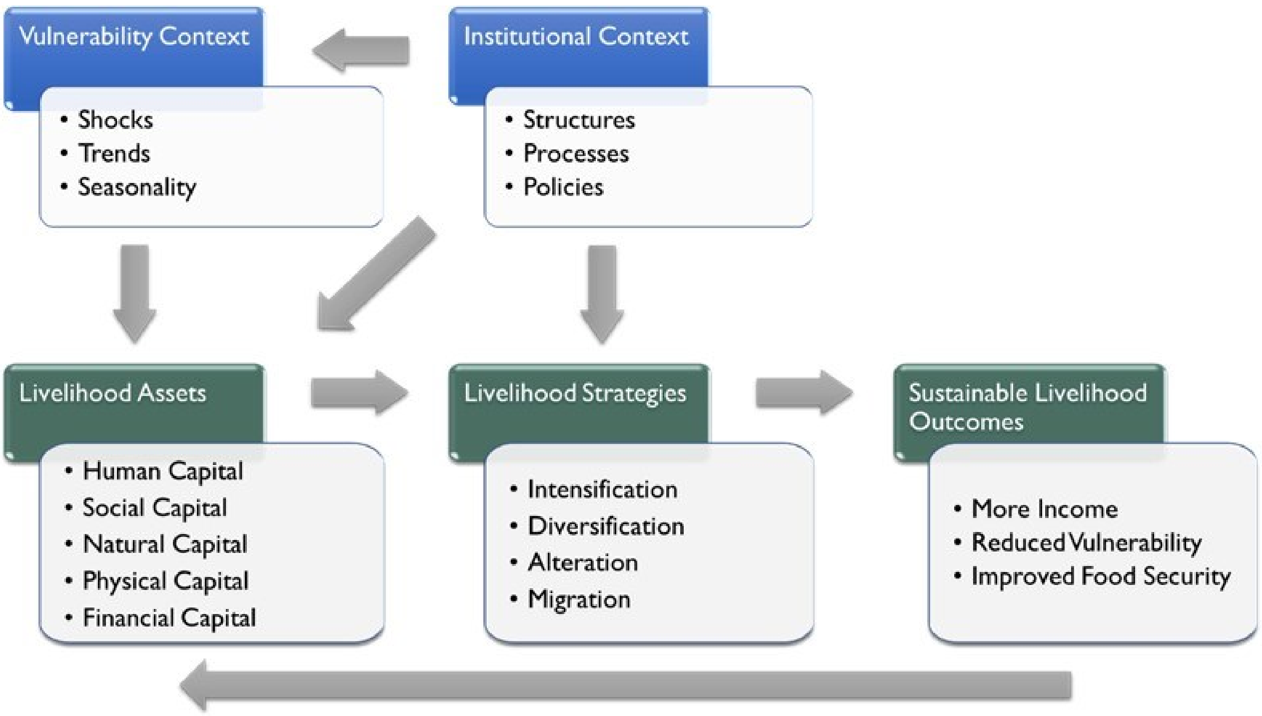
The rest of the paper unfolds as follows: paragraph 2.2 introduces the theoretical framework underlying this study; paragraph 2.3 describes the study context; paragraph 2.4 presents the methodological approach to the analysis; paragraph 2.5 reports and discusses the main findings. The analysis ends with the conclusions and relevant policy implications.

2.2 Conceptual Approach

Recognition that climate change could have negative consequences for agricultural production, and thereby for large percentages of the world's population that depends upon agriculture for their livelihoods, has stirred the necessity to build resilience into agricultural systems (Lin, 2011). The concept of resilience pertains to the ability of a system to imbibe disturbances without changing its structure or function, and still preserving options to develop (Walker et al., 2002; Carpenter et al., 2001). In this context, adaptive capacity and adaptation are respectively the resources and strategies necessary to uphold the function of a system and to influence its state of resilience (Nelson, 2011; Berkes et al., 2008; Eriksen and Kelly, 2007; Füssel, 2007; Tompkins and Adger, 2005).

The current study has chosen to analyse these concepts of adaptive capacity, adaptation and resilience and the relationship between them by considering the Sustainable Rural Livelihoods (SRL) framework (Martin and Lorenzen, 2016; Niehof, 2004; Bebbington, 1999; Ellis, 1999; Scoones, 1998) as a theoretical basis for the current study (Figure 2.1).

Figure 2.1. *The Sustainable Rural Livelihood Framework*



Source: Adapted from Carney et al. (1999) and Scoones (1998).

This framework recognizes households themselves as actors with a combination of assets (i.e. adaptive capacity) who implement specific strategies (namely adaptation) in order to pursue their own livelihood outcomes (viz. resilience). The asset base upon which households build their livelihoods is a portfolio of five different types of assets: human, social, natural, physical and financial capitals (Mayunga, 2007; Scoones, 1998). Human capital (e.g. knowledge and skills) refers to humans' capacity to understand risk and undertake adaptation strategies against climate change. Social capital (e.g. networks, social relations and associations) embraces the social connections and bonds that facilitate coordination and cooperation when pursuing different livelihood strategies. Natural capital (e.g. land and water) refers to the natural resource stocks and environmental services that provide capacity to sustain the livelihood strategies. Physical capital (e.g. infrastructures and technologies) includes material tools that will never be transformed into cash but help to increase agricultural productivity. Finally, financial capital (e.g. savings and credits) refers to the monetary resources to which a household has access.

Numerous studies have demonstrated that different endowments of the aforementioned capitals may explain a household's implementation of specific adaptation strategies against climatic stressors (García de Jalón et al., 2018; Wheeler et al., 2013; Below et al., 2012). Households will combine different assets to design specific strategies to achieve desirable "livelihood outcomes" (FAO, 2019). Broadly, smallholders can adopt different strategies in response to climate stress, namely agricultural intensification, diversification, alteration and migration. (Mutabazi et al., 2015). For instance, using physical and financial capital, smallholders may mitigate the possible fall in production by increasing the use of yield-enhancing agricultural inputs (Speranza, 2013; Paavola, 2008; David and Otsuka, 1994). On the other side, a richer endowment of natural and human capitals may enhance the diversification of farming activities, by increasing the types or varieties of crops in the field (Douxchamps et al., 2016; McCord et al., 2015; Lin, 2011; Yachi and Loreau, 1999), the integration of crops and livestock (Lemaire et al., 2014; Di Falco et al., 2011; Russelle et al., 2007; Wilkins, 2007), the integration of trees into crop and/or livestock systems (i.e., agroforestry) (De Giusti et al., 2019; Hansen et al., 2019; Ajayi et al., 2009; Verchot et al., 2007) or via intercropping with legumes (Workayehu, 2014; Rusinamhodzi et al., 2012). Previous research finds that households are likely to diversify income sources to increase livelihood security and improve farm efficiency (Bandyopadhyay and Skoufias, 2015; Porter, 2012; Ito and Kurosaki, 2009; Mehta, 2009; Paavola, 2008; Rose, 2001; Kochar, 1999). Another strategy to deal with the effects generated by climate change is based on the choice of crops to grow on-farm. Some farmers tend to introduce stress-resistant crop varieties that better suit the local conditions they face (Moniruzzaman, 2015; Cho et al., 2014; Kurukulasuriya and Mendelsohn, 2008). Among the various off-farm diversification strategies, the most widespread one focuses on the migration of one or more members of the household (Marchiori et al., 2012; Laczko and Aghazarm, 2009; Ellis, 2000). This is because migration for wage labour can produce remittances that lowers the liquidity constraint on non-migrating household members (Paavola, 2008).

The above-mentioned adaptive strategies provide households with a form of "insurance" against negative effects generated by climate stressors (Yachi and Loreau, 1999; Barrett et al., 2001) and can be considered stand-alone measures or can be combined with each other. Some households may intensify, others diversify, while there may be some who prefer to opt for migration, and households may also employ multiple livelihood strategies (Paavola, 2008).

It is evident that livelihood outcomes can vary from one household to the next because they so heavily depend on multiple, multidirectional influences. Some studies consider conventional indicators such as crop yield, income, food consumption and sustainable use of natural resources as livelihood outcomes (Gotor et al., 2017; Bellon et al., 2015a; Gotor et al., 2013). In other cases, a strengthened capital base, less vulnerability and improvements in other aspects of well-being such as health, self-esteem and even the maintenance of cultural assets are considered potential outcomes (Adato and Meinzen-Dick, 2002). Moreover, livelihood outcomes are not necessarily the end point, as they can generate a feedback effect on the future state of vulnerability and base assets (Randolph et al., 2007).

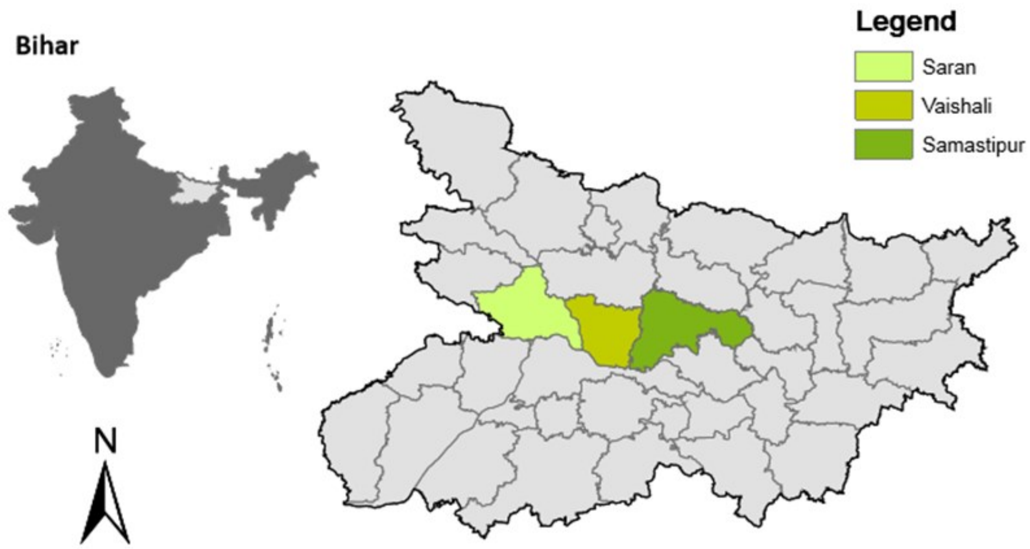
Finally, it is important to highlight that the SRL framework embraces two sets of forces that are beyond the control of the household, but which influence households' livelihood outcomes: the vulnerability context and the institutional context. The concept of vulnerability refers to unpredictable shocks that can undermine households' livelihoods. It is not objective "risk" that matters, but households' subjective assessments of things that make them vulnerable. This is important because both perceived and actual vulnerability can impinge upon households' assets, and consequently their livelihood strategies (Adato and Meinzen-Dick, 2002). The institutional context refers to outside policies, institutions and processes which influence access to assets and the vulnerability context, leading to the adoption of specific strategies to manage the negative impacts caused by extreme climatic events (ibid.).

The present paper is theoretically based upon this framework, while empirically it is contextualized in a specific study site: the State of Bihar, as illustrated in the next paragraph.

2.3 CONTEXT OF THE STUDY

The study was conducted in three districts of the State of Bihar: Saran, Vaishali, and Samastipur (Figure 2.2). Bihar is located in north-east India in the plains of the Ganga river basin. It is the twelfth-largest state in India with an area of 94,163 sq km (Majumder and Kumar, 2019) and is endowed with fertile alluvial land and rich water resources, especially groundwater (Tesfaye et al., 2017).

Figure 2.2. *Location of the study areas in Bihar, India*



Nevertheless, Bihar has always faced significant obstacles to economic growth and development (Jha and Gundimeda, 2019). According to Rasul and Sharma (2014), the state's poor economic performance over the years is due to high population numbers with poor skills, its weak agrarian structure, poor physical and economic infrastructures, issues of governance and institutional factors, an unequal distribution of resources and scarce foreign direct investments. Bihar's poverty ratio stands at 33.7% (Government of Bihar, 2015) while the Human Development Index (HDI) is equal to 0.367 (Jha and Gundimeda, 2019). According to the 2011 population census, Bihar is the third-most populous state in India, with almost 8.6% of the country's total population (Chandra et al., 2018) of which nine out of every ten people being rural residents (Jha and Gundimeda, 2019). The literacy rate is equal to 61.8% which is below the national rate of 74%.

As previously stated, the economy of Bihar is largely dependent on agriculture. Indeed, agriculture contributes to one-fifth (21.3%) of Bihar's GDP and is the prime source of livelihood for about 90% of the population (Government of Bihar, 2014). Several crops in different soil categories available in different agro-climatic zones are cultivated. For instance, Bihar is the sixth largest fruit producer in India (Kumar, 2018), while rice, wheat, and maize are the major cereal crops. Rice is the main monsoon crop and is cultivated in all districts of Bihar. Wheat was increasingly planted by Bihari farmers after the Green Revolution and is currently the major crop of the winter season. Maize is also cultivated, with an average annual production level of approximately 1.5 million tons and a steady positive trend in production. Pulses such as mung bean, peas, and lentils are mostly grown in the southern parts of Bihar (Tesfaye et al., 2017; Government of Bihar, 2014). However, 82% of landowners have less than one hectare of land (Kumar, 2018) and the economic condition of farming communities is still miserable (Ahmad et al., 2017). Furthermore, average productivity for most of the crops, except maize and pulses, is well below the national average while population pressure is rising day by day (ibid.).

As for the exposure to the whims of an unpredictable climate, Bihar is definitely a disaster-prone state, especially concerning floods and droughts (Majumder and Kumar, 2019). The high vulnerability of the state is due to the fact that Bihar forms a saucer-shaped valley located between the wet eastern coastal regions and the moderately dry continental region of the western plain (Jha and Gundimeda, 2019). This means that regional variations in precipitation distribution and precipitation variability are much higher. Generally, the eastern and northern areas receive 2,000 mm rainfall, whereas the western and south-western parts receive less than 1,000 mm rainfall (Aryal et al., 2018). Consequently, southern Bihar is highly drought-prone, whereas northern Bihar is a highly flood-prone area (Government of Bihar, 2012).

Recent studies project a general increase in monsoon rainfall and increases in both minimum and maximum temperatures across Bihar (Tesfaye et al., 2017; Kumar et al., 2006; Lal et al. 2001). The magnitudes of rainfall and temperature changes will vary depending on the site, indicating that the effect of climate change on crops will also vary by location (Tesfaye et al., 2017). This will be a major risk for crop production across Bihar. Particularly, changes in rainfall could mostly affect autumn crops while the increase in temperature, particularly minimum temperatures, could be a major threat for winter- and spring-sown crops. Furthermore, an increase in rainfall amount and intensity would increase the chance of flash floods, flood conditions and lesser groundwater recharge, that in turn would also lead to an increase in atmospheric humidity, and in the duration of the wet season (Mall et al., 2006). Combined with higher temperatures, these conditions could favour the development of fungal diseases, or the incidence of insect pests and vectors (Sharma et al., 2007). Overall, Bihar presents a high exposure to climatic vagaries, and the myriad of social, economic, and institutional factors and their interplay shape the vulnerability of its people and the places they reside (Jha and

Gundimeda, 2019). Adaptation measures thus need to be designed and evaluated for the different farming systems of the state (Tesfaye et al., 2017).

2.4 EMPIRICAL ANALYSIS

2.4.1 Sample and Data Collection

Data were collected as part of the Seeds for Needs India Impact Assessment study (Gotor et al., 2018a). A household questionnaire was administered between February and August 2018 in three districts of Bihar state: Saran, Vaishali, and Samastipur. The analysis is based upon 600 rural households, which included 300 participants in a development program promoted by the Consultative Group on International Agricultural Research (CGIAR).

The data collection team consisted of three enumerators who attended a four-day training and field-testing series. One enumerator was designated team leader and was responsible for cross-checking all household data at the end of each day. The enumerators used electronic tablets to record the data using the Open Data Kit (ODK) platform. All data was uploaded to a server at the end of each day after being checked by the team leader. The household questionnaire used was adapted from the Rural Household Multi Indicator Survey (RHoMIS) (Hammond et al., 2017) following enumerators' feedback during the training. RHoMIS is a household survey tool designed to rapidly record a series of standardized indicators across the spectrum of agricultural production and market integration, nutrition, food security, poverty and GHG emissions. The questionnaire also collected standard socioeconomic information about household demographics, education, landholdings, sources of income, migration, and the gender-disaggregated allocation of decision-making power.

2.4.2 Definition of the SRL concepts

The first step of this study is the identification of specific variables to adequately represent the different concepts embodied by the SRL framework, namely livelihood assets, livelihood strategies and sustainable livelihood outcomes. As illustrated in paragraph 2.2, the interactions between the above-mentioned domains explain how rural households can adapt to a changing environment and build their livelihoods, but, from an empirical point of view, a concrete quantification of the SRL concepts is far from straightforward.

2.4.2.1 Livelihood Assets

Livelihood assets include human, social, natural, physical and financial capitals. The variables selected to quantify the different livelihood assets are the following:

i. *Human capital*: age and level of education of the household head, as well as the dependency ratio, are selected for human capital-related variables. Age of the household head can be considered as a proxy for farming experience (Deressa et al., 2009). Previous literature has identified both positive and negative relationships between the number of years of experience and the adoption of adaptive strategies (Maddison, 2007; Shiferaw and Holden, 1998). This study hypothesizes that age influences households' adaptation. Similarly, a higher level of education facilitates access to information about agro-climatic aspects, so farmers with higher levels of education should adapt faster to climatic stressors (Below et al., 2012; Maddison, 2007). Finally, the dependency ratio reflects the age structure of households by comparing the dependent household members (those under the age of 10 and over the age of 50) with the productive household members (those aged 11-50). A negative relation is expected between the dependency ratio and the adoption of adaptation measures (Below et al., 2012).

ii. *Social capital*: high levels of trust and cooperation within the community are assumed to enable the adoption of adaptive strategies. Female-headed households may have a lower ability to cope with climatic stressors since traditional social barriers may limit their access to information and other resources (Hassan and Nhemachena, 2008; Tenge et al., 2004), in which case a negative relation is expected. Lastly, household participation in a specific development initiative was included as a variable to account for this source of social interaction.

iii. *Natural capital*: farm size easily represents the endowment of natural capital (Deressa et al., 2009). It is expected that larger-scale farmers are likelier to undertake adaptive strategies than small-scale farmers would be.

iv. *Physical capital*: the household appliance index has been calculated as the physical capital-related variable[1]. A home with a stove, refrigerator, television or motor vehicle denotes a certain level of well-being, which is a determinant of the likelihood that a household will adapt (Kuntashula et al., 2015). Moreover, a variable measuring whether a household has land ownership rights was

[1] The predicted 1st factor from a Factor Analysis performed on assets such as a refrigerator, stove, pressure cooker, dressing table, electric fan, television, dining table or motor vehicle owned by a household was calculated.

measured, since it may influence investment decisions and households' resilience (Mutabazi et al., 2015).

v. *Financial capital*: the financial capital-related variables measure whether a household has access to formal sources of credit (from the government, NGOs or other organisations) and/or informal sources of credit (from family, friends, or neighbours) (Bryan et al., 2013). Financial capital may positively influence the resilience capability, since financial resources are crucial to implement various adaptation options (Bahinipati and Venkatachalam, 2015). Whether a household has debts may adversely affect households' resilience capability (Taylor, 2013).

The selected variables and their description can be found in Table 2.1.

Table 2.1. *Description of the livelihood assets and their expected influence on adaptation*

Livelihood Assets	Expected influence	References
Human Capital		
Age of HH head (number)	+	Deressa et al., 2009
Education of HH head (1 educated/0 no)	+	Maddison, 2007
Dependency Ratio (Ratio of dependent versus productive household members %)	-	Below et al., 2012
Social Capital		
Gender of HH head (1 female/0 male)	-	García de Jalón et al., 2018
Trust & cooperation community	+	Goodwin, 2003
Project participation (1 yes/0 no)	+	Wheeler et al., 2013
Natural Capital		
Farm size (acres)	+	Asfaw et al., 2019
Physical Capital		
Land ownership right (1 yes/0 no)	+	Mutabazi et al., 2015
Appliance Index	+	Gotor et al., 2018b
Financial Capital		
Debts (1 yes/0 no)	-	Taylor, 2013
Formal credit (1 yes/0 no)	+	Bryan et al., 2013
Informal credit (1 yes/0 no)	+	Bahinipati and Venkatachalam, 2015

2.4.2.2 Livelihood Strategies

In order to identify which livelihood strategies households are adopting and to what extent, the resilience-building adaptive strategies (REBAS) index developed by Mutabazi et al. (2015) was implemented.

The first step in REBAS development is the selection of a set of variables related to the possible adaptive strategies (intensification, diversification, alteration and migration) that may contribute to the household's resilience. To compensate for a potential fall in yields, smallholders may choose a strategy of agricultural 'intensification' through the employment of yield-enhancing agricultural inputs (Speranza, 2013; Paavola, 2008). Consequently, in order to capture the presence of the intensification strategy, the number of different inputs (viz. fertilizer, manure, compost, pesticides and irrigation facilities) used for carrying out agricultural activities was counted. The diversification strategy included information on crop diversification (through the Simpson's Diversity Index) (Gotor et al., 2018b; Douxchamps et al., 2016; McCord et al., 2015), the use of intercropping with legumes (Workayehu, 2014; Rusinamhodzi et al., 2012), the presence of other forms of on-farm diversification (coexistence of livestock and/or agroforestry) (De Giusti et al., 2019; Wilkins, 2007), as well as off-farm diversification (i.e. the amount of off-farm income sources). Concerning the alteration strategy, the use of early-maturing, drought-resistant or flood-resistant varieties and the early harvest of crops have been used (Moniruzzaman, 2015; Cho et al., 2014; Kurukulasuriya and Mendelsohn, 2008). Finally, in the case of migration, the indicator used is the access to remittances from migrated household members (Marchiori et al., 2013; Paavola, 2008).

The next step is to create an objective weighting scheme that summarizes all the resilience-building adaptive strategies (intensification, diversification, alteration and migration) into a single composite indicator (the REBAS index). A principal component analysis (PCA) will then be carried out. Once the PCA is performed, the calculation of the REBAS index is computed as in Eqs. 1 and 2:

$$C_{jk} = \sum_{l} a_k^l (X_j^l) \quad (1)$$

$$REBAS_j = \sum_{k} v_k (C_{jk}) \quad (2)$$

where C_{jk} is k-th principal component for the j-th household, a_k^l is the loading of the k-th component for the l-th variable and X_j^l are the j-th household's values for the i-th construct indicator. Moreover, $REBAS_j$ is the composite score of resilience-building livelihood strategies of the j-th household and v_k is the variance accounted by the k-th principal component.

Finally, to obtain a standardized value, the REBAS was transformed into values ranging from 0 to 100 as follows in Eq. 3:

$$REBAS_j^s = \frac{H_i - H_{min}}{H_{max} - H_{min}} * 100 \qquad (3)$$

$j = 1, 2, 3, \ldots, N$

where $REBAS_j^s$ is the adjusted index of the j-th household; H_i is the unadjusted index value for the *i*-th household in the sample, while H_{min} and H_{max} are respectively the minimum and the maximum value of the unadjusted index in the sample.

2.4.2.3 Livelihood Outcomes

The current study aims to determine whether a linkage exists between the livelihood assets, the livelihood strategies (proxied by the REBAS index) and the livelihood outcomes in Bihar, India. Here, food security is used as the main livelihood outcome. Food security is directly and indirectly related to climate change. Climatic stressors affect food security by influencing the availability and accessibility of food, steadiness of food supplies and instability in food prices (Birthal et al., 2014). Obviously, the impacts of climatic stressors on households' food security are unforeseeable as they depend on the type and extent of the shock and the characteristics of the reference context (Vermeulen et al., 2012; Hertel and Rosch, 2010).

To determine the relation between the livelihood strategies (proxied by the REBAS index) and the livelihood outcomes, the Household Food Insecurity Access Scale (HFIAS[2]) was employed in this analysis (Coates et al., 2007). The HFIAS is a set of nine questions that covers a recall period of 30 days and captures households' behavioural and psychological manifestations of insecure food access. Each of the nine questions is scored 0-3, with 3 indicating the highest frequency of occurrence. At the end, the scores for all questions are added together. The total HFIAS can range from 0 to 27 allowing the household to be pinpointed on a spectrum that indicates a higher degree of food insecurity with a higher score.

[2] The HFIAS was developed between 2001 and 2006 by the USAID-funded Food and Nutrition Technical Assistance II project (FANTA) in collaboration with Tufts and Cornell Universities, among other partners.

2.4.3 Empirical Model

Once the different concepts embodied by the SRL framework (livelihood assets, livelihood strategies and sustainable livelihood outcomes) have been properly identified and quantified, the following step consists of analysing the relationships and interactions between the above-mentioned domains to explain how rural households may adapt to a changing environment and build their livelihoods in terms of food security. In a nutshell, the study aims to understand the relationship between livelihood resources, livelihood strategies and livelihood outcomes theorized by the SRL framework.

From an empirical point of view, a Tobit model with endogenous regressors (Eq. 4 – 5) was implemented. It is a two-stage model able to deal with censored data and endogeneity. Indeed, the identification of the causal effect of REBAS on the HFIAS (as hypothesised in the SRL) may suffer from some endogeneity bias, as the food security (HFIAS) may directly or indirectly influence the household adoption of livelihood strategies (REBAS) as well.

$$HFIAS_j^* = Rebas_j\beta + z_{1j}\delta + \varepsilon_j \qquad (4)$$

$$REBAS_j = z_{1j}\pi_1 + z_{2j}\pi_2 + u_j \qquad (5)$$

Wherein, for each j-th households, $REBAS_j$ is the endogenous variable; z_{1j} is a $1\times k_1$ vector of exogenous variables, with δ the relative parameter $1\times k_1$ vector; z_{2j} is a $1 \times k_2$ vector of additional instruments. By assumption $(u_i, \varepsilon_i) \sim N(0)$. β is the parameter measuring the effect of REBAS on HFIAS, and π_1 and π_2 are matrices of reduced-form parameters.

Within the SRL framework, the variables representing the exogenous change of the vulnerability and institutional contexts are reasonable candidates to address endogeneity, affecting the adaptation level of rural households (REBAS), without having any direct impact on the livelihood outcome (HFIAS). Therefore, this study employs two variables as instruments: whether households were exposed to climatic stressors and a dummy variable identifying the villages where a development program was implemented. The validity of the instruments has been tested through the Sargan test of over-identifying restrictions.

2.5 Results and Discussion

2.5.1 SRL Concepts

As previously illustrated, the initial part of the study identifies and quantifies the different concepts embodied by the SRL framework, namely livelihood assets, livelihood strategies and livelihood outcomes. The descriptive statistics of the variables employed in the analysis are presented in Table 2.2. Among the livelihood assets, the Table shows that the average age of the household heads of the sample is around 47 years with only 24% of them as female. The average size of farms is 7 acres and 96% of the households claim to own the land they cultivate. Almost 60% of the sample finds it difficult to repay debts, while just a small percentage of people sampled have access to formal or informal sources of credit (5% and 3% respectively). Focusing on the livelihood strategies, the variable related to the intensification strategy presents a mean value of 4.83, indicating that farmers employ almost all the agricultural inputs considered (viz. fertilizer, manure, compost, pesticides and irrigation facilities). Conversely, the Simpson's Diversity Index is equal to 0.21. This is evidence that a strategy based on the diversification of cultivated crops is not widespread among the rural households considered in the analysis. Moreover, the dummy variables associated with the alteration strategy present a mean value above 0.70, except for the adoption of flood-resistant varieties that has a mean value of 0.50. Lastly, only one-fifth (22%) of the sample received remittances from migrant household members. The bottom of the Table provides values for the livelihood outcome considered by this study. As can be seen, the HFIAS is equal to 1.46 which indicates that the observed households have a high level of food security.

2.5.2 Adaptation Level

Once the empirical construct of the SRL framework was established, the next step concerned the calculation of the resilience-building adaptive strategies (REBAS) index, reflecting the portfolio of adaptive strategies adopted by the farm households and their correlations. The computation of such an index is based on an objective weighting scheme derived from the PCA of the dataset[3]. Table 2.3 illustrates that the first component of the PCA is based on all the alteration practices, i.e. the adoption

[3] Varimax rotation has been performed to minimize the number of variables that have high loading on one component. Statistical tests such as Bartlett's sphericity test and the Kaiser–Meyer–Olkin measure indicate that the PCA is appropriate.

of drought- and flood-resistant varieties, early-maturing varieties and the adjustment of harvesting dates according to weather conditions. Migration (receiving remittances) and a subset of diversification strategies (namely carrying out off-farm activities) have highest loadings in the second component. Two different practices of an on-farm diversification strategy (the integration of livestock and/or agroforestry and intercropping with legumes) have maximum loading in the third component. The last component shows a high correlation between the identified intensification measure (viz. amount of inputs used in the agriculture activity) and a subset of diversification strategies (namely crop diversification).

These results illustrate the internal correlations among the different classes of adaptive strategies identified in the study (intensification, diversification, alteration and migration). The diversification strategies observed within the sample population are comprised of on-farm diversification and intercropping with legumes. Intercropping with legumes is an appealing option to address climate risk for farm households, because it can reduce the risk of crop failure and improve productivity (Workayehu, 2014; Rusinamhodzi et al., 2012). On-farm diversification activities include the integration of crops and agroforestry and/or livestock. Tree-based systems are able to maintain production during wetter and drier periods and to mitigate climate change through enhanced carbon sequestration (Verchot et al., 2007). Local integration of cropping with livestock systems would allow greater flexibility of the whole system to cope with potential socio-economic and climate change induced threats and improve the quality of grasslands through periodic renovations (Lemaire et al., 2014; Di Falco et al., 2011; Wilkins, 2007; Russelle et al., 2007). Households tend to combine different diversification strategies within a portfolio as a sort of “insurance” against unpredictable, future stressors. The fact that on-farm diversification and intercropping with legumes present a high positive correlation indicates that Indian farmers tend to adopt a portfolio of strategies that reduce the risk of crop failure while providing an alternative source of income if the crop failure actually occurs. This is in line with the study by Beillouin et al. (2019) which shows that a combination of different diversification strategies can generate better results than the adoption of a single strategy. The second and fourth components of the PCA instead highlight that some strategies are considered by Indian farmers as alternative strategies. Not surprisingly, diversification beyond on-farm activities and migration are negatively correlated, as is the intensification strategy and the strategy based on interspecies diversification. Only the alteration strategy is adopted by rural households as a stand-alone measure. The PCA does not reveal hidden correlations with other adaptive strategies. Considering that Bihar is a state particularly sensitive to climatic whims, especially droughts and floods, it is intuitive that farmers tend to introduce stress-resistant crop varieties that better suit the local conditions they face and also adjust harvesting dates according to weather conditions.

2.5.3 Econometric Results

The final part of the study analyses the relationships between livelihood resources, livelihood strategies and livelihood outcomes as indicated by the SRL framework. To assess this objective, a Tobit model with endogenous variables was implemented. Results of this part of the study can be found in Table 2.4[4]. The results of the first stage of the model bring out a number of insights about the linkages between the livelihood assets and the identified strategies. Both social and natural capital-related variables have a significant positive effect on the resilience-building measure. This is in accordance with previous studies (Mutabazi et al., 2015; Isham, 2002). Belay et al. (2017) show that natural capital improves the ability of households to develop adaptive measures by providing critical resources that are often readily available and whose use does not require in-depth knowledge. In particular, the study by García de Jalón et al. (2018) found that natural capital has a strong effect in terms of introducing crop varieties which are more resistant to droughts. Moreover, high levels of trust and cooperation within the community have been shown to reduce social barriers that may hamper the employment of adaptation strategies (Groenewald and Bulte, 2013). Interestingly, the model shows that female-headed households are more likely to take up climate change adaptation methods. This could be related to the fact that women are deeply engaged in agricultural work and therefore have greater experience and access to information about management and farming practices (Nhemachena and Hassan, 2007).

Among the physical capital variables, whether households have land ownership rights does not appear to significantly affect adoption, while the appliance index has a significantly negative effect on rural adaptation levels. This could be explained by substitution in adaptation options (García de Jalón et al., 2018), where some wealthier rural households may prefer coping strategies over adaptation strategies.

In case of financial capital, access to formal sources of credit positively and significantly influences the REBAS index. It can be inferred that receiving financial aid from the government, NGOs or other organizations loosens liquidity constraints and stimulates households' adaptation to climatic stressors. Conversely, the coefficient of the debts variable is negative and significant. As expected, farmers who find it difficult to repay their debts are less likely to adopt adaptation measures against climate stress.

[4] The Sargan test showed exogeneity of instruments. Moreover, results from the test for weak instruments indicates that the selected instruments were relevant.

Despite evidence from various sources suggesting human capital is an important determinant of adoption of farm-level adaptation measures (García de Jalón et al., 2018; Below et al., 2012; Deressa et al., 2009; Hassan and Nhemachena, 2008; Maddison, 2007), this study's results did not suggest that this capital positively affects the adaptation level of rural Indian households.

Results of the second stage of the Tobit model highlight the negative and significant influence of the REBAS index on the HFIAS. This means that high levels of adaptation are associated with positive levels of food security. The result is in line with previous research suggesting that the adoption of adaptive measures improve the food security status of households (Douxchamps et al., 2016). It represents a noteworthy result because much of Bihar's population depends on agriculture, a famously climate-sensitive sector. Extreme climatic events can cause a drastic decline in agricultural outputs, exacerbating problems of food insecurity and rural poverty. Finally, among the capital-related variables, the empirical analysis suggests that only the appliance index directly influences the level of food security of rural households in the study site. This in alignment with the study by Mbukwa (2014) that shows that physical capital is positively associated with food security.

Table 2.2. *Description of the Sustainable Rural Livelihood constructs and descriptive statistics of the variables employed in the analysis*

SRL Construct	Variable	Mean	Std. Dev.	Min	Max
Human Capital	Age of HH head (number)	47.39	12.50	16	90
Human Capital	Education of HH head (1 educated/0 no)	0.68	0.47	0	1
Human Capital	Dependency Ratio	77.70	65.27	0	350
Social Capital	Gender of HH head (1 female/0 male)	0.24	0.43	0	1
Social Capital	Trust & cooperation community (level)	2.24	0.72	0	4
Social Capital	Project participation (1 yes/0 no)	0.50	0.50	0	1
Natural Capital	Farm size (acres)	7.03	10.62	0	50
Physical Capital	Land ownership right (1 yes/0 no)	0.96	0.19	0	1
Physical Capital	Appliance Index	66.04	29.76	0	100
Financial Capital	Debts (1 yes/0 no)	0.59	0.49	0	1
Financial Capital	Formal credit (1 yes/0 no)	0.05	0.22	0	1
Financial Capital	Informal credit (1 yes/0 no)	0.03	0.18	0	1
Intensification Strategy	Agricultural inputs (count)	4.83	0.52	0	5
Diversification Strategy	Simpson’s Diversity Index	0.21	0.26	0	1
Diversification Strategy	Intercropping with legumes (1 yes/0 no)	0.41	0.49	0	1
Diversification Strategy	Diversification on-farm (n. activities)	0.80	0.45	0	2
Diversification Strategy	Diversification off-farm (n. activities)	0.76	0.53	0	2
Alteration Strategy	Harvest early (1 yes/0 no)	0.79	0.41	0	1
Alteration Strategy	Early-maturing varieties (1 yes/0 no)	0.79	0.41	0	1
Alteration Strategy	Drought-resistant varieties (1 yes/0 no)	0.71	0.45	0	1
Alteration Strategy	Flood-resistant varieties (1 yes/0 no)	0.50	0.50	0	1
Migration Strategy	Remittances (1 yes/0 no)	0.22	0.41	0	1
Adaptive Strategies	REBAS Index	51.68	23.55	0	100
Outcome	HFIAS	1.46	2.02	0	27

Table 2.3. *PCA components used for resilience-building adaptive strategies (REBAS) index construction*

Resilience-building strategy	Indicators	Components*			
		1	2	3	4
Intensification	Agricultural inputs	-0.0549	-0.0479	-0.0219	**0.8320**
Diversification	Crop diversification (SDI)	-0.3009	-0.1327	-0.1159	**-0.4694**
Diversification	Intercropping with legumes	-0.0070	-0.0905	**0.7297**	-0.0006
Diversification	Diversification on-farm	-0.0154	0.3706	**0.4302**	0.0589
Diversification	Diversification off-farm	0.1137	**0.6824**	0.0363	-0.1279
Alteration	Harvest early	**0.4248**	-0.1324	-0.2430	0.1430
Alteration	Early-maturing varieties	**0.4150**	0.0470	-0.2088	-0.1589
Alteration	Drought-resistant varieties	**0.4795**	-0.1165	-0.0283	-0.0466
Alteration	Flood-resistant varieties	**0.5252**	0.1555	0.2102	-0.0540
Migration	Remittances	0.1866	**-0.5581**	0.3458	-0.1296
Percentage of variance explained		0.25	0.17	0.13	0.12
Cumulative variance percentage		0.25	0.41	0.54	0.67

*Bold figures highlight the highest component loading

Table 2.4. *Results of the Tobit regression with endogenous variables*

Variables	Regression results			
	Coef.	SE	*z*	
REBAS Index				
Age of household head	-0.053	0.063	-0.84	
Education of household head	-1.490	1.985	-0.75	
Dependency Ratio	-0.014	0.012	-1.16	
Gender of household head	10.032	2.112	4.75	***
Trust & cooperation community	13.984	1.160	12.05	***
Project participation	7.918	2.013	3.93	***
Farm size	0.672	0.230	2.92	***
Squared farm size	-0.022	0.007	-3.06	***
Land ownership right	-3.735	4.334	-0.86	
Appliance Index	-0.113	0.027	-4.13	***
Debts	-4.413	1.593	-2.77	***
Formal credit	11.505	3.582	3.21	***
Informal credit	-4.856	4.416	-1.10	
Exposure to climatic stressors	0.421	5.158	0.08	
Village project implemented	-4.915	2.407	-2.04	**
Constant	33.824	7.745	4.37	***
HFIAS				
REBAS Index	-0.399	0.198	-2.01	**
Age of household head	0.005	0.028	0.20	
Education of household head	-1.238	0.853	-1.45	
Dependency Ratio	-0.007	0.005	-1.25	
Gender of household head	1.514	2.036	0.74	
Trust & cooperation community	3.538	2.898	1.22	
Project participation	1.786	1.303	1.37	
Farm size	-0.055	0.155	-0.36	
Squared farm size	-0.003	0.005	-0.68	
Land ownership right	-2.559	2.068	-1.24	
Appliance Index	-0.041	0.024	-1.74	*
Debts	-0.540	1.115	-0.48	
Formal credit	2.042	2.689	0.76	
Informal credit	-2.434	2.043	-1.19	
Constant	18.059	6.995	2.58	***

Level of significance: * 10 %; ** 5 %; *** 1 %

2.6 Conclusions

This study empirically contextualized the SRL framework in Bihar, one of the most climate-sensitive states in India wherein widespread floods and droughts threatened the agricultural production of the state (Aryal et al., 2018) undermining the livelihood of its extremely dense and poor rural population (Tesfaye et al., 2017).

The identification of main SRL concepts first allowed to understand in which way household livelihood resources and strategies are interconnected and may impact livelihood outcomes, such as food security.

The first objective of the analysis was to identify adaptation strategies adopted in the study site's agricultural systems. Results showed that only the alteration strategy is adopted by Indian farmers as stand-alone measure. The other identified strategies are considered as alternative measures, such as diversification beyond on-farm activities and migration or intensification and crop diversification. Only a subgroup of diversification strategies (i.e. intercropping with legumes and other practices of on-farm diversification) is perceived as complementary measures.

Lastly, the study aimed to further understand the relationships traced by the SRL framework. To examine the interplay of capitals, strategies, and outcome, a Tobit model with endogenous variables was implemented. The results of the empirical model bring quantitative evidence on how livelihood resources (human, social, natural, physical and financial capitals), livelihood strategies (proxied by the REBAS index) and livelihood outcomes (food security) are linked. The results emphasise that adaptation of the farming system is influenced by the livelihood resources of rural households, in particular with regard to social, natural, physical and financial capitals. Moreover, adaptation of the farming system is positively linked to food security status of the farm households. This is not a foregone conclusion, however, because is not always possible to increase the resilience of agricultural systems even if adaptive measures are adopted (Nelson, 2011).

Interestingly, the empirical analysis shows that human capital has no significant influence on households' choice of livelihood strategies, while physical capital is negatively associated with adaptation level, but it positively influences rural households' food security level. Such results suggest remarkable considerations: (1) not all livelihood assets are associated to adoption of livelihood strategies; (2) the influence of some livelihood assets on the livelihood outcomes could be conveyed by the adoption of specific livelihood strategies, while in other cases (3) some livelihood assets could be directly linked to livelihood outcomes.

The current study thus emphasizes the importance of targeted interventions to improve specific forms of households' livelihood resources, being key determinants for adaptation strategy adoption in the face of climate stressors. In particular, interventions need to focus on dismantling barriers to social integration among community members. Social networks can promote cooperation and facilitate access to information about best farming management practices and climate change. At the same time, policy interventions should create the financial environment that allows farmers to adapt to climate change. All this is pivotal to guarantee the maintenance and improvement of the resilience of environmentally dependent households in the developing world.

The results of this analysis do not offer a one-size-fits-all solution. As illustrated above, different rural households adopt different livelihood strategies because adaptation occurs across broad spatial and temporal scales. Consequently, farmers could adopt different adaptive strategies in other parts of the world, or they could switch their livelihood strategies as climate and demographic conditions evolve. Our results thus refer to the specific context of the research but our empirical quantification and validation of the SRL framework may represent a valid operating procedure to better understand dynamics between livelihood assets, livelihood strategies and livelihood outcomes in other contexts. Further research could improve the methodological approach of the current analysis by including more predictors of adaptation, such as variables that describe farmers' perceptions and attitudes toward climatic risks, or by extending the range of livelihood outcomes that could be pursued by the households, such as yield stability or the sustainable use of natural resources.

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3 VARIETAL DIVERSIFICATION THROUGH PARTICIPATORY SELECTION ENHANCES THE ADAPTIVE CAPACITY OF SMALLHOLDER FARMERS IN BIHAR, INDIA

3.1 INTRODUCTION

Smallholder farmers are exposed to growing uncertainty and risks (Castells-Quintana et al., 2018; IPCC, 2014). Weather disturbances are increasingly affecting agricultural systems and alternative sources of income are often limited (Gitz and Meybeck, 2012; Lobell et al., 2011). The likelihood for an agricultural system to be adversely affected by climatic stressors depends on both social and biophysical factors (Nelson et al., 2009). Vulnerability is a result of exposure and sensitivity of agricultural systems to climatic variation as well as the capacity of producers to adapt within their livelihood systems (Adger, 2006; Turner et al., 2003). Short-term and long-term climate variation can jointly contribute to vulnerability. For example, smallholders might erode their assets and resources to cope with the short-term consequences of climatic shocks, and thereby undermine their long-term adaptive capacity (Call et al., 2019; Hansen et al., 2019; Otto et al., 2017).

Smallholders can adopt different strategies in response to climate stressors. These strategies include a more efficient use of the production factors (including natural resources) (Speranza, 2013; Paavola, 2008), changes in the production technology through the introduction of novel crop management techniques or the adoption of stress-tolerant varieties or crops (Call et al., 2019; Moniruzzaman, 2015; Mutabazi et al., 2015; Salazar-Espinoza et al., 2015; Cho et al., 2014). Different strategies can help households to manage risk through resource allocation (Ellis, 2000) or (financial or non-financial) insurance (Barrett et al., 2001; Yachi and Loreau, 1999). Unfortunately, smallholders often lack the capital or knowledge to effectively implement some of these strategies (Burnham et al., 2018; Gallopín, 2006). Thus, farmers tend to manage risk largely through labour and land allocation and seed management (Di Falco et al., 2007).

An important option to respond to climate risk is on-farm diversification. It may be achieved through the diversification of the portfolio of farming generating activities through increasing the types or varieties of crops in the field (Di Falco et al., 2011), crop rotation (Helmers et al. 2001), intercropping (Raseduzzaman and Jensen 2017), integration of crops and livestock (Di Falco et al., 2011; Yesuf et al., 2008) or integration of trees into crop and/or livestock systems (i.e., agroforestry) (Hansen et al., 2019; Verchot et al., 2007).

In this paper, we focus on the use of different varieties on farms. This strategy relies on the genetic diversity among the range of varieties used by the farmer. Varietal diversity can help the farming system to buffer against adverse environmental conditions (Kiær et al., 2009; Østergård and Jensen, 2005; Akem et al., 2000; Zhu et al., 2000; Lannou and Mundt, 1996; Wolfe, 1985). There is evidence that varietal diversification can reduce crop disease through three mechanisms: (a) reducing the spread of pathogens, (b) increasing the distance between sensitive host plants or (c) increasing the presence of resistant plants that form a barrier to prevent dispersion of pathogens (Mundt, 2002; Zhu et al., 2000; Mundt et al., 1999; Finckh and Wolfe, 1998; Smithson and Lenne, 1996; Chin and Wolfe, 1984). Further studies provided empirical evidence that variety richness is associated with an increase of productivity and a reduction of yield variability (Di Falco et al., 2007; Østergård and Jensen, 2005; Yachi and Loreau, 1999). Varietal diversity reduces yield variability because different varieties respond in different ways to different stresses. Different varieties can be combined into a portfolio that has a more stable average yield than any of the individual varieties (Sukcharoen and Leatham, 2016; Nalley and Barkley, 2010). Indeed, rural households often maintain more than one variety on their farm (Bellon et al., 2015a; Jarvis et al., 2008).

The above-mentioned studies analysed the benefits generated by varietal diversification strategy mainly through two types of studies. Observational studies look at empirical relationships in existing farming systems (e.g. Di Falco et al., 2007). Experimental studies look at biological mechanisms and experimentally controlling for a large number of factors (e.g. Sukcharoen and Leatham, 2016; Nalley and Barkley, 2010). Even though there is evidence for a causal relationship in reality, this does not mean that interventions introducing new varieties automatically activate this mechanism. Among other things, this assumes that farmers are able to identify suitable varieties for risk reduction and yield increase under diverse field conditions (van Etten et al., 2019; Creissen et al., 2016). Under real farming condition, the variety selection process can be time-consuming and costly (Joshi et al., 1997). Smallholder farmers often lack the knowledge needed to properly manage and deploy this diversity (Nankya et al., 2017; Mulumba et al., 2012). Also, farmers' adoption of genetic diversity on-farm is often limited by the constraints of modern plant breeding and commercial seed sector in creating and distributing varieties suited for marginal niches (van Etten et al., 2017; Ceccarelli, 1989).

A third type of study would be needed, linking varietal diversification interventions to livelihood outcomes. This study attempts to fill this gap in the literature investigating whether the adoption of the varietal diversification strategy is effectively associated to livelihood benefits at household level.

More specifically, if intra-species diversity of major staple crops is associated with (1) crops productivity and (2) households' ability to recover from agricultural shocks occurrence.

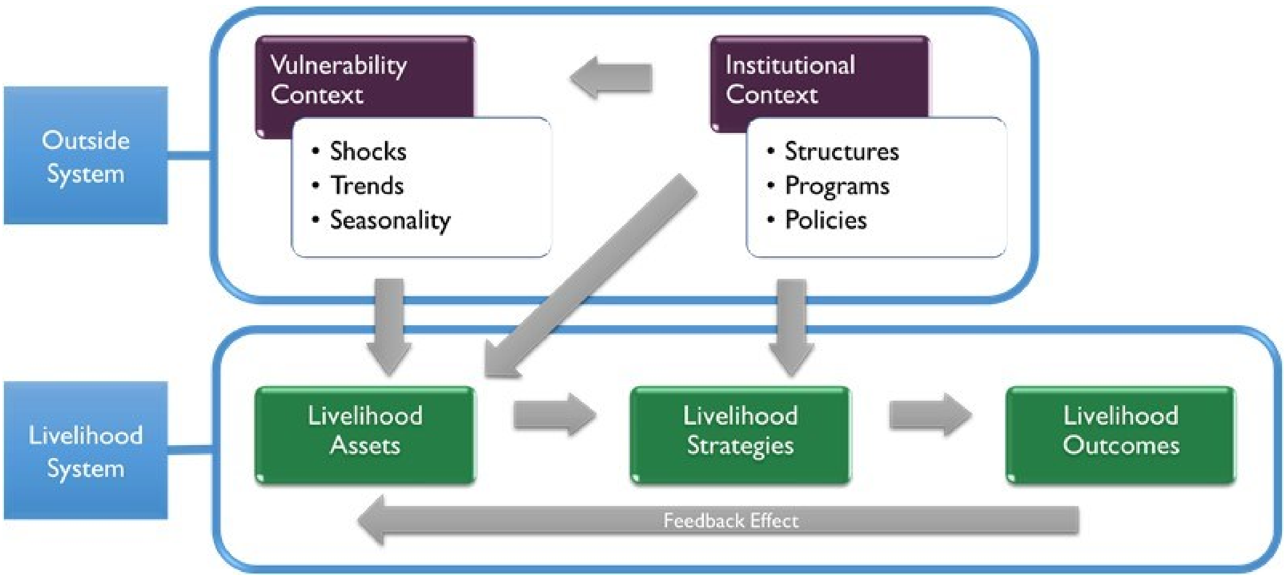
To achieve this objective, the current study is carried out to evaluate the impact of an agricultural research for development program in Bihar, India that took place from 2010 to 2017. This specific study context provides a quasi-experimental framework that allows to better identify the outcomes of varietal diversification as an intervention strategy. We compare the responses between households who obtained seeds and knowledge on how to diversify the variety portfolio and households who were not part of the intervention.

The current analysis is structured as follows: paragraph 3.2 presents the conceptual framework; paragraph 3.3 introduces the study context; paragraph 3.4 describes the data collection process, the outcome variables of interest, and the methodological approach to the analysis; while paragraph 3.5 reports the main results. The analysis ends with a discussion of the results and their implications.

3.2 Conceptual Framework

Agricultural production systems are undergoing an unprecedented pressure from the adverse effects of climate change. This in turn threatens rural households' livelihoods that often have to cope with the effects of shocks and associated risks on their own (Nguyen et al., 2015). Extensive literature has suggested that a viable farming strategy to manage climate risk is based on the use of different varieties in the field (Sukcharoen and Leatham, 2016; Nalley and Barkley, 2010; Kiær et al., 2009; Di Falco et al., 2007). The current study aims to investigate if the implementation of varietal diversification interventions is associated to livelihood benefits at household level. In order to asses this objective, the theoretical foundation of this study relies on the Sustainable Rural Livelihoods (SRL) framework (Figure 3.1) (Martin and Lorenzen, 2016; Niehof, 2004; Bebbington, 1999; Carney et al., 1999; Ellis, 1999; Scoones, 1998). It proposes a comprehensive insight that emphasizes the livelihood system of the rural households and analyses the ways in which they adapt their farming strategies to manage external changes and to preserve their livelihoods (Scoones, 1998).

Figure 3.1. *The sustainable Rural Livelihood Framework*



Source: Adapted from Carney et al. (1999) and Scoones (1998).

A key feature of this framework is that it recognizes households themselves as actors with assets and capabilities who act in pursuit of their own livelihood goals. The asset base upon which households build their livelihoods comprehends a wider range of asset than are usually considered. Rather than looking only at the general socio-economic status of the households, the SRL invites to consider a portfolio of five different types of assets: natural, financial, physical, human and social capitals (Scoones, 1998). *Natural capital* (e.g. soil, water) refers to the natural resource stocks and environmental services that gives capacity to sustain the livelihood strategies. *Financial capital* (e.g. savings, debts) refers to the economic and monetary sources household may benefit. These assets can be used to purchase items that either directly contribute to livelihood outcomes or may increase the productivity of livelihood activities. *Physical capital* (e.g. machinery or mechanical or electrical appliances) includes basic farming equipment that may increase labour productivity. *Human capital* (e.g. knowledge and skills) refers to human capacity to understand risk and pursue different livelihood strategies. Finally, *social capital* (e.g. networks, social relations and associations) embraces the social connections and bonds that facilitates coordination and cooperation when pursuing different livelihood strategies. These categories are not formally distinguished from each other and can be constructed in various ways. This classification is mainly illustrative of the wide range of activities that make up many livelihoods. A household will combine the different categories of assets available to it in a strategy designed to cope with the various challenges it must face, the so-called *vulnerability context*, and accomplish desirable *livelihood outcomes* (FAO, 2019).

As for the concept of vulnerability, it has been used in different research areas (Adger, 2006; Smit and Wandel, 2006) but there is not a commonly shared definition (Gallopín, 2006). Adger (2006) reports that vulnerability is often defined as a set of components that include exposure to perturbations or external stresses, sensitivity to perturbation, and the capacity to adapt. Within the SRL framework, the concept of vulnerability refers to things that are beyond the control of the household. It is not objective "risk" that matters, but households' subjective assessments of things that make them vulnerable. This is important because both perceived and actual vulnerability are able to influence households' choices and hence their livelihood strategies (Adato and Meinzen-Dick, 2002).

Consequently, livelihood outcomes depend heavily on multiple and interactive influences. Some precedent studies tend to consider conventional indicators such as yield, income, food consumption and security and sustainable use of natural resources as livelihood outcomes (Gotor et al., 2017; Bellon et al., 2015a; Gotor et al., 2013). In other cases, a strengthened capital base, less vulnerability and improvements in other aspects of well-being such as health, self-esteem and even the maintenance of cultural assets are considered potential outcomes (Adato and Meinzen-Dick, 2002). Although, what it is important to highlight is that livelihood outcomes are not necessarily the end point, as they can generate a feedback effect on the future state of vulnerability and base asset of households (Randolph et al., 2007).

Of particular interest in the SRL framework is the institutional context. This refers to a set of formal and informal institutions and organizations that mediate the ability to implement specific strategies and achieve definite results. Indeed, policies, institutions, and processes influence how households use their assets to pursue different livelihood strategies. Household assets interact with structures (government, private sector) and processes (policies, laws, institutions) responsible for social, economic, and political transformation that can shape the vulnerability context, the access to the assets and the choice of livelihood strategies (Adato and Meinzen-Dick, 2002). This may take place at multiple levels, from the household to community, national, and even global levels. The institutional focus of the SRL approach gives a practical gain when considering policy applications, by identifying those structures that play an important role in resource allocation, and by identifying those social rules and norms which would have an impact on the outcome of an external intervention (Brock, 1999). This makes it possible to observe how policies and programs are able to influence the portfolio of assets of the households and the vulnerability context of reference, and how this in turn leads to the adoption of specific strategies capable of managing the negative impacts on income and food security caused by extreme climatic events, uncertain agricultural production and unexpected market shocks. Indeed, the advantage of the SRL approach is that it provides a framework for a holistic interpretation of the dynamics of development. Often with the addition of a little scientific knowledge, improved technologies, financial facilities, or changes in government policies, adaptive strategies can be made more efficient and even sustainable in the long term thanks to the potential multiple interactions that are activated within the system (Butler and Mazur, 2007; Helmore and Singh, 2001).

Within the SRL framework, this paper mainly focuses on the role of the institutional context, aiming to identify its effective impact on shaping the relation between the smallholder's adoption of a specific livelihood strategy, (*varietal diversification*), and the *livelihood outcomes.* The next paragraph will provide a more detailed picture of the study context.

3.3 STUDY CONTEXT

In the context of our study, the SRL framework provides the theoretical architecture of our analysis. Specifically, this study focuses on the relation between the intra-species diversity (a specific livelihood strategy) and the livelihood outcomes and how this relation could be affected by a change within the institutional context. The implementation of a development program can be fully considered as an exogenous shock of the institutional context within the communities involved. This study focuses on the Seeds for Needs (S4N) initiative. Several development programs have been carried out aiming at nurturing agricultural diversity, including intra-varietal, and reducing vulnerability. Among them, the CGIAR supported S4N initiative can be considered as an important and innovative multi-country intervention. Started in the 2010, S4N has been implemented in 14 countries in Africa, Asia and Central America with the aim of promoting and using the diversity of plant genetic resources as a means to reduce the vulnerability of farmers to climate change (Bioversity International, 2018; van Etten et al., 2016). More specifically, the main component of the program addressed the scarce availability of stress-tolerant cultivars, as cropping systems adaptation requires the continuous delivery of varieties able to address "gene by environment" interaction (van Etten et al., 2019). After seed varieties potentially adapted to the local agro-ecological and climatic conditions were identified, they were distributed to farmers for participatory selection by means of on-farm experiments in collaboration with scientific staff (Dawson et al., 2008). The range of collaborative research activities engaging farmers together with scientist is defined "citizen science", an emerging trend which enables R&D to be faster, larger in scale and aimed at addressing community needs and contextual factors (Resnik et al., 2015), particularly in terms of agricultural research (Ryan et al., 2018). A second, complementary component addressed the need to raise farmers' awareness by conducting capacity-building activities on sustainable production techniques and the importance of a diversified agricultural production. Trainings were conducted in the form of Farmer Field Schools (FFS), a bottom-up and participatory approach used by scientists and national extension officers to engage with smallholder farmers' (Braun et al., 2000). These trainings were based on a "Learning by Doing" concept and were meant to build farmers' capacity for informed decision-making through hands-on experimentation and frequent interaction for knowledge and experience sharing (Chandra et al., 2017).

In India S4N program has involved over 25,000 farmers from 600 villages of 49 districts in 7 states, participating in around 46,000 participatory trials as 'citizen scientists' (Bioversity International, 2017). In this study we analyse the resulting outcomes of the activities carried out in India, in the

Vaishali district of Bihar[5] that started in 2010. For the current analysis, the State of Bihar was chosen as a case study for a twofold reason: firstly, it is the State where the program implementation started in the first place, offering the possibility to study the potential benefit of a change of the institutional context affecting the livelihood strategies on a longer time span. Secondly, Bihar is one of the most climate-sensitive states in India due to its hydro-meteorological fluctuation, and where 90% of its extremely dense and poor rural population is directly employed in agriculture (Tesfaye et al., 2017).

The implementation of this initiative in Bihar provides a source of exogenous change to the institutional context that allows to the social scientist an ideal perspective for an empirical identification of the link between the different domains of the SRL framework. Indeed, thanks to the institutional activities it is possible to compare the livelihood strategies and their outcomes of households under the effect of an institutional change with a counterfactual provided by similar communities and households that were not explicitly covered by the development program.

The basic assumption is that the S4N program can improve the livelihood strategies of smallholder farmers, also influencing their livelihood assets. Particularly, providing knowledge, skills and practices the program intended to enhance household's human capital of those actively participated into the process. While distribution and trails of new seed varieties, potentially adapted to the local agro-ecological and climatic conditions, contributes to the improvement of their natural and physical capital. Finally, the participatory approaches encourage the connection between and within communities and farmers, expanding the social capital of the rural households.

The changes made to the asset portfolio of smallholder farmers will in turn lead to the adoption of the seed varieties promoted by the program (rice and wheat), thus increasing the genetic diversity in their field. Finally, farmers who adopt strategies of varietal diversification can obtain further livelihoods benefits in terms of crops productivity (1) and (2) households' ability to recover from agricultural shocks occurrence.

[5] Since 2011, the initiative has been further extended to nine more Indian states: Uttar Pradesh, Odisha, Madhya Pradesh, Chhattisgarh, Orissa, Punjab, Haryana, Jammu and Kashmir (Singh, 2017).

3.4 METHODOLOGICAL APPROACH

3.4.1 Data

A household questionnaire was administrated between February and August 2018 in three districts of Bihar: Saran, Vaishali, and Samastipur (Table 3.1). Data are available for 600 randomly selected rural households, of which 300 represent the households directly exposed to the development program (treatment group that voluntarily expressed their willingness to participate) and 300 represent those households not involved in the initiative (control group).

Table 3.1. *Sample Composition*

District	Village	Exposed Group	Non-exposed Group	Total
Saran	Bhagwanpur	3	15	18
	Dharmagt Tola	0	19	19
	Khanpur	0	19	19
	Rampur Jaitti	18	21	39
	Sabalpur	8	13	21
	Sultanpur	10	24	34
Sub-total		39	111	150
Samastipur	Dhobgama	0	20	20
	Harpur	32	16	48
	Madapur	14	5	19
	Mahamada	36	12	48
	Narayanpur	0	17	17
Sub-total		82	70	152
Vaishali	Bhathadasi	57	28	85
	Fatehpur Chauthai	0	18	18
	Kariyo	10	3	13
	Kutubpur	0	23	23
	Mirpur Patadh	0	5	5
	Mukundpur	31	2	33
	Panapur	4	1	5
	Rajapakar	77	10	87
	Sembhopatti	0	20	20
	Vishanpura	0	9	9
Sub-total		179	119	298
Total		300	300	600

The data collection team consisted of three enumerators. Enumerators attended a four-day training and field-testing series. One enumerator was designated team leader and was responsible for cross-checking all household data at the end of each day. The enumerators used electronic tablets to record the data using the Open Data Kit (ODK) platform. All data was uploaded to a server at the end of each day after being checked by the team leader. The household questionnaire used is composed of 17 sections, of which three are specifically devoted to measure the possible effect of the S4N program and focusing on: (1) the smallholders' participation in the S4N activities, (2) households' exposure to shocks and recovery capacity and (3) detailed information on the wheat and rice cultivation (S4N target crops). As concerns the latter, specific information was gathered on the number of varieties of wheat and rice that were sown in the past 5 years, the seed source, the characteristics of most preferred seeds, the quantity produced in the last and second to last growing season, quantities consumed and sold, as well as the average market price. Moreover, the questionnaire explored the frequency of climate-induced harvest losses of rice and wheat cultivation, and a self-reported scale was used to assess the perceived extent of recovery following their occurrence. The remaining sections are adapted from the Rural Household Multi Indicator Survey (RHoMIS) (Hammond et al., 2017) following enumerators' feedback during the training. RHoMIS is a household survey tool designed to rapidly characterize a series of standardized indicators across the spectrum of agricultural production and market integration, nutrition, food security, poverty and GHG emissions. As well as standard socioeconomic information on household demographics, education, landholdings, sources of income, migration, and gender-disaggregated decision-making power allocation (Gotor et al., 2018a).

As the participants to the S4N program were exposed to several rice and wheat varieties, and at the same time encouraged to personally evaluate the potential benefits of diversifying their farm production (Witcombe et al., 1996), it is expected that the varieties of rice and wheat adopted by those involved in the activities increase. The Simpson's Diversity Index (SI) (Simpson, 1949) is used to test such hypothesis. It is the most suitable index for measuring crops diversification patterns and is calculated as:

$$Simpson's\ Diversity\ Index\ (SI) = 1 - \sum_{j=1}^{J} \mathrm{P}_j^2$$

where, $P_j = A_j / \sum A_j$ is the share of the j-th varieties area over the total cultivated area for the specific crop. With values close to zero, SI indicates that the household has little diversification in field (i.e equal to zero if only one crop variety is cultivated) while on the opposite, SI tends to one as the number of varieties increases. Following Gotor et al. (2013), effect on crops productivity was measured in terms of perceived yield change (PYC)**:** the perceived yield change of rice and wheat in the past five years is a self-reported measure which ranged from -4 (total decrease of yield) to 4 (increase of 100% or more). The variable assumes a positive (negative) value equal to 3, 2 or 1 when the household perceived in the last five year an overall yield increase (decrease) of around respectively 75%, 50% and 25%.

Moreover, the model controls for both financial and weather-related shocks and a specific set of questions was formulated to capture the ability of households to recover from them. To obtain a measure of ability to recover, households self-assessed their capacity to recover from: (a) a decrease of the sales price, (b) a shock involving their assets, (c) an increase of pest and disease occurrence and (d) from more explicit climatic stressors. Based on the answers on (a), (b), (c) and (d), a cumulative variable on the household recovery capacity (RC) was constructed. The frequency of positive (+1) and negative (-1) answers was summed, indicating their ability or not to recover from shocks. If the household declared that it was not exposed to the specific shock, it was counted as a 0 response. Thus, RC values can range between -4 and +4.

Finally, the specific variables selected to define the different livelihood assets are based on theoretical and empirical literature. Age and level of education of the household head, as well as the number of household members are selected as human capital-related variables. The social capital is represented by the gender of the household head and self-assessments of trust in people and levels of trust and cooperation within the community. The extension of cultivated land and the total amount of agricultural inputs (i.e. fertilizer, manure, compost, pesticide, irrigation facilities and tillage methods) are selected respectively as natural and physical capital-related variables. Lastly, four different dummy variables are employed to embody the financial capital: pursuit of off-farm income generating activities, ownership of debts, access to formal sources of credit (from the government, NGOs or other organizations) and access to informal sources of credit (from family, friends or neighbours). The description and descriptive statistics of the variables used in the empirical analysis are shown in Table 3.2.

3.4.2 Empirical Analysis

Two empirical analyses were carried out: the first analysis consists in the identification of the casual effect of the institutional context change on a set of key households' outcomes. The research hypothesis underpinning the overall study is that the household's exposure to program activities may provoke changes to the seed portfolio of smallholder farmers, increasing the genetic diversity in their field, and thus households can obtain livelihood benefits in terms of crops productivity and ability to recover from agricultural shocks occurrence.

However, the institutional change does not occur randomly, since, even if there are households coming from communities not involved in the program at all, the sample obviously include a group of households that have autonomously decided to participate to the program activities. Thus, the group of participants households has not be randomly assigned to the exposure, and therefore large differences in terms of compounding factors may exist between the two groups, yielding to biased estimates of the program effects. For this reason, this empirical analysis relies on a specific estimator used in quasi-experimental study, the doubly robust (DR), to quantify if any substantial differences between households participating to the program comparing to those that have not been involved can be effectively attributed to the institutional change.

DR estimator combines two different approaches to estimate the causal effect of an exposure on the outcome: a specification for the outcome regression and a specification for the exposure. This ensures the robustness of the results because possible forms of misspecification of the model due to selection bias and confounding effects are both considered (Caracciolo and Furno, 2017; Emsley et al., 2008).

The second empirical analysis consists in the assessment of the specific consequentiality of the steps as theorized in the SRL framework, linking the livelihood benefits (i.e. the impacts on the capacity to recover) to the households' adoption of varietal diversification strategies and the institutional context. To assess the above-mentioned relationships, it is necessary to link how the exposure to the program activities may influence the varietal diversification on farm, and if the latter can be reasonably linked to the yield change and the household recovery capacity to shocks. In order to test all the above-mentioned relationships, a simultaneous system of equation has to be ad-hoc formulated and estimated via a Generalized Method of Moments (GMM).

The stochastic version of the system is formulated for the i-th household and for the j-th crop in the following way:

Equations 1&2: $SI_{j,i} = x_i'\theta_j + \gamma_j Participation_i + \tau_j Adoption_{j,i} + v_{j,i}$

Equations 3&4: $PYC_{j,i} = x_i'\alpha_j + \beta_j SI_{j,i} + u_{j,i}$

Equation 5: $RC_i = x_i'\omega + \sum_{j=1}^{J} \delta_j PYC_{j,i} + e_i$

More specifically, the system of equations analyses explicitly the dynamic linkages among program participation (*Participation*), adoption of the wheat and rice varieties supported by the program (*Adoption*) and program outputs, such as varietal diversification measures (the *Simpson Index* for wheat and rice). Moreover, it analyses the link between the program outputs (varietal diversification) and livelihood outcomes such as perceived yield change (*PYC*) for wheat and rice and the overall recovery capacity of the households from shocks (*RC*).

The system of equations includes as confounding variables the livelihood assets $\mathbf{x}_i$ (variables capturing human, physical, natural, financial and social capital of the *i*-th household) while θ, α and ω are the parameter vectors of the equations' system that measure the effects of the livelihood assets on the dependent variables; while v_{ji}, u_{ji} and e_i are the error components. Finally, the estimation of the parameters τ, β and δ that allows to test the consequential links between the outputs and outcomes of the program. Indeed, through the estimation of the parameter τ, the model measures whether adoption of the varieties disseminated through the program affects infra-specific diversity of wheat and rice (Equations 1 and 2). The β parameters test, for each crop, the existence of a linear relation between the infra-specific diversity and the perceived yield change (Equations 3 and 4), while the parameter δ measures the association between the perceived yield changes of the two crops and the *i*-th household's capacity to recover from shocks (RC) (Equation 5). Since two target crops exist, a total of five simultaneous equations will be estimated (two for the SI, two describing the perceived change of yield, and one for the overall recovery capacity).

The above-mentioned approach controls for reverse causality and other possible sources of endogeneity (Heckman and Vytlacil, 2005), conditionally on the variables chosen as instruments. Instruments have been selected according to the assumption's plausibility as well as by the outcomes of the diagnostics tests. Household participation to the program (yes or not) and the number of adopted wheat and rice varieties supported by the program have been used as instruments, assuming that they may influence the perceived yield change only through the use of varietal diversification. Similarly, the varietal diversification is assumed to influence the households' recovery capacity only through an effect on the perceived yield trend. Finally, following Bellon et al., (2015b), households were weighted by the inverse probability (IPW) of program participation, which control for potential sources of selection bias: more specifically IPW allows to consider the observable differences of the livelihood assets between households that have the opportunity to be exposed to the program and those households that were excluded. Diagnostic tests were carried out to confirm the validity of the instruments (Durbin–Wu–Hausman test for endogeneity and the Weak Instrument test) (Cameron and Trivedi, 2005).

3.5 RESULTS

3.5.1 Livelihood Assets and Varietal Diversification

The mean value and the standard deviation of the variables employed in this study are shown in Table 3.2. At the top of it are reported the variables related to the five capitals (i.e. human, social, natural, physical and financial). The principal differences between the two groups are in terms of human, social, natural and financial capitals. Households exposed to the program have on average a greater number of members and are headed by older people, besides have a higher level of confidence in people and among community members. Moreover, exposed households have a lower extension of cultivated land (5.47 acres compared to 8.59 acres for the non-exposed) but exhibit a higher level of indebtedness (an average value of 0.60 compared to 0.52 for the non-exposed). Conversely, there are not significant differences in terms of physical capital between those exposed to the program compared to those who have not been exposed.

When considering the variables related to the vulnerability context, the two groups show similar exposure to pest & disease and climatic stressors, while the difference among the two groups in exposure to financial shocks is only weakly statistically significant (p=0.058), with the households participating to the program registering on average higher value.

As expected, the number of program's varieties adopted by the households is higher for those exposed to the program even if the differences in terms of varietal diversification between the two groups are not so evident (the differences between exposed and not exposed are significant only for the level of infra-specific diversity of wheat). With regards to the perceived yield change of the program's crops the mean value of the exposed households is bigger than the value of the not exposed one (as can be seen from Figure 3.2). Lastly, data reported in the Table show that there are no noticeable differences in terms of ability to recover between households exposed and non-exposed to the program.

3.5.2 S4N Program Impact

As showed in the previous paragraph, the two groups of households show some differences in terms of livelihood assets. These discrepancies if are not properly addressed may yield to bias comparison of the livelihood outcomes and outputs between the two groups. By using DR estimator, a proper comparison between the two groups can be performed, associating the observed differences to the institutional change.

DR estimator results are shown in Table 3.3, identifying the effect of the institutional context change on household's livelihood outcomes and output. Indeed, exposure to program activities generates positive and significative changes on the seed portfolio of smallholder farmers, specifically on the varietal diversification of target crops. The program resulted in an increase of more than 9% in the genetic diversity of rice. The genetic diversity of wheat grew even more, with almost 40%.

Moreover, the DR results confirm the research hypothesis underpinning the overall study, namely that exposed households can obtain livelihood benefits in terms of crops productivity and ability to recover from shocks occurrence. As can be seen, the effect on the perceived change of yield is positive and significant. In this case, the impact generated by the program was similar for both crops, i.e. +13.55% for rice and +13.62% for wheat. Lastly, at the bottom of the Table, the effect on the recovery capacity of households is reported. Exposed households obtain an increase in their ability to recover from shocks occurrence of around the 10%.

3.5.3 Econometric Results

The last part of the current analysis is based on the estimate of the system of five simultaneous equations (Table 3.4). The first and second equations analyse the relationship between the change of the institutional context (measured in terms of participation in the activities proposed by the program and the intensity of adoption of the varieties promoted by the program) and the level of variety diversification maintained on-farm by the households (proxied by the Simpson's Diversity Index for rice and wheat). The results of both equations (Eqs. 1 and 2) show a positive and significant relation between the adoption of the program varieties and the level of diversification, both for rice and wheat. This is also evident from Figure 3.3 which shows that the Simpson's Diversity Index increases as the number of program varieties adopted increases. However, the relation changes course when the quantities adopted are greater than six. This is probably due to the fact that the varieties promoted by the program replace the varieties already present in the field, reducing the overall level of intra-specific diversification held by the household. That is, once households have the possibility to test the different varieties in their fields, they can choose to increase the amount of varieties produced or can substitute the previously adopted varieties with the new ones.

The positive and significant relation between diversification and the perceived yield change of rice and wheat is evident from equations 3 and 4. Additionally, the level of education of the household head positive influence perceived change of rice yield, while it is negatively influenced by the gender of the household head, the amount of cultivated acres and the access to informal sources of credit. On the contrary, perceived change of wheat yield is negatively associated with the Tropical Livestock Unit (TLU).

The last equation analyses the influence of the perceived yield change on the overall recovery capacity of the households. This relation is significant only for wheat, but not for rice. Such result is probably due to the fact that the impact of the program was lower for the latter crop, as previously indicated. The recovery capacity is influenced even by the social capital, explicitly it is positively related to female-headed households and negatively related to high levels of trust in people. Finally, it is possible to observe that the recovery capacity is positively linked to financial and weather-related shocks. These results highlight the fact that an increase in resilience occurs only if households have been exposed to shocks.

The system of equations demonstrates the consequentiality and causality of the relations between the outputs and outcomes of the program. Regression's results provide evidence that: (a) the adoption of the varieties disseminated through the program positively affects infra-specific diversity of rice and wheat (Equations 1 and 2); (b) a more diversified production has in turn positively influenced the perceived yield changes of the two crops (Equations 3 and 4), and lastly, the improved wheat yield trends have enhanced overall recovery capacity of the households from shocks (Equation 5).

Figure 3.4 helps to understand more in detail the relation between the observed level of wheat diversification and the estimated perceived wheat yield trend (graph on the left side) and the relation between the latter and the estimated overall recovery capacity of households (graph on the right side).

In fact, a Simpson's index of 0.8 is associated with a perceived increase of wheat yield of over 50% (graph on the left side), that in turn is linked to positive levels of the household recovery capacity (graph on the right side).

Table 3.2. *Definition and descriptive statistics of variables used in the empirical analysis*

Variable Name	Description	Non-Exposed		Exposed		*t*-test [1]	
		Mean	Std.dev	Mean	Std.dev		
Human Capital							
Age of household head	Years of age	46.40	12.96	48.38	11.96	-1.95	*
Education of household head	Completed years of formal education	3.04	1.67	3.16	1.54	-0.97	
Household size	Number of household members	7.35	3.00	7.78	3.14	-1.71	*
Social Capital							
Gender of household head	Dummy variable: 1 = female, 0 = otherwise	0.23	0.42	0.25	0.43	-0.67	
Trust in people	Dummy variable: 1 = people can be trusted, 0 = otherwise	0.48	0.50	0.78	0.41	-8.10	***
Trust & cooperation community	Level of trust and cooperation among community members	2.07	0.73	2.40	0.68	-5.79	***
Natural Capital							
Land Cultivated	Number of acres cultivated by a household	8.59	11.43	5.47	9.51	3.63	***
Physical Capital							
Inputs	Total inputs used by a household	5.84	0.40	5.78	0.72	1.13	
TLU	Tropical Livestock Unit	0.82	0.85	0.79	0.91	0.50	
Financial Capital							
Off-farm Income	Dummy variable: 1 = household engaged in off-farm activities, 0 = otherwise	0.83	0.38	0.84	0.37	-0.44	
Debt	Dummy variable: 1 = household find difficult to pay debts, 0 = otherwise	0.52	0.50	0.60	0.49	-1.98	**
Formal credit	Dummy variable: 1 = household access to formal sources of credit, 0 = otherwise	0.01	0.11	0.09	0.29	-4.42	***
Informal credit	Dummy variable: 1 = household access to informal sources of credit, 0 = otherwise	0.02	0.14	0.04	0.20	-1.63	
Vulnerability Context							
Weather-related shock	Household exposure to pest & disease and climatic stressors	0.05	0.89	-0.05	1.10	1.15	
Financial shock	Household exposure to decrease sales prices and assets shocks	-0.08	0.94	0.08	1.05	-1.90	*
Livelihood Outputs & Outcomes							
Adoption Rice	Number of program's rice varieties adopted by the household	0.20	0.50	1.65	1.08	-21.08	***
Adoption Wheat	Number of program's rice varieties adopted by the household	0.31	0.61	1.91	1.12	-21.79	***
Rice SI	Measure of rice diversification in the field	0.60	0.22	0.62	0.22	-1.32	
Wheat SI	Measure of wheat diversification in the field	0.56	0.21	0.60	0.22	-2.33	**
Rice PYC	Perceived rice yield trend (5 Years)	1.10	0.96	1.37	0.91	-3.14	***
Wheat PYC	Perceived wheat yield trend (5 Years)	0.67	0.95	0.92	1.00	-3.59	***
Recovery Capacity	Household's ability to recover from shocks	1.44	1.43	1.52	1.46	-0.62	

[1] t-test H_0: diff = 0. Level of significance: * 10 %; ** 5 %; *** 1 %. Vectors of means are equal for the two groups, F(22,577) = 30.7077, Prob > F(22,577) = 0.000

Table 3.3. *Results of the Doubly Robust estimator*

	Non-Exposed	Exposed	DR estimate	*p*-value	% Effect
Rice SI	0.605	0.630	0.057	0.001	9.41
Wheat SI	0.562	0.619	0.224	0.009	39.82
Rice PYC	0.653	0.877	0.224	0.002	13.55
Wheat PYC	1.076	1.358	0.283	0.002	13.62
Recovery Capacity	1.400	1.729	0.329	0.001	9.69

Table 3.4. *Results of the system of simultaneous equations*

	Rice SI		Wheat SI		Rice PYC		Wheat PYC		Recovery Capacity	
	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
Livelihood Outputs & Outcomes										
Participation	-0.029	0.231	0.019	0.265						
Adoption Rice	**0.047**	**0.001**								
Adoption Wheat			**0.028**	**0.000**						
Rice SI					**1.968**	**0.009**				
Wheat SI							**3.006**	**0.010**		
Rice PYC									0.260	0.746
Wheat PYC									**1.810**	**0.049**
Human Capital										
Age of household head	0.000	0.694	0.000	0.541	0.000	0.964	0.001	0.819	-0.009	0.316
Education of household head	0.004	0.520	0.009	0.146	**0.093**	**0.014**	0.077	0.130	-0.186	0.088
Household size	0.002	0.450	-0.001	0.655	0.011	0.444	0.008	0.626	0.011	0.768
Social Capital										
Gender of household head	**-0.060**	**0.018**	-0.040	0.105	**-0.262**	**0.052**	-0.266	0.104	**1.004**	**0.005**
Trust in people	0.028	0.291	-0.007	0.809	0.218	0.165	0.218	0.229	**-1.341**	**0.001**
Trust & cooperation community	**-0.053**	**0.001**	**-0.046**	**0.003**	-0.013	0.897	0.147	0.173	-0.241	0.279
Natural Capital										
Land Cultivated	**0.003**	**0.004**	**0.003**	**0.005**	**-0.011**	**0.072**	-0.004	0.566	-0.005	0.767
Physical Capital										
Inputs	0.010	0.497	**0.046**	**0.007**	0.046	0.616	-0.145	0.141	-0.163	0.383
TLU	**0.031**	**0.002**	**0.019**	**0.042**	0.014	0.804	**-0.109**	**0.080**	0.018	0.917
Financial Capital										
Off-farm Income	-0.033	0.169	-0.001	0.958	0.105	0.461	0.032	0.854	-0.232	0.491
Debt	**0.067**	**0.000**	**0.047**	**0.007**	-0.011	0.911	-0.123	0.320	0.100	0.627
Formal credit	0.004	0.929	-0.035	0.625	-0.107	0.669	-0.062	0.862	0.366	0.530
Informal credit	**0.153**	**0.000**	**0.132**	**0.000**	**-0.438**	**0.091**	-0.389	0.287	0.175	0.782
Vulnerability Context										
Weather-related shock	0.002	0.849	0.009	0.228	-0.041	0.347	0.021	0.687	**0.283**	**0.026**
Financial shock	**0.025**	**0.005**	**0.028**	**0.002**	0.039	0.364	-0.066	0.266	**0.208**	**0.045**
Constant	**0.535**	**0.000**	**0.296**	**0.009**	-1.101	0.129	-0.296	0.676	**2.255**	**0.097**

Note: Significance of bold values <0.1.

Figure 3.2. *PYC for wheat and rice, and recovery capacity index by exposure to S4N program*

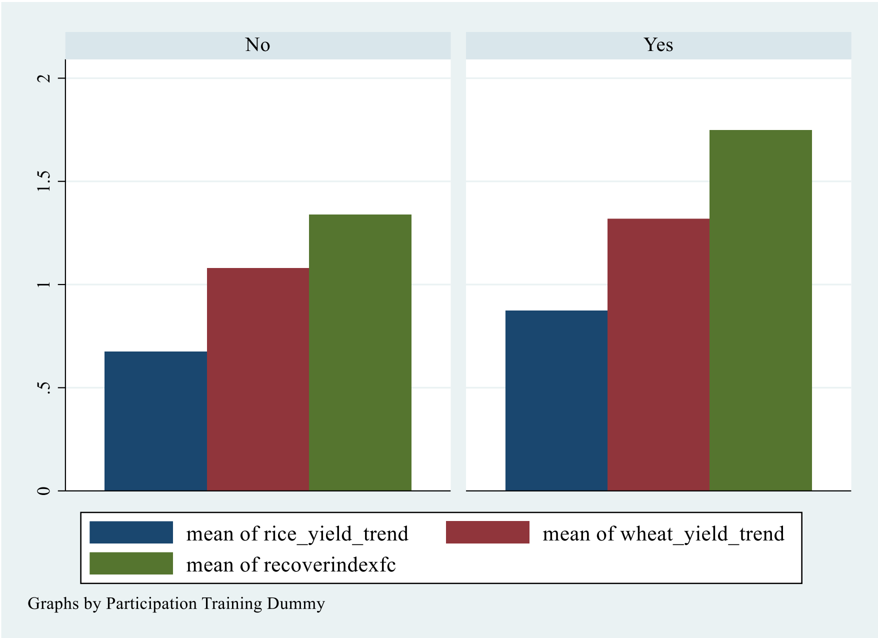


Figure 3.3. *Relations between number of program's rice and wheat varieties adopted by the household and varietal diversification of wheat and rice (Simpson's Diversity Index) (average per household)*

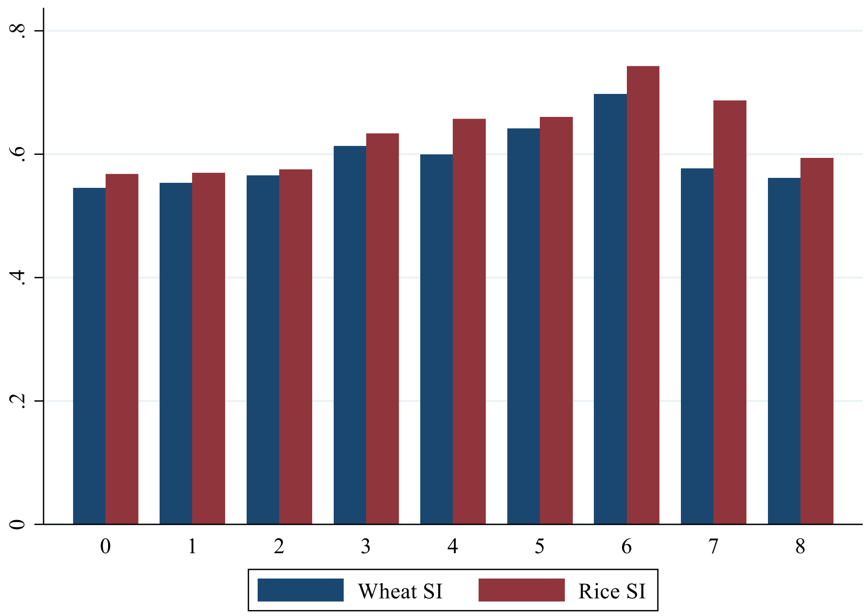
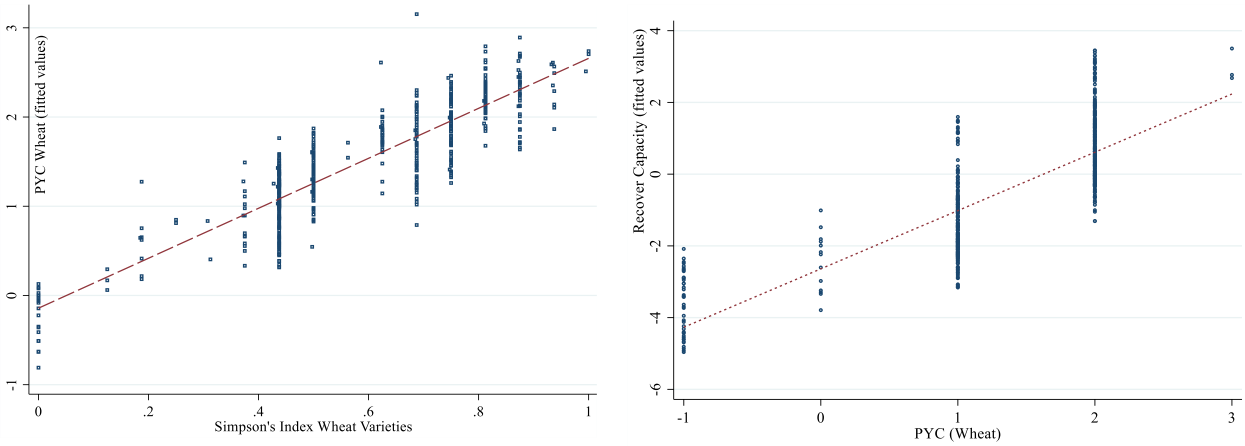


Figure 3.4. *Relation between observed wheat diversification and the estimated PYC (left) and the relation between the observe PYC (wheat) and the estimated recovery capacity (right)*



3.6 Discussion and Conclusions

The current study aimed to analyse the role of the institutional context in shaping smallholder's adoption of a specific livelihood strategy and the livelihood outcomes generated by such strategy. In particular, the analysis focused on the Seeds for Needs (S4N) initiative. The implementation of this initiative provided a source of exogenous change to the institutional context that allowed an ideal perspective for an empirical identification of the link between the different domains of the SRL framework. Thanks to the institutional activities it was possible to compare the livelihood strategies and their outcomes of households exposed to institutional change with a counterfactual provided by similar communities and households that were not explicitly covered by the development program. More in detail, the analysis was fitted to a sample of 600 randomly selected rural households, of which 300 households directly exposed to the development program (treatment group that voluntarily expressed their willingness to participate) and 300 households not involved in the initiative (control group).

Empirically, two analyses were conducted. The first empirical analysis relied on a specific estimator used in quasi-experimental study, namely the doubly robust (DR). This estimator was implemented in order to quantify if any substantial difference between households participating to the program comparing to those that have not been involved can be effectively attributed to the institutional change. DR estimator results indicated that exposure to program activities generated positive and significative changes on the seed portfolio of smallholder farmers, specifically on the varietal diversification of target crops. Moreover, the DR results confirmed the research hypothesis underpinning the overall study, namely that exposed households can obtain livelihood benefits in terms of increased crops productivity and improved ability to recover from shocks occurrence.

The second empirical analysis consisted on a system of simultaneous equations formulated and estimated via a Generalized Method of Moments (GMM) to assess the consequentiality and causality of the relations between the outputs and outcomes of the program. Indeed, the first and second equations analysed the relationship between the change of the institutional context and the level of variety diversification maintained on-farm by the households. The relation between diversification and the perceived yield change of rice and wheat was examined in equations 3 and 4. The last equation evaluated the influence of the perceived yield change on the overall recovery capacity of the households. Regression's results identified strong causal linkages between households' exposure to the program activities, increase varietal diversification on farm and livelihood benefits.

Previous studies analysed the benefits generated by a varietal diversification strategy mainly through the underlying biological processes and ecological synergies mainly in experimental plots. Conversely, the current study enriched the understanding of the benefits associated to the implementation of a strategy focused on variety richness analysing the impact of this strategy at household level.

These findings should stimulate further research on knowledge transfer and promote the development of programs aimed at strengthening rural livelihoods through participatory approaches and use of local variety richness, while sustaining the conservation of important genetic resources. This because rural households are the main keepers of the intraspecific crop genetic variation and they need to be supported.

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4 INFLUENCE OF LIVELIHOODS ASSETS ON UGANDAN FARMERS' DECISIONS TO CONTROL BANANA XANTHOMONAS WILT (BXW)

4.1 INTRODUCTION

Like in other developing countries, banana production contributes significantly to food security and household income of rural populations in Uganda. It is estimated that 75% of Ugandan households grow the crop and per capita consumption of bananas in the country is the highest in the world (Karamura, 1993). Besides being considered an important staple food and cash crop, bananas are also valued for their medicinal properties and are associated with many cultural ceremonies and traditional beliefs. However, banana production in Uganda has been severely threatened by Banana Xanthomonas Wilt (BXW) since 2001. The disease often leads to complete crop loss and until now no banana variety is resistant to the disease. During the first peak the incidence in affected fields raised up to 70% in a period of one year (Kalyebara et al., 2006), while in 2013, during the second peak, the incidence rate was over 50% (National Banana Research Program Website, 2015). Only in 2015, the situation in Uganda was declared under control, with just 1.9% of households showing BXW symptoms in their fields (ibid.). However, there is a high risk of resurgence of the disease. The study by Tinzaara et al. (2016) reported that the disease continued to expand not only in previously disease-free areas, but also in areas where BXW had been declared under control. This possibly because of the survival of latently infected planting materials (Ocimati et al., 2013), the fact that the disease can rapidly increases to endemic level (Nakakawa et al., 2017) or the poor understanding by the banana-based households of the factors that influence the spread of the disease (Tinzaara et al., 2016). Considering the central role that banana production has for the livelihood of Ugandan rural households, it is top-flight to prevent resurgence of the disease and its spread to new areas.

The Ugandan Government jointly with different international, national and local organizations have identified the most effective farming practices to limit the disease spread and the ensuing loss of yield (Blomme et al., 2017). The identified combination of practices that complement each other included: (a) de-budding with forked stick, (b) disinfecting tools with fire or JIK, (c) sick plants removal (cutting down only the single stem affected or the whole mat) and (d) replanting using clean planting material (Kubiriba and Tushemereirwe, 2014; Kubiriba et al., 2014; Tripathi et al., 2009; Tushemereirwe et al., 2006). Such integrated system of practices was widely promoted throughout the country in order to inform households about the methods of spreading of the disease, to promote available control options and boost proper adoption of the practices (Kubiriba and Tushemereirwe, 2014). This because it will be possible to prevent the resurgence of the BXW only through the sustained adoption of the integrated package of practices that maintain the incidence of the disease at manageable levels. Consequently, understanding the factors influencing farmers' adoption behaviour is critical for effective control of the BXW.

To our knowledge, previous studies on the determinants of adoption of BXW control package in Uganda are still limited. Most of them following the farmers' utility maximization framework which assumes that adoption of an innovation is the end-result of farmers' decisions based on maximization of their expected utility (Kikulwe et al., 2019; Jogo et al., 2013; Bonabana-Wabbi et al., 2006). If the expected utility of the new technology exceeds that of the current technology, farmers will adopt the new one. However, the Sustainable Rural Livelihood (SRL) framework can be a much more useful tool as it focuses on the livelihood systems of the poor rural households and on the ways in which they adapt their farming strategies to handle multiple external stressors and to preserve their livelihoods (Scoones, 1998).

Furthermore, the empirical models implemented by most of the previous studies tend to be binary or censored data models (e.g. Kikulwe et al., 2019; Jogo et al., 2013). A common feature of these models is the idea that the adoption process is considered the same as the one that determines the intensity of adoption. While such assumption may be valid, there is no reason to expect this a priori. The Double-Hurdle model developed by Cragg (1971) allows to separately analyse the factors that influence the choice to adopt or not the recommended practices, from those that influence the intensity of adoption. Besides, the double-hurdle model considers that there are two types of zero observations: an individual can be a zero type, and the outcome will always be zero, or the individual might not be a zero type, but the circumstances in which the individual is at the time of the decision might dictate that the outcome is zero. This is an important distinction that allow to analyse separately non-adopters (subjects who would never adopt under any circumstances) from potential adopters.

On the basis of the above, the current study contributes to the growing literature on pest management analysing the influence of livelihoods assets on Ugandan farmers' decisions to control BXW. In order to asses this objective, firstly, the emergence of the disease and its impacts on the livelihoods of rural households in Uganda was theoretically contextualized following the SRL framework. The perspective offered by this framework allows a more comprehensive insight into the decision-making process of banana-dependent households on the adoption of the integrated BXW control package, moving beyond a focus on merely maximization of the expected utility. Secondly and finally, the Double-Hurdle model was implemented in order to identify the ways in which the five capitals (viz. human, social, natural, physical and financial capitals) influence both the decision to adopt or not the recommended strategy, and the intensity of adoption. Results of the current study could provide insights for more effective political intervention and consequently ensure an adequate level of adaptation to the BXW by Ugandan farmers.

This study is organized as follows: paragraph 4.2 illustrate the framework adopted and the case study analysed; while paragraph 4.3 introduces the methodological approach employed. paragraph 4.4 and 4.5 show and discuss the result achieved. The final paragraph of this study presents some concluding remarks.

4.2 CONTEXT OF THE STUDY

Banana Xanthomonas Wilt (BXW), caused by *Xanthomonas vasicola* pv. *musacearum* (*Xvm*) (formerly *Xanthomonas campestris* pv *musacearum*) (Valentine et al., 2006), is a vascular disease and it represents one of the greatest threats to banana production in East and Central Africa (ECA). The disease was first reported in Ethiopia on enset (Ensete ventricosum), a relative of banana, in 1968 and afterwards on banana in 1974 (Yirgou and Bradbury, 1974, 1968). BXW remained confined to Ethiopia until first outbreaks were observed in Uganda in 2001 (Tushemereirwe et al., 2003). Since then, BXW has propagated through to DR Congo (2001), Rwanda (2002), Tanzania, Kenya (2005) and Burundi (2010) (Tushemereirwe et al., 2003).

BXW symptoms are cultivar-specific and determined by the course and stage of the infection (Brandt et al., 1997). Once BXW is established in an area, the disease spreads rapidly and all banana cultivars are susceptible to the disease. Field observations indicate that the disease reduces yields to varying levels, depending on the growth stage of the crop, degree of cultivar susceptibility and prevailing climatic conditions (Biruma et al., 2007).

During the first peak, between 2001 and 2004, the incidence in affected fields raised up to 70% in a period of one year (Kalyebara et al., 2006), with losses estimated at US$ 34.3 million in 2005 and US$ 75.6 million in 2006 (Mwangi and Nakato, 2008). The second peak occurred in 2013, with more than 50% incidence rate (National Banana Research Program Website, 2015). As a result, many households have abandoned the cultivation of bananas and in some cases, they have replaced them with annual crops resistant to Xanthomonas, such as beans, cassava, maize and potato (Tushemereirwe, 2001). However, the switch from perennial bananas to annual crops may have potentially serious implications for soil erosion and fertility. Moreover, the advent of BXW has led to a reduction of the social capital, to the loss of employment opportunities (Karamura et al., 2010) and the scarcity of bananas has sharply increased their price and local consumer could no longer purchase their main source of nutrition (Vurro et al., 2010). Thus, since the first outbreak of the disease, a fruitful mix of international, national and local efforts has been implemented in order to find the most effective farming practices able to limit the spread of the BXW (Blomme et al., 2017). Field experiments were established and, in some cases, rural households have had the opportunity to adapt the recommended strategies to make them more consistent with their conditions and knowledge (Bagamba et al., 2006). The strategies identified for BXW control were based on the following four farming practices: (1) de-budding; (2) sick plants removal; (3) disinfection of tools; and (4) use of clean planting material.

Since disease transmission through the male bud is one of the main ways of spreading, de-budding (1), i.e. the timely removal of the male buds by twisting the peduncle with a forked stick, is regarded as the first line of defence against the disease (Kubiriba and Tushemereirwe, 2014; Tripathi et al., 2009; Karamura et al., 2008; Tinzaara et al., 2006; Blomme et al. 2005). Once BXW infection has been detected in a field, farmers are advised to remove infected plants (2) (Tushemereirwe et al., 2004). Some farmers uproot the whole stool once they find an affected plant, others remove the only infected plants from the affected stool (Kubiriba and Tushemereirwe, 2014). However, the former is wearisome, labour intensive, time consuming and costly due to the invasive nature of uprooting entire plantations (Tinzaara et al., 2013), while the second option is relatively simple, low cost, and easy to apply, but it does not completely remove the BXW from the field and requires rigorous application for as long as the disease is present on or near the farm (McCampbell et al., 2018). Since the BXW is systemic, when the working tools come in contact with the bacterial ooze, they increase the likelihood of plant-to-plant disease transmission (Karamura et al., 2008). For this reason, disinfection of cutting tools (3) limits mechanical spread of BXW. The tools can be disinfected by washing them in Sodium hypochlorite solution, locally named "Jik", or they can be flamed in fire. Unfortunately, this practice is not widespread since many farmers find the use of fire too laborious to apply, while the use of Jik is limited due to the relatively high cost and limited accessibility in the rural areas. Finally, the disease could also spread due to the use of infected planting material. For this reason, the use of clean planting material (4) represents another important practice to avoid the dissemination of infected suckers and plantlets. Where possible, tissue culture material, seeds cleaned from known mother gardens of clean seeds or macro-propagation techniques should be used (Karamura et al., 2008).

However, it is important to emphasize that the majority of farmers in Uganda have considerable difficulty in managing plant diseases (Sherwood, 1997). This may be due to the fact that they cannot see the organisms that cause the plant diseases (Nelson et al., 2001). Moreover, there are some elements (such as the different socio-cultural backgrounds, linguistic barriers and geographical remoteness) that make the task of disclosing information challenging. Because of such heterogeneity, communities have a complex understanding of diseases, their spread and management (Tinzaara et al., 2013). Successful control of BXW is possible by deploying the identified package of practices with communication approaches that sensitize and mobilize households towards the disease and adopting correctly the suggested practices (Kubiriba and Tushemereirwe, 2014). This is because the acquisition of information on a new technology allows farmers to learn about the existence and effective use of the technology and this facilitates their adoption.

Consequently, BXW control strategies were promoted in Uganda using a mix of conventional and participatory approaches (Kubiriba et al., 2012). The first are commonly top-down approaches that consider affected communities as passive recipients of information (Tinzaara et al., 2013). Some examples of the conventional communication approaches adopted in Uganda are the use of print and mass media; publications, seminars and workshops (Tinzaara et al. 2013). On the other hand, the participatory approaches use communication as an instrument to promote community participation in a development strategy (Bessette, 2004). Dissemination of new science-based knowledge and information to farmers enables them to make logical crop management decisions, exposes them to new ways of thinking and problem solving, and encourages them to implement and discuss their own ideas (Kubiriba and Tushemereirwe, 2014; Nankinga and Okasaai, 2006; Hakiza et al., 2004). The approach warrants that the needs, preferences, knowledge and constraints of the community are understood and considered in developing disease management strategies. As a result, the chosen strategy at the end of this process is effective, practical and locally adapted, and can be easily adopted and sustained by communities. Some examples of the participatory approaches adopted in Uganda are: Participatory Development Communication (PDC); Farmer field schools (FFS); farmer exchange visits and Community structures (task forces) (Kubiriba and Tushemereirwe, 2014; Nankinga and Okasaai, 2006; Tushemereirwe et al., 2006).

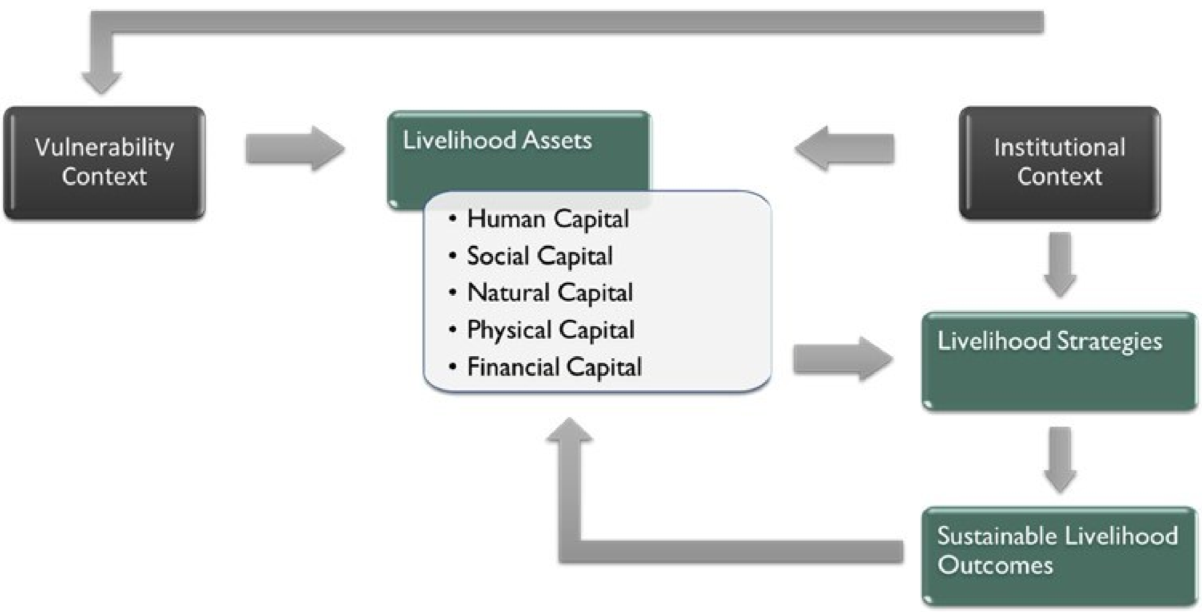
4.3 METHODOLOGICAL APPROACH

4.3.1 Theoretical Framework

Recognition that BXW could have severe consequences for the livelihood of rural households, has stimulated the identification of an effective strategy that maintain the incidence of the disease at manageable levels. At the same time, the promotion of such strategy and the understanding of the factors influencing its adoption are critical for effective control of the BXW.

On the basis of the above, the current study aims to identify the livelihood assets that affect the Ugandan farmers' decision to control the BXW. These findings could provide insights for more effective political intervention and consequently ensure an adequate level of adaptation to the BXW by rural households. In order to asses this objective, the Sustainable Rural Livelihood (SRL) framework (Figure 4.1) is adopted as theoretical architecture of the current study since it could offer a comprehensive insight of the decision-making process of banana-dependent households in the study context.

Figure 4.1. *The Sustainable Rural Livelihood Framework*



Source: Adapted from Carney et al. (1999) and Scoones (1998).

The framework emphasizes the livelihood systems of the rural households, which are based on the linkages between livelihood assets, livelihood strategies and sustainable livelihood outcomes.

However, livelihood systems must interact with the outside system, composed of the vulnerability context (namely the unpredictable events that can undermine livelihoods and cause households to fall into poverty) and the institutional context (viz. policies, organizations and processes that mediate the ability to implement specific strategies) (Scoones, 1998). Changes of the outside system will modify the strategies adopted by the households in order to preserve their livelihoods. Rural households will adopt different livelihood strategies to handle multiple stressors coming from the outside system depending on their livelihood assets (namely human, social, natural, physical and financial capitals) (Jezeer et al., 2019).

The perspective offered by the SRL framework represents a very useful theoretical architecture for analysing (1) the function performed by the banana production within the household livelihood system, (2) how the BXW disease modified it, (3) the role played by the institutional context, and finally, (4) the way in which the livelihood assets of the Ugandan farmers' influence their decisions to adopt the different farming practices for controlling the spread of the BXW.

The theoretical architecture adopted by the present study offered a broad-spectrum view of the livelihood system of Ugandan rural households and how it interacts with the external context. The next paragraph will illustrate the empirical approach employed in the current analysis.

4.3.2 Sample and Data Collection

The data used in this study come from a survey conducted between April and May 2018 in Uganda, with the objective of establish farm typologies for effective targeting, promotion and sustainable adoption of BXW control practices among banana farming households in Uganda.

The sampling method follows a previous BXW incidence and management survey done in the 2015. The survey was administered through face to face interviews using a pre-tested questionnaire. The enumerators were well trained and had previous experience in banana surveys. The respondents were located in four selected major banana-growing and consuming regions (i.e. Central, Eastern, Mid-Western and South-Western) in Uganda. From each region, three districts were randomly selected. Only for the Eastern region were randomly selected 5 districts. Totalling 14 districts were randomly selected: Kayunga, Kiboga, and Luwero from Central; Bukedea, Kumi, Mbale, Kamuli and Manafwa districts from Eastern; Kabarole, Masindi and Mubende districts from Mid-Western and Bushenyi, Rukungiri and Ntungamo from South-Western region. Two major banana-producing sub-counties were purposively selected per district and from each sub-county one parish was randomly selected. At the parish level, three villages were randomly selected, and 15 households randomly selected per village from village household lists provided by the local council authorities. In total 1,058 rural households were interviewed from all the study sites.

The survey collected data on the following themes: household socio-economic characteristics, farm profiling; BXW prevalence on farm; farmers' knowledge of BXW symptoms, mechanisms of spread and control measures; cultural practices adopted by the households; banana production and consumption; livelihoods strategies and coping mechanisms.

4.3.3 Empirical Model Variables

As illustrated in paragraph 4.2, the current study is theoretically based on the SRL framework. For the empirical contextualization of the different concepts embodied by the framework, namely livelihood assets, livelihood strategies and outside context, this study identifies the following variables.

4.3.3.1 Livelihoods Strategies

Livelihood strategies are the range and combination of activities that households implement in order to achieve their livelihood goals (Stewart Carloni and Crowley, 2005). In this case, the strategy that could be adopted by the Ugandan farmers to limit the spread of the BXW is based on the following four farming practices: (1) de-budding, (2) disinfecting tools, (3) sick plants removal and (4) use of clean planting material. Consequently, for the purposes of this analysis, the dependent variable will range from 0 to 4, according to the level of adoption of these practices. Where the value 0 refers to non-adopters, that is, smallholder farmers who have not practiced the BXW strategy at all. The other values that the dependent variable can assume (from 1 to 4) indicate the intensity of adoption of the recommended strategy, namely banana-based households who applied only one or two or three out of the four main practices (partial adopters), or smallholders who applied all the four main practices altogether (full adopters).

4.3.3.2 Livelihood Assets

Livelihood assets refer to the resource base of households and they are often grouped into human, social, natural, physical and financial capitals (Ellis, 2000). To measure each of the five capitals we chose a set of indicators based on literature and data availability.

To measure human capital, the age and the level of education of the household head and the number of household members were included in the analysis. Age of the household head can be considered as a proxy of the farming experience (Deressa et al., 2009). A high education level influences farmers' attitudes and thoughts making them more able to acquire, synthesise and use information and knowledge about the problem they face and the possible solutions that they can implement (Mignouna et al., 2011; Waller et al., 1998). Lastly, the number of family members is used as a proxy for availability of labour. It determines adoption process as a larger household have the capacity to relax the labour constraints required during introduction of new practice (Mwangi and Kariuki, 2015; Mignouna et al, 2011; De Souza Filho et al., 1999). Households containing members able to participate in on-farm activities enable farmers to adopt labour-intensive activities (Feder et al., 1985).

For social capital, the variables used were the gender of the household head and the access to extension services. Gender can influence strategy implementation since the household head is the primary decision maker. Gender-linked disparities in access to inputs, resources and services, due to socio-cultural values and norms, can be the channel through which these decisions are influenced (Mignouna et al., 2011; Hassan and Nhemachena, 2008; Omonona et al., 2006; Tenge et al., 2004; Doss and Morris, 2001). Besides, interaction with extension agents greatly increases farmers' knowledge of available technologies and their potential benefits, hence acting as a trigger mechanism for intensive adoption (Peshin, 2013).

To measure natural capital the variables selected were (1) the location of the farm, since regional differences can influence farmers' adoption decisions (Kikulwe et al., 2019; Otieno et al., 2011; Adeoti, 2008), (2) the total farm area as the extension of cultivated land tends to be associated with greater wealth thus it is expected that larger-scale farmers may be more prone to take adaptive measures than small-scale farmers (Deressa et al., 2009; Langyintuo and Mulugetta, 2008; Nyangena, 2007) and (3) the proportion of land area allocated to banana production as a proxy for the importance of banana as food and income crop (Jogo et al., 2013).

In addition, the type of house and the farm equipment of the households were employed as physical capital-related variable inasmuch they denote a certain level of household well-being which rises the likelihood of adoption of adaptation measures (Kuntashula et al., 2015).

Finally, financial capital was measured by (1) the banana farming objective (subsistence or commercial) as a proxy of the centrality of the crop to farmers' livelihoods (Kikulwe et al., 2019) and by (2) the ownership of off-farm income sources and (3) the access to credit facilities because they represent important strategies for overcoming liquidity constraint faced by many rural households in developing countries (Reardon et al., 2007).

4.3.3.3 Outside Contexts

The SRL framework includes two sets of forces that are beyond the control of the household but, although this, they are able to influence households' livelihood outcomes: the vulnerability context and the institutional context. The concept of vulnerability refers to unpredictable shocks that can impinge households' assets, and consequently their livelihood strategies (Adato and Meinzen-Dick, 2002). To embody this aspect of the framework in the current analysis, a variable related to the BXW status on households' farm was used. The variable ranges from 0 (BXW is still present on the farm) to 4 (BXW was last observed more than a year ago). The institutional context refers to outside policies and processes which are able to influence access to assets and the vulnerability context of reference, and in turn leads to the adoption of specific strategies capable of managing the negative impacts caused by external stressors (Adato and Meinzen-Dick, 2002). Since several studies have shown that information and knowledge about innovative agricultural practices are important determinants of adoption (Aïtchédji et al., 2010; Katungi and Akankwasa, 2010), in Uganda different communication approaches have been used in order to develop the knowledge and skills of the farmers on the characteristics of the integrated package of practices against the BXW and in return to mobilize them for its adoption. Therefore, a variable on the access to specific communication approaches on the BXW have been incorporated into the analysis to assess whether they have actually been able to influence the decision of adoption of smallholder farmers. The specific variable assumes value 1 if the households have participated in trainings, farmer fields schools or community actions, 0 otherwise.

4.3.4 Analytical Model

In this study, a double-hurdle model is used to analyse the ways in which the five capitals (viz. human, social, natural, physical and financial capitals) influence both the decision to adopt or not the BXW control strategy, and the intensity of adoption of the farming practices incorporated in the recommended strategy.

A feature of many models of adoption is that the process, which leads to the decision to adopt or not, is assumed to be the same which determines the intensity of adoption. However, this is not always the case. Decisions about whether to adopt and how much to adopt can be done together or separately (Gebremedhin and Swinton, 2003). The double-hurdle model, originally due to Cragg (1971), is based on the idea that an individual's decision is the result of two processes: the first hurdle, determining whether the individual is a zero type, and the second hurdle, determining the intensity of adoption given that the individual is not a zero type. Both hurdles have equations associated with them, incorporating the effects of individual's characteristics and circumstances. Such explanatory variables may appear in both equations or in either of one. Besides, a variable appearing in both equations may have opposite effects in the two equations. This cannot be properly handled by the Tobit model. Indeed, the implicit assumption of the Tobit model is that the two decisions (adoption and intensity of adoption) are affected by the same set of factors (Greene, 2000).

Furthermore, the double-hurdle model considers that there are two types of zero observations: an individual can be a zero type, and the outcome will always be zero, regardless of the circumstances in which the individual is at the time of the decision; alternatively, the individual might not be a zero type, but the circumstances in which the individual is at the time of the decision might dictate that the outcome is zero. This means that zero values may be reported in both decision stages. The zero-value reported in the first stage arises from non-adoption (subjects who would never adopt under any circumstances), and in the second stage it comes from non-adoption due to respondents' deliberate decisions or random circumstances (potential adopters). This characteristic of the double-hurdle model is in contrast to Heckman's (1979) procedure. In fact, the Heckman procedure does not consider the non-values in the second stage. For these reasons, both Wooldridge (2002) and Cameron and Trivedi (2005) conclude that the double-hurdle model can be considered as an improvement both on the Tobit and Heckman models.

A number of different approaches have been developed to estimate the double-hurdle model. In this paper we follow the one proposed by Engel and Moffatt (2014) that uses the inverse Mills ratio derived by the hurdle equation for augmenting the equation for choices (Heckman ,1979).

As mentioned above, the strategy that could be adopted by the Ugandan farmers to limit the spread of the BXW is based on four farming practices: (1) de-budding, (2) disinfecting tools, (3) sick plants removal and (4) use of clean planting material. For the purposes of this analysis, the dependent variable will range from 0 to 4, according to the level of adoption of these practices. Empirically, the double-hurdle model contains two equations: one related the decision to adopt or not the recommended strategy, and the other related to the intensity of adoption of the farming practices incorporated in the BXW control strategy. Such equations can be considered as a combined Probit and Tobit estimator (Engel and Moffatt, 2014). From the Probit and Tobit models derive the initial values for the estimation of the maximum likelihood.

The adoption equation (D) of the BXW control strategy is:

$$d_i^* = z_i'\alpha + \varepsilon_{1,i}$$

While the intensity of adoption (Y) of the adaptive strategy has an equation of the following:

$$y_i^{**} = x_i'\beta + \varepsilon_{2,i}$$

Where d_i^* and y_i^{**} are the latent (unobserved) variables underlying, respectively, the adoption and the intensity of adoption of the BXW control strategy for the i-th household, β and α are the parameter vectors to be estimated and z_i' and x_i' are vectors of variables (in the specific case, the livelihood assets). The errors terms, ε_1 and ε_2, are distributed as follows:

$$\begin{pmatrix} \varepsilon_{1,i} \\ \varepsilon_{2,i} \end{pmatrix} \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & 0 \\ 0 & \sigma^2 \end{pmatrix}\right]$$

The first hurdle, defined by the latent variable d_i^*, is represented by:

$$d_i = 1 \; if \; d_i^* > 0$$

$$d_i = 0 \; if \; d_i^* \leq 0$$

The second hurdle strongly resembles the Tobit model:

$$y_i^* = \max(y_i^{**}, 0)$$

Finally, the observed variable, y_i, is determined as:

$$y_i = d_i y_i^*$$

The log-likelihood function for the double-hurdle model is:

$$LogL = \sum_0 ln\left\{1 - \Phi(z_i'\alpha)\Phi\left(\frac{x_i'\beta}{\sigma}\right)\right\} + \sum_+ ln\left\{\Phi(z_i'\alpha)\frac{1}{\sigma}\phi\left(\frac{y_i - x_i'\beta}{\sigma}\right)\right\}$$

Where ϕ and Φ, respectively, are the probability density function and the cumulative distribution function of the standard normally distributed random variable. The loglikelihood function is maximized with respect to the parameters contained in the vectors β and α and the standard deviation parameter σ.

Once the theoretical framework and the methodological approach used by the current study have been illustrated, the results identified will be presented in the next paragraph.

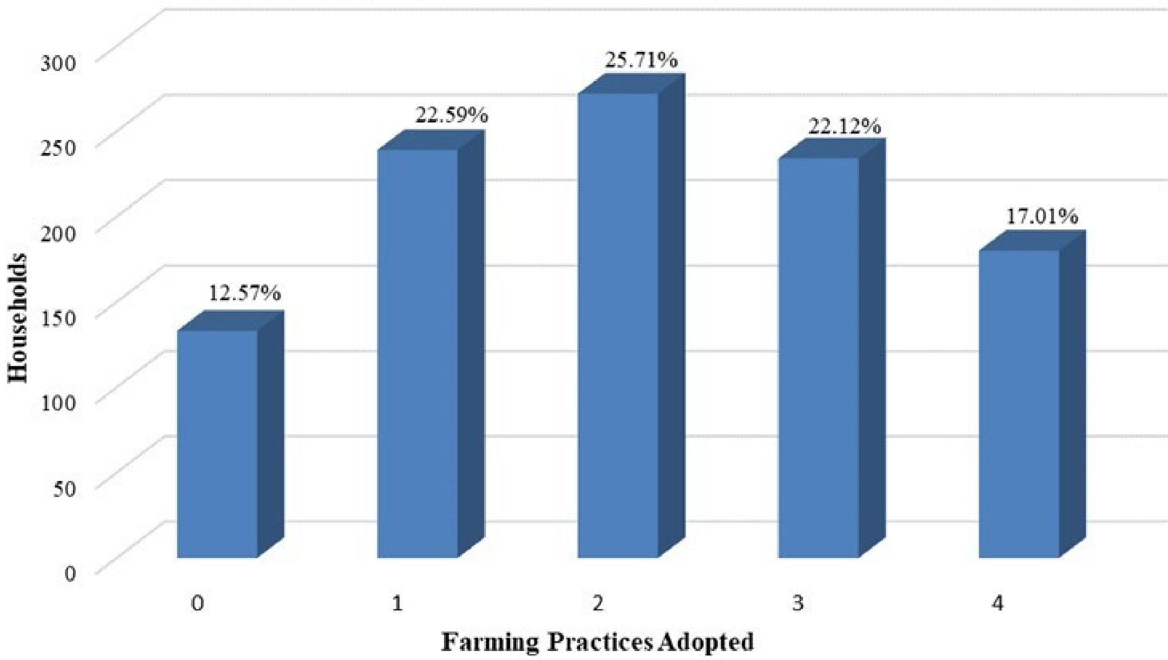
4.4 Results

4.4.1 Livelihood Strategy

As previously stated, the livelihood strategy identified to maintain the incidence of the disease at manageable levels is based on four farming practices: (1) de-budding; (2) sick plants removal; (3) disinfection of tools; and (4) use of clean planting material.

Figure 4.2 illustrates that full adopters of the BXW control strategy represent about 17% of the sample (180 smallholders over the total surveyed 1,058), while non-adopters are approximately 13% of the sample (recognized to be 133 rural households). On the other side, partial adopters embody the remaining 70% of the sample. These findings indicate that a large percentage of the sample only partially adopts the complete package of practices in their farms making the eradication of the disease intricate.

Figure 4.2. *Level of adoption of the BXW control strategy*



Further information is provided on the BXW management strategy in Table 4.1. Among the four BXW control practices, significantly more households practiced replanting using clean planting material, with a percentage of approximately 62%. Around 58% of the sample practiced sick plants removal, followed by timely removal of male buds with a forked stick (i.e. 50%). Use of fire and/or JIK for disinfection of tools was the least adopted practice (just 38% of the sample).

A similar trend is observed for farmers that apply only one or only two of the farming practices. Slightly different is the rate of adoption of the different practices when considering households that implement just three practices. In that case, the most adopted practice is the removal of diseased plants (95%), followed by the use of clean planting material (81%) and disinfection of agricultural inputs (73%). The least adopted practice is de-budding (50%).

4.4.2 Livelihood Assets and Outside Context

Table 4.2 shows the mean value and the standard deviation of the explanatory variable used in this study. The descriptive statistics refer both to the entire sample and to each individual adoption category.

Among the livelihood assets, Table 4.2 shows that the differences across the groups were significant for the social, natural, physical and financial capitals. In particular, if we consider the social capital-related variables, the 74% of the households of the considered sample have a male as household head. This value is smaller for farmers that adopts only 2 practices, i.e. 70%, while the higher percentage is related to the group of full adopters, namely 82%. A similar trend can be observed with regard to households with access to extension services: the mean value of the sample is 0.54, the smaller value of 0.45 is associated to adopters of only one practice, while the higher value is related to the full adopters, viz. 0.66.

The group of non-adopters has the highest percentage out of all the groups considered in the case of farm equipment (viz. a mean value of almost 47) and ownership of off-farm income (approximately 95%). Conversely, the group of full adopters presents the highest values in terms of proportion of land allocated to banana production (viz. a mean value of more than 47%) and farming objective (a mean value close to 2). Indicating that for full adopters the banana production is more oriented to market than for the rest of the groups. Indeed, in average, the percentage of farmland for the production of bananas is almost 42% for the sample. For non-adopters this percentage is less than 20%. While, banana production is intended for commercial purpose only for 10% of the sample. This confirms the importance of bananas in the diet of Ugandan households. Nevertheless, the difference is not significant across the groups. The trend in the case of access to credit facilities is more linear but the differences across the groups are still significant.

Regarding the location of the farm, it is possible to observe that the regional difference between each level of adoption is significant. As for the non-adopters it is possible to observe that about 59% is located in the Eastern Region and only 11% is located in the South-Western Region. On the contrary, full adopters are mostly present in the South-Western Region, i.e. 59%, while they are far less numerous in the Eastern Region, only 6%. The regional distribution of partial adopters is instead in line with the sample average.

At the bottom of the Table, information is provided on the BXW status on the farms and the households' access to the communication approaches promoted in Uganda to control the spread of the BXW. Full adopters present the smaller value in terms of disease status indicating that for most of them the BXW is currently infecting their banana mats. On the contrary, they present the higher value in terms of access to institutional initiatives to limit the spread of the disease.

4.4.3 Econometric Results

The SRL framework assess that the households' livelihood assets are forecasters of the adaptive strategies implemented by the rural households. Therefore, the current study implements a double-hurdle model to analyse the relationship between livelihood assets and Ugandan farmers' decision to control the spread of the BXW.

Table 4.3 shows marginal effects of the double-hurdle model. As expected, there are different sets of livelihood assets behind the decision to adopt and the decision about to which extent to do so. The inverse Mills ratio is significant, indicating that the error terms are correlated.

The first hurdle of the empirical model employed in the current analysis shows that the adoption of the livelihood strategies is positively affected by the percentage of land used for banana production and negatively associated with the BXW status on the farm.

Focusing on the determinants of the intensity of adoption, the results of the second hurdle of the model indicate that both access to credit facilities and to extension services positively and significantly influence this decision. Household access to credit lines increases the likelihood that smallholder farms adopt a greater number of practices by almost the 14%, while the possibility to received support from extension practitioners increases the probability by the 20%. As for the proportion of land area allocated to banana production and the farm equipment, their coefficients are significant and negative. Finally, from the results of the model it is possible to observe that the marginal effects of the dummies regions are all negative and significant (at 1%). Farm households living in the Central, Eastern and Mid-Western regions are less likely to adopt more than one BXW control strategy compared to those in the South-Western region of around 33%, 42% and 54% respectively.

Table 4.1. *Livelihood strategies to control the spread of the BXW by adoption level*

BXW Control Practices	All Sample (obs. 1058) Mean (SD)	Non-Adopters (obs. 133) Mean (SD)	1 Practice (obs. 239) Mean (SD)	2 Practices (obs. 272) Mean (SD)	3 Practices (obs. 234) Mean (SD)	Full-Adopters (obs. 180) Mean (SD)	F-test[1]
De-Budding (1 Yes)	0.50 (0.50)	0.00 (0.00)	0.31 (0.46)	0.57 (0.50)	0.50 (0.50)	1.00 (0.00)	131.48 ***
Disinfecting Tools (1 Yes)	0.38 (0.49)	0.00 (0.00)	0.01 (0.11)	0.18 (0.38)	0.73 (0.44)	1.00 (0.00)	477.93 ***
Sick Plants Removal (1 Yes)	0.58 (0.49)	0.00 (0.00)	0.24 (0.43)	0.58 (0.49)	0.95 (0.21)	1.00 (0.00)	296.90 ***
Clean Planting Material (1 Yes)	0.62 (0.48)	0.00 (0.00)	0.44 (0.50)	0.68 (0.47)	0.81 (0.39)	1.00 (0.00)	162.57 ***

[1] *ANOVA oneway.* Level of significance: * 10 %; ** 5 %; *** 1 %. Note: Values in parentheses are standard deviations (SD).

Table 4.2. *Descriptive statistics of the explanatory variables*

Explanatory Variables	All Sample (obs. 1058) Mean (SD)	Non-Adopters (obs. 133) Mean (SD)	1 Practice (obs. 239) Mean (SD)	2 Practices (obs. 272) Mean (SD)	3 Practices (obs. 234) Mean (SD)	Full-Adopters (obs. 180) Mean (SD)	F-test*	
Human Capital								
HH Head Education (years)	5.95 (3.91)	5.90 (4.00)	6.02 (3.82)	6.09 (4.13)	5.52 (3.81)	6.25 (3.71)	1.10	
HH Head Age	56.62 (14.46)	57.56 (15.38)	55.44 (14.37)	56.36 (14.69)	58.12 (14.52)	55.94 (13.33)	1.29	
HH Size	6.37 (3.14)	6.34 (3.83)	6.46 (3.08)	6.15 (3.15)	6.47 (3.01)	6.49 (2.81)	0.52	
Social Capital								
HH Head Gender (1 Male)	0.74 (0.44)	0.74 (0.44)	0.74 (0.44)	0.70 (0.46)	0.71 (0.46)	0.82 (0.39)	2.20	*
Access Extension Services (1 Yes)	0.54 (0.50)	0.55 (0.50)	0.45 (0.50)	0.56 (0.50)	0.53 (0.50)	0.66 (0.48)	4.61	***
Natural Capital								
Central Region	0.22 (0.41)	0.14 (0.35)	0.19 (0.39)	0.27 (0.44)	0.25 (0.43)	0.19 (0.39)		
Eastern Region	0.20 (0.40)	0.59 (0.49)	0.29 (0.46)	0.12 (0.33)	0.10 (0.30)	0.06 (0.24)	14.63	***
Mid-Western Region	0.23 (0.42)	0.17 (0.37)	0.30 (0.46)	0.26 (0.44)	0.23 (0.42)	0.16 (0.37)		
South-Western Region	0.35 (0.48)	0.11 (0.31)	0.22 (0.42)	0.35 (0.48)	0.42 (0.50)	0.59 (0.49)		
Land Owned	4.51 (7.19)	3.82 (5.16)	4.64 (8.43)	4.53 (4.69)	4.07 (4.45)	5.41 (11.43)	1.25	
Land Banana Percent	41.52 (31.07)	19.84 (30.26)	40.38 (31.88)	45.03 (30.07)	46.56 (29.00)	47.22 (27.81)	21.78	***
Physical Capital								
Home Index	38.54 (21.44)	37.92 (24.12)	36.32 (20.30)	40.25 (20.43)	39.01 (21.38)	38.77 (22.35)	1.13	
Farm Equipment Index	43.47 (21.19)	46.68 (21.63)	46.37 (22.04)	42.92 (21.03)	41.45 (20.45)	40.73 (20.35)	3.24	**
Financial Capital								
Farm Objective	1.79 (0.63)	1.60 (0.66)	1.74 (0.67)	1.83 (0.62)	1.80 (0.59)	1.92 (0.59)	5.40	***
Access Credit Facilities (1 Yes)	0.81 (0.39)	0.70 (0.46)	0.64 (0.48)	0.68 (0.47)	0.72 (0.45)	0.79 (0.41)	3.00	**
Off-farm Income (1 Yes)	0.88 (0.33)	0.95 (0.21)	0.90 (0.30)	0.85 (0.36)	0.86 (0.34)	0.84 (0.37)	3.58	***
Vulnerability Context								
BXW Status	2.02 (1.75)	3.71 (1.01)	2.99 (1.64)	1.99 (1.79)	0.91 (1.16)	0.98 (1.00)	134.26	***
Institutional Context								
Access BXW Initiatives (1 Yes)	0.22 (0.41)	0.08 (0.26)	0.17 (0.38)	0.21 (0.41)	0.24 (0.43)	0.38 (0.49)	12.13	***

[1] *ANOVA oneway.* Level of significance: * 10 %; ** 5 %; *** 1 %. Note: Values in parentheses are standard deviations (SD).

Table 4.3. *Result of the Double-Hurdle model*

Variables	*First Hurdle*			*Second Hurdle*		
	Coef.	SE	p-value	Coef.	SE	p-value
Human Capital						
HH Head Education	0.008	0.027	0.755	-0.003	0.009	0.740
HH Head Age	-0.003	0.007	0.665	0.002	0.002	0.435
HH Size	0.035	0.041	0.402	0.005	0.012	0.661
Social Capital						
HH Head Gender	-0.065	0.220	0.769	0.089	0.078	0.256
Access Extension Services	0.002	0.196	0.992	0.199	0.070	0.005
Natural Capital						
Central Region	-0.150	0.282	0.595	-0.327	0.090	0.000
Eastern Region	-0.268	0.313	0.392	-0.419	0.117	0.000
Mid-Western Region	0.032	0.299	0.915	-0.540	0.094	0.000
Land Owned	0.016	0.015	0.277	-0.005	0.005	0.272
Land Banana Percent	0.009	0.004	0.035	-0.006	0.001	0.000
Physical Capital						
Home Index	0.006	0.005	0.274	0.001	0.002	0.510
Farm Equipment Index	-0.001	0.004	0.817	-0.004	0.002	0.016
Financial Capital						
Farm Objective	-0.101	0.156	0.518	-0.007	0.056	0.897
Access Credit Facilities	-0.015	0.201	0.940	0.138	0.077	0.072
Off-farm Income	-0.017	0.270	0.949	-0.002	0.095	0.986
Vulnerability Context						
BXW Status	-0.315	0.061	0.000	-	-	-
Institutional Context						
Access BXW Initiatives	0.227	0.253	0.369	-	-	-
Inverse Mills Ratio	-	-	-	-2.943	0.181	0.000
Constant	2.001	0.722	0.006	2.949	0.250	0.000
Sigma – Constant	-	-	-	0.941	0.025	0.000

4.5 DISCUSSION

The current study implemented the Double-Hurdle model in order to identify the influence of the livelihood assets on both the decision to adopt and the intensity of adoption of the BXW control strategy.

Farm households' decision on adoption of BXW control practices is associated with the natural capital and the vulnerability context. The first corroborates the assumption that farmers' willingness to eradicate the disease from their own farm is subject to the importance they attribute to bananas as a food and income crop. The later indicates that farmers are aware of this strategy, consider it effective and therefore adopt it as an adaptive strategy to the shock. This allows us to infer that rural households will modify their farming practices if a high percent of their land is destined to banana production and it is currently affected by the disease.

Unlike other studies that have shown that farmers' participation in communication programs is important in promoting the adoption of new agricultural technologies (Kikulwe et al., 2019; Aïtchédji et al., 2010; Erbaugh et al., 2010; Bunyatta et al., 2006; Ooi and Kenmore, 2005), this study does not highlight a significant relationship between the variable related to the institutional context (proxied by the access to the BXW initiatives) and the adoption of the livelihood strategy.

Farmers' decision on the extent of adoption is instead negatively influenced by the natural and physical capitals. Proportion of land area allocated to banana production and the farm equipment are livelihoods assets that limit the intensity of adoption of the strategy identified to limit the spread of the BXW. Probably adoption of the full package is too demanding for farmers who have an extensive banana production, even if they have a high availability of agricultural endowments.

Nevertheless, social and financial capitals are livelihoods assets that widen the intensity of adoption of the BXW control package. In particular, access to extension services and to credit facilities positively and significantly influence this decision. The frequency of contacts between farmers and extension staff facilitates trust, idea and information exchange, thus acting as a trigger mechanism for intensive adoption (Akudugu et al., 2012; Mignouna et al., 2011; Lawal and Oluyole, 2008; Sserunkuuma, 2005; Karki and Siegfried, 2004; Nkonya et al., 1997; Polson and Spencer, 1991). As for the access to credit facilities, it loosens the liquidity constraint and stimulate household's-risk bearing ability (Bahinipati and Venkatachalam, 2015; Idrisa et al., 2012; Mohamed and Temu, 2008). Consequently, a rural household will perceive the adoption of the livelihood strategy less risky and will have more incentive to adopt it if it can receive financial aid to support the investment required.

Lastly, the current analysis does not show any influence of the human capital on the decision to adopt or the intensity of adoption of the identified strategies. Broadly, human capital refers to human and productive capacities that make a household more able to understand risk and uptake adaptation strategies (García de Jalón et al., 2018). However, this is not a surprising result since contention on the direction of the effect of this capital on adoption exists (Kikulwe et al., 2019; Jogo et al., 2013; Deressa et al., 2009; Samiee et al., 2009; Baidu-Forson, 1999; Shiferaw and Holden, 1998; Rahm and Huffman, 1984).

4.6 CONCLUSIONS

This study contributes to the body of literature on pest management by identifying the livelihoods assets responsible for the adaptation of rural farmers to Banana Xanthomonas Wilt in Uganda. Theoretically, this paper builds upon the Sustainable Rural Livelihood framework as it allows a more comprehensive insight into the ways in which rural households adapt their farming practices to handle external stressors and to preserve their livelihoods (Scoones, 1998). Empirically, the double-hurdle class of model has been applied in this study with the base assumption that the two adoption decision processes (adoption and intensity of adoption) are separate. The model was fitted to a sample of 1058 smallholder farmers located in four selected major banana-growing and consuming regions in Uganda (i.e. Central, Eastern, Mid-Western and South-Western).

Following the SRL framework, it is possible to assess that banana production embody a significant part of the livelihood of rural households in Uganda. It is important not only in terms of household income and food security, but also social and cultural wellbeing. Unfortunately, since 2001 the livelihood system of the Ugandans farmers was threatened by the BXW. The disease represents an enormous stressor since all banana cultivars are susceptible to the disease (Welde et al., 2006), symptoms are cultivar-specific and determined by the course and stage of infection (making it difficult for the farmers to identify them promptly) (Brandt et al., 1997); it spreads rapidly (Biruma et al., 2007) and it can quickly increase to endemic level (Nakakawa et al., 2017), causing the loss of the entire production (Ssekiwoko et al., 2015). An intensive collaboration between the Ugandan Government and several organizations led to the identification of a BXW control strategy based on four farming practices (i.e. de-budding, sick plants removal, disinfecting tools and clean planting materials). This strategy has been widely promoted throughout the country in order to boost proper adoption and contain the spread of the disease (Kubiriba and Tushemereirwe, 2014).

Among the four farming practices, the present study has shown that the practice most adopted by the sample analysed is the use of clean planting materials, while the less adopted is the disinfection of agricultural tools, with an adoption rate of 62% and 38% respectively. Moreover, the analysis shows that those who fully adopt the integrated package against BXW are about 17% of the sample. The farm households who have not practiced BXW management at all are approximately 13% of the sample. Finally, those banana-based households that adopt only one, only two or only three of the four recommended strategies represent the remaining 70% of the sample. Therefore, it is possible to conclude that currently there are still some rural households that are not implementing the complete package of strategies in their farms and this makes it difficult to eradicate the disease.

Double-hurdle results confirm the assumption that the two adoption decision processes (adoption and intensity of adoption) are separate and influenced by different sets of livelihood capitals. The reasons that drive farmers to adopt the identified strategy are the vulnerability context and the natural capital. Farmers' decision on the extent of adoption is instead negatively influenced by the natural and physical capitals and positively associated with social and financial capitals.

These findings indicate that precedent studies implementing econometric models based on the idea that the adoption process is considered the same as the one that determines the intensity of adoption are inadequate to model the decision process of adaptation to BXW disease of banana-based households in Uganda. The implementation of a two-step model has indeed allowed to deepen the understanding of the phenomenon under consideration. Therefore, the double-hurdle model is the best specification to identify the factors that influence these decisions at both stages.

It is worth noting that these data were collected in 2018, when the situation in Uganda was declared under control. Determinants of adoption of the strategy to control the spread of the BXW could be different during the outbreak of the disease. Moreover, the study does not consider the origin of the clean planting material. In fact, the informal source of inputs (such as farmer-to-farmer exchange) is preferred by farmers as the cost is lower than when buying from formal sources (Bagamba et al., 2006). This practice could aggravate the problem because it increases the risk of BXW spreading (McCampbell et al., 2018; Tinzaara et al., 2013). However, for the purposes of this study it was not considered relevant to deepen the distinction between formal and informal source of clean planting material. These are the limitations of this study, and there is a need for longitudinal research assessing determinants of adoption even elsewhere.

Despite this, is recommended that the National Government and other stakeholders of the banana value considering variation in livelihood assets to enable tailored support to farmers. Particularly regarding social and financial capitals that facilitate information exchange and loosens the liquidity constraint related to the adoption of the integrated package of strategies for BXW control. This because there is a strong possibility of the disease resurgence and it is important to prevent the next BWX outbreak as it might lead to potentially heavy negative impacts on the livelihood of rural households in Uganda.

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5 CONCLUSIONS

Rural households living in developing countries are often exposed to multiple stressors that threaten their livelihood. Widespread absence of social safety nets forces rural households to cope with the effects of shocks and associated risks on their own.

During the years, numerous policies and programs have being implemented by different international development agencies with the aim of strengthening rural livelihoods. Unfortunately, there are still many rural households characterized by a high brittleness deriving from conditions such as reduced income levels, inadequate adaptation capacity and prominent dependence on natural resources.

In the 1990s the Sustainable Rural Livelihoods (SRL) became a predominant international development approach since it provides a framework for a holistic interpretation of the dynamics of development. It was adopted by different international development agencies and it has been long debated in the literature. However, empirical studies seeking to demonstrate the linkages identified by the SRL framework from a quantitative point of view are still limited.

In light of this, this Ph.D. thesis aimed to fill this gap with the purpose of offer a wide-ranging understanding of the dynamics of development. This represents an important step forward for the implementation of development programs by the international development agencies. In order to achieve this objective, three papers have been developed.

The first paper aimed to empirically contextualize the SRL framework in the context of resilience to climate vagaries. The state of Bihar has been chosen since it is one of the most climate-sensitive states in India. Given the expected weather vagaries and their unpredictable consequences on agricultural production, shoring up farming systems' resilience to climatic stressors is imperative to shield the livelihood of its extremely dense and poor rural population.

Objective of the analysis was the identification and quantification of the different concepts embodied by the SRL framework, but of particular interest for the study was the identification of the different adaptive strategies adopted in the study site and their correlations. The REBAS index, that ranges from 0 to 100, indicated that the level of adaptation of Indian farmers is medium (just above 51). Principal Component Analysis showed that only the alteration strategy is adopted as stand-alone measure, while the other identified strategies are considered as alternative measures. Moreover, a subgroup of diversification strategies presented high loadings. Rural farmers tend to associate intercropping with legumes with other practices of on-farm diversification (i.e. integration of livestock and/or agroforestry) probably because such combination may outperform each strategy undertaken independently.

Lastly, the study aimed to further understand the relationships traced by the SRL framework. To do this a Tobit model with endogenous variables was implemented. First of all, the results of the empirical model bring quantitative evidence on the assumption that livelihood resources (in particular with regard to social, natural, physical and financial capitals) influence the adaptation level of the farming system which in turn influences the food security status of the farm households. However, results suggest further considerations: (1) not all livelihood assets are associated to adoption of livelihood strategies ; (2) the influence of some livelihood assets on the livelihood outcomes could be conveyed by the adoption of specific livelihood strategies (as formulated by the theoretical framework), while in other cases (3) some livelihood assets could be directly linked to livelihood outcomes (contrary to what is asserted by SRL framework).

The second paper aimed to analyse the role of the institutional context in shaping smallholder's adoption of a specific livelihood strategy and the livelihood outcomes generated by such strategy. In particular, the analysis focused on the Seeds for Needs (S4N) initiative. The implementation of this initiative provided a source of exogenous change to the institutional context that allowed an ideal perspective for an empirical identification of the link between the different domains of the SRL framework. Indeed, thanks to the institutional activities it was possible to compare the livelihood strategies and their outcomes of households exposed to institutional change with a counterfactual provided by similar communities and households that were not explicitly covered by the development program.

DR estimator results indicate that exposure to program activities generates positive and significative changes on the seed portfolio of smallholder farmers, specifically on the varietal diversification of target crops. Moreover, the DR results confirm the research hypothesis underpinning the overall study, namely that exposed households can obtain livelihood benefits in terms of crops productivity and increase ability to recover from shocks occurrence.

The second empirical analysis, consisted on a simultaneous system of equation formulated and estimated via a Generalized Method of Moments (GMM), identified strong causal linkages between households' exposure to the program activities, varietal diversification on farm and livelihood benefits. Such results confirm the specific consequentiality of the steps as theorized in the SRL framework, linking the livelihood benefits to the households' adoption of varietal diversification strategies and the institutional context.

The third and final paper was theoretically built upon the SRL framework in order to offer a more comprehensive insight into the decision-making process of banana-dependent households on the adoption of the integrated Banana Xanthomonas Wilt (BXW) control package in Uganda.

Banana production contributes significantly to the livelihood of rural households in Uganda as bananas are important not only in terms of household income and food security, but also social and cultural wellbeing. The advent of BXW in 2001 has led to (1) the replacement of many perennial bananas with annual crops that could have potentially serious implications for soil erosion and fertility (Tushemereirwe, 2001), (2) a reduction of the social capital, (3) the loss of employment opportunities (Karamura et al., 2010) and (4) a sharply increase of bananas' price which means that local consumers could no longer buy their main source of nutrition (Vurro et al., 2010). An intensive collaboration between the Ugandan Government and several organizations led to the identification of a BXW control strategy based on four cultural practices (i.e. de-budding, sick plants removal, disinfecting tools and clean planting materials). Among them, the present study has shown that the practice most adopted by the sample analysed is the use of clean planting materials, while the less adopted is the disinfection of agricultural tools, with an adoption rate of 62% and 38% respectively. Moreover, the analysis shows that those who fully adopt the integrated package of practices against BXW are about 17% of the sample. The farm households who have not practiced BXW strategy at all are approximately 13% of the sample. Finally, those banana-based households that adopt only one, only two or only three of the four recommended strategies represent the remaining 70% of the sample. Therefore, it is possible to assert that currently there are still some rural households that are not implementing the promoted strategy in their farms and this makes it difficult to eradicate the disease.

Double-hurdle results indicated that the reasons that drive farmers to adopt the identified strategy are the vulnerability context and the natural capital. Farmers' decision on the extent of adoption is instead negatively influenced by the natural and physical capitals and positively associated with social and financial capitals.

In the light of the result achieved by the current Ph.D. thesis, it is possible to assess that the perspective offered by the SRL framework represents a very useful and versatile theoretical architecture.

The emphasis on the livelihood system of the rural households improved the understanding on the ways in which rural households combine and mobilize their livelihood assets in order to implement different livelihood strategies with the aim of pursuing their own livelihood outcomes. However, these strategies are modified from time to time by rural households in order to adapt to unpredictable changes coming from the external system, in particular from the vulnerability context.

Moreover, the institutional focus of the SRL framework gives a practical gain when considering policy applications, by identifying those structures and social rules and norms which would play an important role for the outcome of an external intervention. This makes it possible to observe how policies and programs are able to influence the portfolio of assets of the households and the vulnerability context of reference, and how this in turn leads to the adoption of specific strategies capable of managing the negative impacts on income and food security caused by extreme climatic events, uncertain agricultural production and unexpected market shocks.

The current Ph.D. thesis thus emphasizes the importance of targeted interventions to improve specific forms of households' livelihood assets, being key determinants for adaptation strategy adoption in the face of unprecedented confluence of pressures. Particularly, interventions need to focus on dismantling barriers to social integration among community members. Social networks can promote cooperation and facilitate access to information about best farming management practices and climate change. At the same time, policy interventions should create the financial environment that loosens the liquidity constraints and allows farmers to implement the identified adaptive strategies. All this is pivotal to guarantee the maintenance and improvement of the resilience of environmentally dependent households in the developing world.

The results of this Ph.D. thesis do not offer a one-size-fits-all solution. As illustrated above, different rural households adopt different strategies to improve their livelihoods since adaptation occurs across broad spatial and temporal scales. Consequently, farmers could adopt different adaptive strategies in other parts of the world, or they could switch their livelihood strategies as climate and demographic conditions evolve. These findings refer to the specific context of the research but the empirical quantification and validation of the SRL framework implemented in this Ph.D. thesis may represent a valid operating procedure to better understand dynamics between livelihood assets, livelihood strategies and livelihood outcomes in other contexts. These results can provide a valuable contribution for international development agencies as they provide a better interpretation of the reference context. A better knowledge of internal development dynamics would allow the implementation of more targeted development projects and a more effective contribution to improving the livelihood of rural households.

Further research could improve the methodological approach of the current analysis by including more predictors of adaptation, such as variables that describe farmers' perceptions and attitudes toward specific risks, or by extending the range of livelihood outcomes that could be pursued by the households, such as yield stability or the sustainable use of natural resources.

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