The Impacts of Cash Transfer Programs on Rural Livelihoods: a Study of *Caboclos* in the Brazilian Amazon Estuary Region

by

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

I choose the manuscript option under the guidelines from the joint Waterloo-Laurier Graduate Program in Geography to conduct my Ph.D dissertation. Three manuscripts are presented in Chapter 3 to Chapter 5 respectively and I am the first author for all of them. These manuscripts are the products of mainly my intellectual efforts from proposing the research questions, designing the methodology and experiments, analyzing the results, and writing the report. During these processes, I constantly discuss with my co-authors, most of whom are my committee members and colleagues of the research project. Their roles and contributions are explained and listed in details along with the plan of submissions. Changes in context and format are made, for the sake of consistency, to integrate three manuscripts as Chapter 3, 4, and 5 into a thesis.

The first manuscript is titled “Mapping the heterogeneous impacts of cash transfer programs on rural livelihoods: a case study in the Brazilian Amazon estuary”. I wrote this manuscript under supervision of Dr. Peter Deadman and Dr. Derek Robinson from my committee, as well as in collaboration with Dr. Oriana Olmeida, Dr. Sergio Rivero, and Dr. Nathan Vogt from Brazil. I conducted the design of the methodology, carried out the data analysis, and wrote the manuscript. Dr. Deadman and Dr. Robinson constantly offered me suggestions on how to improve my analysis and results interpretation, and they also reviewed the manuscript. The original dataset was provided by Dr. Olmeida, Dr. Rivero, and Dr. Vogt, all of whom also actively participated in the discussion. The results have been presented in AAG-2014, Tampa, with positive feedback. This manuscript will be submitted to the journal *Human Ecology*.

The second manuscript is “Understanding rural farming systems with agent-based modelling and decision making ensembles—a case study in the Brazilian Amazon estuary”. I constructed the model, designed the experiments, and carried out the analysis. I wrote the manuscript, which was inspired and guided by Dr. Deadman and Dr. Robinson on how to interpret the results to a higher theoretical level. M.S. Bogdan Caradima involved in the result presentation. Dr. Rivero, Dr. Olmeida, and Dr. Vogt provided information on how to accurately represent the local farming system. The preliminary results have been presented in AAG-2015, Chicago, and in the World Water Congress 2015 in Scotland. The full report will be presented in the International Society for Ecological Modelling Global Conference 2016, and we modelling aim to submit to the journal *Ecological Modelling*.

The third manuscript, "Through the lens of development resilience: using agent-based modelling to explore rural livelihood resilience", was written by me under supervision of Dr. Deadman, Dr. Dawn Parker, and Dr. Robinson. We collaborated with Dr. Marta Berbes to implement the concept of "development resilience" into ABM outcomes. The results will be presented in AAG-2016, San Francisco. We plan to submit this manuscript to *Ecology and Society*.

Below are the signatures of co-authors, indicating that they are in agreement with the evaluation of the roles and contributions:

First Manuscript: Mapping the heterogeneous impacts of cash transfer programs on rural livelihoods: a case study in the Brazilian Amazon estuary

Co-author:

Peter Deadman ____________________ Derek Robinson ____________________

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Second Manuscript: Understanding rural farming systems with agent-based modelling and decision making ensembles—a case study in the Brazilian Amazon estuary

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Third Manuscript: Through the lens of development resilience: using agent-based modelling to explore rural livelihood resilience

Co-author:

Peter Deadman	______________________	Marta Berbes	______________________
Dawn Parker	______________________	Derek Robinson	______________________

Abstract

Rural households that rely on agricultural and natural resources for their livelihoods have been exposed to increasing socio-economic and climatic challenges over the past few decades, which requires urgent scientific exploration to effectively inform policies and other interventions. This dissertation investigates the rural livelihood of smallholders and the impacts of cash transfer programs through the use of empirical analysis and agent-based modelling and simulation (ABM) of the *Caboclos* in the Brazilian Amazon estuary region. The findings in this dissertation deepen the understanding of the livelihood dynamics of small farming households, provide insight about modelling uncertainty, and evaluate the impacts of policies and other approaches meant to alleviate poverty and enhance resilience.

First, the empirical patterns of rural livelihoods, with a focus on the heterogeneous impacts from cash transfer programs, have been captured through statistical analysis of a household survey. Households were classified based on the amount of cash transfer and dependence on cash transfers to demonstrate the heterogeneity in this significant income of rural livelihoods. The results show the high level of heterogeneity among the value of cash transfers that households receive and in the households' level of reliance on this stipend. Results also illustrate the differences among household characteristics and their significance regarding the degree of household reliance on cash transfers.

Second, we constructed an ABM with an ensemble approach to represent the small farming households and simulate their livelihood outcomes with government cash transfer programs under eight experiments that differentiate main livelihood factors. The three ensemble members reflect a range of household behaviors, which include Max Profit (optimizing net economic returns), Max Leisure (pursuing optimal leisure time once subsistence is met), and Subsistence First (a strategy that maintains subsistence requirement first and then pursues market profit). Sensitivity and post-hoc analyses reveal the variability in the outcomes among three decision regimes, where the decision regime proves to be the most significant factor for livelihood outcomes at both the community level and individual level. The mere presence of cash transfers largely increases income and the equality of income distribution, of which the most drastic change occurs in the Max Leisure decision regime. However, household characteristics influence household livelihood outcomes differently within each decision regime.

Third, we explored rural household livelihood and poverty dynamics using the ABM through the lens of development resilience. Various external shocks were applied to the household agents and their livelihood dynamics, particularly their resilience attribute, were analyzed. Our results first support the existence of the poverty trap and the relatively better-off zone as the "basin of attraction" that were proposed in resilience theory. Results from the simulation also indicate that external shocks, although similar in duration and magnitude, have significantly different impacts on livelihood resilience, with climate shocks being the most influential. Government cash transfer programs are more likely to be effective with a big initial capital boost, and a Subsistence First strategy, relative to Max Profit and Max Leisure strategies, is most likely to be resilient for vulnerable households, but not in households who are close to being trapped.

Key words: rural livelihoods, small farming households, cash transfer, agent-based modelling, poverty reduction, resilience

Acknowledgements

The day I finished this PhD dissertation and submitted it for review was March 21, 2016. It was the first day of spring. It was also the fifth spring that I had been in Waterloo. Even after so many years, my mother and other relatives are still surprised to see me in a T-shirt or tank top when I video chat with them in winter time. The conversation usually ends with them exhorting me to put on more layers to avoid getting sick. Living all their lives in Xiangyang, a small city in the South China, they don’t understand how powerful the indoor heating system is, and they don’t even know that I am so used to the cold that sometimes I jog outside in the snow.

This is just one example among many that my parents and family don’t understand. They also know little about my research. Nevertheless, they are proud of me being the first doctor in the family. They support me with all their heart and soul -- my cousins perform my duties of taking care of my parents while I’ve been 10,000 km away from home for the past five years, and probably for many years to come. I owe my family, especially my parents, a sincere apology, for being absent in their lives for so long.

My parents moved to the city in their early 20s. So, unlike most of my cousins, I grew up in the city and moved overseas without much knowledge of rural livelihoods in the countryside. Over the past few years, my cousins went to coastal cities where the economy is well developed, gaining experience in the factories there, and later coming back to my hometown to become managers. Our trajectories are not so different. They sent money to their parents--my uncles and aunts--who are still in the rural countryside and taking care of my cousins’ kids. This remittance is substantial enough that my aunts and uncles are able to take a break from their labour-intensive farm work and rent out most of their land (thanks to the newly established policies that allow the transaction of rural land use rights in China). Most of them do. However, one uncle is

still tending his garden, even as his son sends back a few thousands yuan every month—he just loves putting his hands in the soil and his heart to the field.

The path of my cousins is an epitome of my generation in China, which shows the rural-urban migration, and has a close resemblance of my case study in Brazil. I am truly happy that living conditions are greatly improved because of the non-farm income earned in my family, something evident in my study based on a small community in the Brazilian Amazon. It is also fascinating to observe the diversity in livelihood strategies adopted by my aunts and uncles in rural China, which has been documented in many studies and eventually built into a model in my dissertation. Being able to expand my knowledge of rural livelihood systems and to complete this dissertation, there are many people that I must thank.

First is my PhD advisor, Dr. Peter Deadman, a distinguished scholar in land use science. He provided me with the perfect project and a worry-free research environment. He guided me through the struggling of conducing scientific studies. He always encouraged and inspired me when analyses or simulations did not go as well as we expected. He spared handholding when I was too nervous to deliver my very first lecture. He and his wife Linda reserve a room in their house whenever I need a place to stay. It is a fine adventure that we've been through these past five years in the landscape of agent-based modeling and rural livelihoods.

I'm also very grateful for my outstanding committee: Dr. Derek Robinson, Dr. Dawn Parker, and Dr. Sergio Rivero, as well as Dr. Robert Feick in my early committee and Dr. Andrew Bell as my external reviewer. I remember the reaction from one professor (Dr. Richard Kelly) when I told him who was in my committee before my comprehensive exam—"Good Luck!", he excitedly said — this group is well-known for their academic integrity and scientific

rigorousness. The intellectual challenges that I received from my committee members are their expression of kind assistance for me to grow as an independent researcher, gradually becomcing a sort of enjoyment for me. Dr. Robinson was always available whenever I knocked on his office door requesting help. Dr. Park provided me accurate reviews and guidance on my research direction and methodology. She is also my role model of a distinguished female scientist. Dr. Rivero's resourcefulness in Brazilian scientific literatures and economic theories was also a huge help throughout my studies. It is the continuous support that I got from my committee that allowed my PhD study to blossom the way it did. I sincerely hope our collaborations continue in the future.

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Parker and her institute Waterloo Institute for Complexity and Innovation (WICI), where I joined the ABM working group and met with many great minds that share similar interests in the modeling field.

The Caboclos communities in Abaetetuba, Ponta de Pedras, and Mazagao deserve special thanks from me. Caboclos are so kind that they completely trusted me and shared their food, their hammock, and their life with me. Without their unreserved offering of information about their livelihoods, this dissertation would not have the empirical bedrock to make strong databased statements.

My friends offered various kinds of support to me during this wonderful (also anti-climactic) journey. Particularly, I'd like to thank Shanqi Zhang, who has been my roommate and a sister-figure since the day I arrived in Waterloo. The Tavakoli family, Victor Cleren, Daniel Dong and his family, Hui Luan, Qingxu Huang, Miao Jiang, Pearl Chang, Zhan Li, Zhenzhong Si, Keenan Lyon and his wife Laura Ni, Danial Mariampillai, Guillermo Azocar, Elena Kraljevski, Ibrahim BenDaya, Audrey Bothwell, Emily Leung, Johnny Chen, Kenan Ali, Adam Celejewski and his wife Aula, my lovely officemates from the Spatial Innovation Lab, friends from my hometown and Wuhan University who I met in Waterloo, and friends from Outers Club and Salsa Club, who all played important supporting roles for me in accomplishing this five-year task. They encouraged and inspired me to keep fearlessly moving, sometimes stumbling, again and again, when facing challenges from work and life.

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Chapter 1 Introduction

1.1 Scope of the thesis

In the past several decades, rural households relying on agricultural and natural resources for their livelihoods have been exposed to increasing threats from climate change, economic unpredictability, and political instability. A number of studies have been conducted to understand the livelihood dynamics of small farming households from theoretical and practical perspectives, to mitigate impacts from these risks and to enhance resilience practices for the rural poor and food insecure people. Among the different measures that are available to help poorer communities adapt to socio-economic or environmental changes, government cash transfer programs have been widely implemented as a new antipoverty approach in developing countries. However, the impacts of cash transfer programs on rural poverty alleviation and resilience enhancement require further investigation to advance our current understanding of their effectiveness. This thesis uses empirical analysis and agent-based modelling to address a series of research questions in relation to rural livelihood systems and cash transfer programs where incisive research into efficacy and efficiency is a necessary tool for policy makers addressing poverty.

1.2 Context and motivation

1.2.1 Rural livelihood and resilience

Almost half of the world's population live in rural areas and rely on agriculture as their main source of income[1]. Among them, 75 % are poor and food insecure people living in developing and least developed countries[2]. On top of already being in a less-favorable position, these agricultural-dependent households are facing multiple challenges, including the degradation and depletion of natural resources (Foley et al., 2005; Grey and Sadoff, 2007), higher pressure on food security with decreasing rural labour (Cohen and Garrett, 2010), the uncertainty in crop production due to increased variability from climate change (Wei et al., 2014; Zinyengere et al., 2014), and a higher-degree of exposure to market volatility (Padoch et al., 2008; Tittonell, 2014).

There has been considerable progress towards eradicating poverty since the adoption of the Millennium Development Goals (MDGs) by the United Nations Development Program (UNDP) in 2000[3], but more efforts are needed to abate poverty under these accelerating shocks and stresses. The MDGs comprise the first objective in the newly established Sustainable Development Goals (SDGs) by the UNDP. Therefore, insightful research into rural livelihood dynamics, especially into methods that enhance resilience to mitigate socio-economic and climate change related risks facing these households is required to deepen our understanding and to advise policy-makers.

Given current attempts to spur rural development and eliminate poverty, attention has shifted towards getting rural livelihoods on "a path of inclusive, sustainable and resilience

[1] http://data.worldbank.org/topic/agriculture-and-rural-development
[2] http://www.fao.org/resilience/background/en/
[3] http://www.undp.org/content/undp/en/home/sdgoverview/post-2015-development-agenda/

development"[4] in both academia and practise (Bennett et al., 2005; Miller et al., 2010; Schwarz et al., 2011; Tittonell, 2014). The perspective of resilience is used as a concept and an approach to understand the dynamics of socio-ecological systems facing potential external shocks (Folke, 2006; Folke et al., 2002; Liu et al., 2007; Walker and Holling, 2004). Though open to interpretation, resilience is often understood as the capacity of a system to retain its essential structure and function by absorbing disturbances (Miller et al., 2010; Walker and Holling, 2004).

To increase resilience, one "desirable" attribute of the system, specific interventions and management principles are required (Biggs et al., 2012; Brian Walker and Salt, 2012; Walker et al., 2010). Within the context of rural livelihoods, strategies to enhance resilience include the diversification of livelihood assets (Hanazaki et al., 2012; Marschke and Berkes, 2006), preserving traditional knowledge (Brondizio and Moran, 2008; Vogt et al., 2016), and moving the system to a higher range of capacity before it flips to another state (B Walker and Salt, 2012). However, more efforts are needed to understand resilience as a property of the complex system and to assess the effectiveness of different interventions at improving the rural poor's overall well-being and ability to cope with changes through certain resilience practices.

To combat poverty and enhance resilience, a range of different techniques have been pursued in developing countries , such as implementing irrigation systems, applying incentives and policies, and adopting transgenic crops (Enfors and Gordon, 2008; Ezzine-de-Blas et al., 2011; Mercer et al., 2012; Wossen and Berger, 2015). Among these approaches, government cash transfer programs have been popular over the past several decades. They are implemented at the macro level, but affect livelihoods at the household level and constitute an important income source for poor households (Grosh et al., 2008, p. 7). Cash transfer programs intend to

[4] http://www.undp.org/content/undp/en/home/sdgoverview/post-2015-development-agenda/

help households escape poverty and achieve their self-defined goals by providing them with increased assets and resources. For example, the *Bolsa Familia* program in Brazil aims to improve children's school attendance in poor households so that their human capital may be enhanced in the future.

Despite good intentions and positive results, cash transfer programs may cause unintended consequences, especially if they count for a large proportion of a poor households' total income. Examples of these unintended consequences include a reduction of labor participation (Bertrand, 2003; Brauw et al., 2015) and inter-household financial transfers (Miranda et al., 2009). In general, cash transfer programs are widely accepted as a feasible approach to alleviate poverty regardless of the potential issues (Grosh et al., 2008). Additional research is needed to measure the impacts and consequences of cash transfer programs on the dynamics of rural livelihood and resilience, so that cash transfer programs can achieve improved effectiveness while minimizing unforeseen negative consequences.

1.2.2 Livelihood approach and agent-based modelling approach

To fully map livelihood dynamics and the impacts from cash transfer, we need to view the components and the processes of rural livelihoods from a systematic perspective, which is often described by a sustainable livelihood approach (Carney, 2003; Development Study Group, 2002; Turner, 2012) as a way of organizing the complex issues (e.g., assets, activities, and people) of livelihood. Rural livelihood systems contain two main reciprocal components: the agricultural households and the environment that they are in, which forms a coupled human-environment system. These two components are connected by livelihood strategies that households adopt to interact with the environment and thereby gain a living. With the possession of various forms of capital and resources (i.e., human capital, natural capital), people are at the center of this livelihood system. Households decide how to use their resources to achieve a desirable livelihood outcome, such as more income or improved resilience (Development Study Group, 2002). Therefore, households may react to cash transfers differently, forming patterns of distinct behaviors and outcomes. There is a lack of substantive research focussed on understanding these patterns of behaviours. Using the sustainable livelihood approach to integrate in these factors and relations and guide our field data collection and analysis, we can reveal the different actions households make based on their available assets along with external shocks, thereby linking heterogeneous micro-processes with the macro-patterns of livelihood outcomes.

Based on the data and conclusions from empirical studies of rural agricultural systems, using computer models provides a further step in analyzing rural households' behaviors within the context of growing social-economic and climatic risks. Modelling allows us to manipulate experimental conditions for different scenarios and evaluate outcomes in a flexible way that is limited in purely empirical and analytical studies. Among the modelling attempts to represent the livelihood dynamics of small farming households[5], agent-based modelling (ABM) stands out as a unique approach for its capability and flexibility. It has been utilized to explore agricultural systems and other coupled human-environment systems, and has proven to be an effective tool to simulate bottom-up processes (Le et al., 2012a, 2010; Mena et al., 2011; Robinson et al., 2007; Schreinemachers et al., 2010; Walsh et al., 2013). Rural households, with their different socio-economic attributes and decision strategies, interact with the environment to produce system-level patterns responding to different environmental conditions and scenario settings, which makes ABM an ideal tool to investigate such a system.

[5] The terms small farming households, smallholders, rural households are used interchangeably in this thesis.

In summary, we use ABM in the rural livelihood context to represent agricultural households with heterogeneous livelihood assets and strategies, so that their behaviors and reactions to cash transfer programs and external environmental shocks can be simulated. The investigation on the uncertainty of human decision making that is inherent in the modelling process has not been directed despite the existence of a rich body of ABM cases, so we pay special attention to explore this uncertainty in this thesis. In addition, aggregated patterns that emerge from the simulation outcomes can be used to identify and explore potential sources of resilience in rural livelihood systems and to evaluate the effectiveness of different policies and interventions.

This thesis is a core part of an international project titled “Sociocultural Adaptations of *Caboclos* in the Amazon Estuary of Brazil to Extreme Tidal Events” that aims to provide scientific data for riverine communities in the region to adapt to increasing hydro-climatic and socio-economic changes. The income of local farmers called *Caboclos* has increased dramatically in the last 10 years as a combined result of a number of government cash transfer programs and the boom market for açaí berries. However, their livelihoods and capacities to adapt are also restricted by daily floods that are becoming more abnormal in frequency and intensity (Pinho et al., 2014; Vogt et al., 2016), and by the risk of a possible bust cycle of this fashionable açaí food item. Therefore, the first two objectives of this project are to monitor the river level and to construct an early-warning system for extreme floods, while this PhD thesis focuses on the impacts of cash transfer programs on *Caboclos*’ livelihoods by empirical analysis and agent-based modelling. By simulating household dynamics and reactions to societal and natural disturbances, this thesis explores the rural livelihoods and the resilience property and contributes the theory development of this field. Moreover, the results from this thesis can be used as evidence to help policy-makers in planning and developing strategies which are useful for this vulnerable population towards preparing and coping with extreme events.

1.3 Research questions, contribution, and objectives

1.3.1 Goals and objectives

Populations in developing countries that are referred to as small farming households will be impacted severely by climate change (IPCC, 2014; Morton, 2007). Combined with other non-climate stressors, including economic oscillation and political instability, poverty reduction among these people is becoming more difficult (Olsson et al., 2014). Resilience, therefore, needs to be built into their livelihood systems. However, as one of the main properties in coupled human-environment systems, resilience is not a concept that can be easily assessed (Liu et al., 2007; Quinlan et al., 2015). A rather novel concept of "development resilience" addresses poverty in the face of various stressors, with the intervention targeted towards increasing people's capabilities through cash transfers and other means (Barrett and Constas, 2014). *Therefore, this thesis contributes to the understanding of rural livelihood dynamics and resilience by demonstrating the impacts of cash transfer programs and evaluating interventions and alternative strategies.* The outcomes of this thesis deepen theories of rural livelihood and resilience, support the development in agent-based modelling, and can be leveraged to policy on local communities and their daily choices to raise the livelihood to a resilient state. This overarching research goal is achieved by the following objectives:

(1) Analyze the distribution of levels of dependence[6] on cash transfer programs within the small farming households *Caboclos* in the Brazilian Amazon estuary region using data from a household survey conducted in 2012;

(2) Identify the drivers that cause the overall patterns of dependence levels; specifically, describe the important livelihood activities at each level and find the significant livelihood factors that contribute to the formation of these patterns;

(3) Construct an agent-based model to represent households with their demographic and socio-economic attributes and the external environment (i.e., a job market and cash transfer programs), based on the empirical data;

(4) Integrate three decision making strategies as ensemble modules in the model, which are chosen based on a review of strategies used in ABMs and small farming theories, to explore the variety of human behaviors and their associated outcomes. In addition, identify and compare the influence of demographic and socio-economic factors on livelihood outcomes when applying different decision strategies;

(5) Utilize the ABM and three decision modules to simulate the behaviors and dynamics of household agents and quantify the resilience of rural livelihoods in the face of various external shocks (i.e., açaí market failure, lack of available jobs);

(6) Determine the conditions that establish a basin that traps people in poverty, and evaluate the effectiveness of different potential interventions to move households out of this poverty trap and enhance their resilience.

[6] We use dependence to indicate the percentage of cash transfer out of the total household income, which does NOT imply households relying on or being controlled by cash transfers. It is rather neutral.

1.3.2 Contribution and research questions

To accomplish the listed research goals and objectives, the following research questions were answered:

(1) Chapter 3: What are the patterns of household dependence levels on cash transfer programs in the estuary region at the Brazilian Amazon? With respect to rural livelihoods, what drivers cause the distribution of such heterogeneity, even when some households receive a similar amount of cash transfers?

(2) Chapter 4: In the context of an ABM that represents a complex human-environment system, how do we resolve the uncertainty that constitutes the nature of human decision making? What are the significant factors determining the outcomes of household livelihoods? Does the significance of these factors change when human behaviors change?

(3) Chapter 5: How are poverty and desirable livelihood states formed? Specifically, what demographic structure, livelihood assets, or decision strategies contribute to the formation of such states? Can cash transfers or certain interventions solve the poverty trap or increase the resilience of desirable-livelihood households?

By addressing the aforementioned research questions, the contribution of this thesis will be multifold. From a theoretical perspective, this thesis advances the resilience concept in a complex system, especially in the rural livelihood system context towards poverty alleviation. It also emphasizes the importance of the relations and impacts between cash transfer programs and rural livelihood system. From the methodology perspective, this thesis first integrates empirical studies and agent-based modelling with the ensemble approach that run different models or the same model with different decision components and a variety of initial states to account for the uncertainties associated with human decision making. This thesis also makes an exploratory attempt to assess resilience in rural livelihoods by showing the trajectories of agents' livelihood dynamics in the alternative livelihood states. From the practical perspective, the results of this thesis can be valuable information for policy-makers who are seeking insights to guide the effective implementation of cash transfer programs or other development of resilience practises for rural vulnerable people.

1.4 Thesis Outline

There are six chapters in this thesis. *Chapter 2* provides a brief explanation of the methodology used in this thesis, which consists of the empirical analysis of a household survey data that produces the dependence pattern on cash transfers, the ABM modelling approach combined with ensemble modules of decision strategies, and the framework for simulation and assessment of livelihood resilience in response to various shocks.

Chapter 3 addresses the first research question. Given the sustainable livelihood system, we demonstrate the patterns of heterogeneous dependence levels on cash transfer programs among individual smallholders as *Caboclos* in the delta region of the Brazilian Amazon. Households show a divergent degree of reliance on the income from cash transfers, ranging from not-dependent to highly-dependent. The main livelihood activities that generate income are identified (i.e., the off-farm activities in households who are less-dependent on cash transfers), along with the significant factors (i.e., the education level) that cause the distribution of the different dependence levels on cash transfers.

Chapter 4, which addresses the second research question, reports the construction of an ABM where the agents are small farming households with different demographic and socio-economic attributes and decision strategies. The main focus of this chapter is an ensemble approach, where three decision strategies (Max Profit, Max Leisure, and Subsistence First) are utilized in one ABM. Eight experiments randomizing four factors (i.e., land type, household size, initial capital, and cash transfers) are executed where cash transfer and land types are found to most significantly affect poverty and income inequality outcomes at the community level among most decision strategies. The PAWN method, a new density-based global sensitivity analysis method that can complement variance-based global sensitivity analysis, is conducted to identify the factors that are significant at the household level, where how many household members are eligible for cash transfer is the most important factor affecting livelihood outcomes among households who adopt Max Leisure strategy, and having várzea is the most important factor for households who are using Max Profit strategy and Subsistence First strategy.

Chapter 5 utilizes the model in the previous chapter and simulates livelihood dynamics and reactions to various shocks and different interventions, which tackles the third research question. We adopt the "development resilience" definition that emphasizes both poverty reduction and resilience enhancement to assess the livelihood and resilience dynamics in light of a resilience framework. Two relatively stable states, the "basins of attraction", are observed from simulation results, and drivers for this phenomenon are identified. Effectiveness of several interventions (i.e., cash transfer programs, initial capital boost, and livelihood strategies) on poverty and resilience are evaluated.

The last chapter is the *Conclusion.* It summarizes the findings from the previous three chapters and provides answers to the three research questions that are listed above. A discussion on current limitations and future research is also included.

Chapter 2 Methodology

2.1 Overview

Among the many challenges in this thesis, the main ones include (1) capturing and explaining the *patterns* of the coupled human-environment systems in a rural livelihood context with the presence of cash transfer programs, (2) modelling the small farming households and explaining the patterns of livelihoods from household decision making *process*, and (3) understanding and assessing *resilience* as a property of the complex system when facing various external shocks using simulation results. To cope with the complexity of livelihood dynamics with cash transfers, two main approaches are used: empirical analysis and agent-based modelling. This chapter provides a general framework and description of the two main methods used in this thesis (Figure 2-1).

2.2 Identifying the empirical patterns of household livelihoods

The first stream of methods was used to demonstrate the empirical pattern of livelihoods and dependence levels among small farming households. Based on a household survey that was conducted among 634 Caboclo households in Abaetetuba, Brazil, in 2012, it addresses the first research question and is used as the input for modelling and simulation in the next steps. Two main methods used in this step are classification and Multi-Nomial Logistic (MNL) regression.

The first classification is based on the amount of cash transfers that households receive, from which we divide the households into four cohorts with no, low, medium, and high amount of cash transfer support; the second classification is based on the share of cash transfers out of total household income, so that four groups were labelled as not-dependent, low-dependence, medium-dependent, and highly-dependent. The quartile values from the dataset (i.e., the lower quartile, medium, and upper quartile) were chosen as the thresholds for both classifications, as quartile values are commonly used in empirical analysis on rural livelihoods (Carter et al., 2007; Ellis and Allison, 2004; Paxson and Schady, 2007) and other fields (Burnicki et al., 2007; Robinson and Brown, 2009).

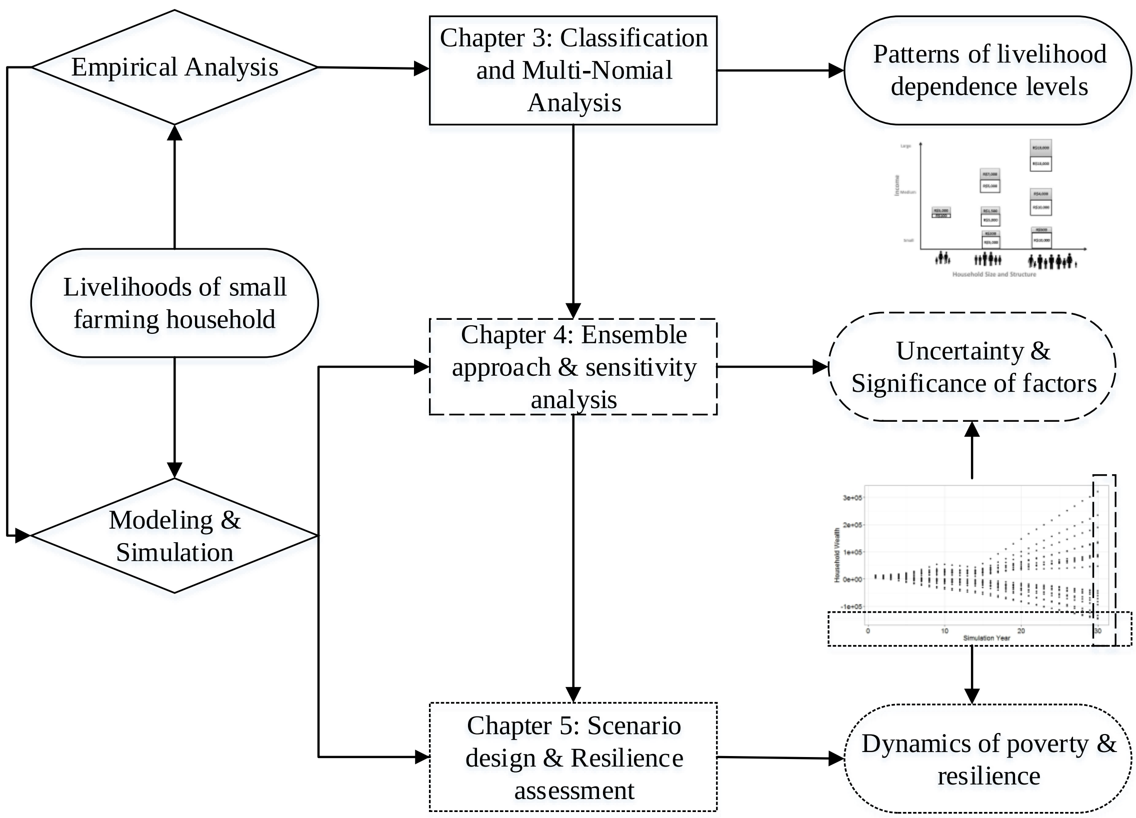

Figure 2-1 General framework of methodology used in the thesis. Two main research approaches are in diamonds, specific methods are in boxes, and core object and results are illustrated using ovals. Sensitivity analysis is applied to one time slot (the end of simulation) while resilience analysis is done to the entire simulation period, which are represented by different dash lines. Chapter 4 uses constant external factors while Chapter 5 simulate dynamic environment.

Based on the results from the classification analysis, statistical tests (e.g., ANOVA) were applied to compare the household characteristics between groups. MNL regression is used to identify the significant household characteristics that are associated with households at different levels of dependence on cash transfers. These tests, together, indicate whether or not a specific household characteristic is statistically different between two groups, while it also shows if this characteristic is significant for households being in a specific dependence level.

2.3 Modelling the process of household behaviors

Given the overall patterns found in the study region in the first step, an agent-based model was constructed to explain how the livelihood behaviors are formed at the household level and to link these behaviors with the patterns identified. The ABM model was developed on the basis of a previous model (Cabrera et al., 2010), but more detailed representations (i.e. cash transfer programs, demographic dynamics, off-farm job probabilities) were added. To cope with the fundamental uncertainties that are associated in the human decision making processes (among many other uncertainties in every modelling process), an ensemble approach, a standard treatment in climate modelling communities, was adopted with the development of the ABM. The ensemble approach is to integrate the results from a variety of models, or from a same model with different components/parameters, which has been used widely in climate models and hydrological models.

Taking the ensemble approach into account, three decision making strategies were implemented in the ABM as ensemble members, which are Max Profit (households optimize economic income), Max Leisure (households maximize the leisure time when subsistence requirement is met), and Subsistence First (households grow domestic crops first and then consider economic return). These three livelihood strategies are stereotypes of different economic and anthropologic theories (Barlett, 1984; Brown et al., 2013; Chayanov, 1966; Colman and Young, 1989; Ellis, 1994; VanWey et al., 2007; Vogt et al., 2016) and commonly used decision making modules in other ABMs (Deadman et al., 2004; Huber et al., 2013; Magliocca et al., 2013; Manson and Evans, 2007; Schreinemachers and Berger, 2011).

The simulation exercise was designed to include two experiments for each of the four major components, eight in total, that influence livelihood dynamics (land type, household capital, labour, and cash transfers). The difference between experiments is that we alter the probability distribution of that variable at initialization while the other variables remain unchanged as the baseline (e.g., for the large capital scenario, we have a higher probability for the capital beyond 5,000 compared to the baseline, while the probability distribution of other factors such as household size and age remains the same as the baseline). Two reasons that these four components are chosen to set the scenarios: (1) they show significance in the MNL analysis in the empirical analysis; (2) the distribution of these factors are easy to manipulate.

Two indicators at the aggregate level (Gini index to measure income inequality and Poverty Gap index for the degree of poverty) and six indicators at the household level (household wealth, annual production income, annual total income, dependence level on cash transfer, production income diversity, and total income diversity[7]) of model outcomes were chosen to reveal the livelihood outcomes for each experiment and among three decision ensembles. To compare the model outcomes and to identify the significant factors in each scenario, we used ANOVA and

[7] The difference between production and total income is the latter includes cash transfer as an income while the former only contains income that households generate from agricultural, agroforestry, and off-farm activities. So are the production diversity and total income diversity.

Tukey's honest significance test (Tukey's HSD) at the aggregate level and the PAWN index, a novel global sensitivity analysis method (Pianosi and Wagener, 2015), at the household level.

The results bring insights into understanding households' decision making processes and to explain the different impacts of cash transfers on livelihood income in accordance with the patterns we found via empirical analysis. Such understanding of the significant differences among outcomes from three decision strategies also inspired us to incorporate the ensemble members in the resilience assessment in Chapter 5, to ensure the system behaviors cover a wide range of possibilities.

2.4 Understanding the resilience of livelihood dynamics

Using the model with decision strategy ensembles constructed in Chapter 4, the resilience of rural livelihoods in face of external shocks was simulated. We selected "development resilience" for its emphasis on both poverty reduction and being resilient for various stressors (Barrett and Constas, 2014), for what poverty and resilience are discussed as separate issues in most literatures. Barrett and Constas (2014, p. 14626) first proposed and defined this concept as "the capacity over time of a person, household or other aggregate unit to avoid poverty in the face of various stressors and in the wake of myriad shocks" to integrate the two bodies of literature in poverty and resilience. Based on this definition, a five-step resilience assessment framework (Resilience Alliance, 2010) was adopted to help us understand the dynamics of livelihood and resilience as a property of a system to external shocks.

The ABM and three ensemble members of our decision module were used to run simulations that were initialized with an empirical distribution, under designed external shock scenarios and cash transfer settings. The drop of açaí price, climatic events that reduce açaí yield, and the shrinking of the job market constitute the single-variable shock scenarios, where combinations of these three can hit the simulations as double-variable shock scenarios, or possibly as a triple-variable shock. In addition to the external shock scenarios, cash transfer programs were also fed into the model with different settings (i.e., there is no cash transfer program, cash transfer is constant through the simulation years, or cash transfer is cancelled during the simulation).

The reason we select these shocks to examine in our model is because of a high probability of them occurring. The boom-bust cycle of the price of a few commodities has been observed periodically on other commodities over the past century, including rubber and sugarcane. The reduction of yield from climate change is also reported from a recent survey that was conducted by us and other studies in the estuary region (Pinho et al., 2014). One of the cash transfer programs that was applied in the estuary (Seguro Defeso, a fishing closure compensation) was cancelled by the federal government abruptly, which makes the cash transfer shock possible in such context. Therefore, the shocks that we are investigating in the model simulation are likely to occur in this region with a high possibility.

Three livelihood states were classified based on the per capita wealth of the household agents: humanitarian emergency zone (HEZ), chronic poverty zone (CPZ), and non-poor zone (NPZ), from where we observe the patterns of being in HEZ and NPZ constantly, suggesting a similar alignment with “basins of attraction” in the resilience theory. The proportions of households in each state are compared between different shock scenarios to evaluate the negative impacts on household livelihoods. Furthermore, Multi-factor analysis (MFA), a type of principal component analysis, is used to identify (1) the constraints for households who are trapped in poverty, (2) the significant resources needed for households to be in the non-poor zone, and (3) factors that make households in between the two basins more vulnerable or more resilient than others. Lastly, intervention approaches including changing livelihood strategies and boosting household wealth at the beginning are also evaluated for their effects on poverty reduction and resilience enhancement.

In summary, this thesis adopts a complete research framework from empirical analysis to modelling, which can capture and model the dynamics of livelihoods in small farming households. The ground truth data from the household survey provides an overall static pattern of livelihood dynamics, which is explored and explained by the outcomes from simulations. In addition, modelling using this empirical calibration can provide us with the flexibility to test various scenarios and interventions.

Chapter 3 Impacts of cash transfer programs on rural livelihoods: a case study in the Brazilian Amazon estuary

3.1 Introduction

Government cash transfer programs have been widely implemented as an antipoverty paradigm in developing countries over the past few decades (Bertrand, 2003; Boone et al., 2013; Manley et al., 2013; Paes-Sousa and Santos, 2009; Sadoulet et al., 2001). On average, most developing countries spend 1 to 2 % of their gross domestic product (GDP) on cash transfer programs, which has become an important income source for many poor households (Grosh et al., 2008, p. 7). The primary objective of these substantial investments is to increase poor and vulnerable households' real income and standards of living through poverty reduction and the improvement of future human capital (e.g., the education and health of children).

The outcomes of cash transfer programs can vary and have unintended consequences. Beneficial outcomes of cash transfer programs include an increase in children's school attendance, health, and nutritional status (Manley et al., 2013; Oliveira et al., 2007); higher capacity of saving and asset investment by having more liquid cash (Gertler et al., 2012); and an increase in household basic income (Sadoulet et al., 2001; Standing, 2008), especially for the extremely poor (Boone et al., 2013). Conversely, negative outcomes observed include: labour reduction or re-allocation (Bertrand, 2003; Brauw et al., 2015), reduction in inter-household transfers (Miranda et al., 2009), and loss of purchasing power due to rises in food prices (Sabates-Wheeler and Devereux, 2010). Despite an ongoing debate about the positive and negative outcomes of cash transfer programs, recent improvements in their design and implementation are believed to be positive initial steps in the battle against poverty (Grosh et al., 2008).

The success of cash transfer programs rests on the allocation of funding to optimize their effectiveness and efficiency. Recent debates regarding implementation focus mainly on conditionality versus unconditionality (Baird et al., 2013; de Janvry and Sadoulet, 2006; Manley et al., 2013; Schubert and Slater, 2006), and “cash” v.s. “food” (Farrington and Slater, 2006; Sabates-Wheeler and Devereux, 2010). However, few have considered the different directions and magnitude of cash transfer impacts and the reasons for such heterogeneity as a key to making the implementation more efficient.

One of the few examples that has addressed the different impacts is the PROCAMPO program in Mexico, which has shown that for every peso given as part of the program to a household, total household income could raise by 1.5 -2.6 pesos (Sadoulet et al., 2001). The effects of the program are not uniform since households with medium-to-large farms, small household size, nonindigenous backgrounds, and at Center and Gulf region have higher multiplier effects (Sadoulet et al., 2001). Furthermore, child nutritional status varies by child sex and age, as well as household income level (Manley et al., 2013). The recognition of the causes and impacts of cash transfer programs’ heterogeneous outcomes can advance cash transfer programs from an “assistant” role to a more dynamic and more comprehensive treatment.

Cash transfers provide an income-generating activity that is used by households to maintain their livelihood, where the livelihood of a household “comprises the capabilities, assets (stores, resources, claims, and access) and activities required for a means of living" (Chambers and Conway 1991, p 6). By focusing on what sustains the livelihood of a household, the livelihood approach (Chambers and Conway, 1991; Development Study Group, 2002) uncovers the constraints and resources driving activity choices and combinations of activities that provide for a living. The livelihood approach is anthropocentric and emphasizes households as human actors who interact with their environment to make a living.

The proportion of a household's total income represented by cash transfers (1) provides an indicator of the level of dependence of the household on the cash transfers and (2) represents how households assemble different livelihood activities (e.g., highly-dependent on forest resources to generate income) to fulfill their subsistence and investment requirements (Babulo et al., 2008; Mamo et al., 2007; Mohammad Abdullah et al., 2016). The choice of "dependence" here does not have a negative indication; it is rather a neutral representation of the percentage. The combination of livelihood activities and the size of cash transfers received by households forms a livelihood strategy that is used to maintain the livelihood and well-being of the houshold. The factors affecting the strategies that can be formed and their application are constrained by livelihood assets (e.g., goods, food, services, money) and capability constraints of the household. Due to the heterogeneous distribution of livelihood assets among households, two households receiving the same cash transfers may adopt different livelihood strategies, resulting in different levels of dependence on the cash transfers.

In addition to cash transfer programs, an important livelihood option for low-income rural farming communities is the participation in off-farm activities. A majority of the rural poor have actively pursued off-farm activities and income from these activities plays an important role in rural livelihoods. For example, more than half of farm households' income in the Mexican *ejido* sector is from off-farm activities (De Janvry and Sadoulet, 2001). Similarly, rural poverty and income inequality would be much higher without non-farm employment in rural China (de

Janvry et al., 2005). In the Brazilian Amazon estuary region, households establish residences in both rural and urban areas to facilitate income generation from off-farm activities (Padoch et al., 2008). Off-farm activities contribute to rural poverty reduction, increased income, and have positive spillover effects on agricultural activities (e.g., allow farmers to invest in productivity-enhancing inputs with cash from non-farm activities when credit is unavailable), which constitute a new approach in rural development and may also affect the efficacy of cash transfer programs. However, the pursuit of off-farm activities may move rural households away from agricultural and agro-forestry activities. This can increase the wealth of these former agricultural households by having a stable wage every month, however, it may also result in a loss of traditional knowledge, or a higher risk of exposure to job market failure, especially when it is only labour-intensive work.

To improve our understanding of the heterogeneous effects of cash transfer programs on rural livelihoods and to identify the livelihood activities and components that cause such patterns, we analyze rural households' dependence level on government cash transfers in the Brazilian Amazon delta region using a livelihood approach. The livelihood approach that we use in the analysis is a way to organize the various components (i.e., people, assets, cash transfers) of rural livelihood in a systematic way (Chambers and Conway, 1991). We give focus to off-farm activities and their relation with the dependence level of the government cash transfers. Achieving this objective will inform policy decisions and provide insight about how to optimize the efficiency and effectiveness of cash transfer programs.

To achieve our objective, the following question is addressed: What are the patterns of different levels of dependence on cash transfers and what factors are significant to these patterns? To answer this question, we follow a conceptual model of the sustainable livelihood as the foundation to understand the components and dynamics of livelihood. We classify sampled households by the absolute amount of cash transfer programs to different cohorts, and later by the share of government cash transfers in total household income to get a dependence pattern. We summarize the main livelihood activities in each dependence level, including off-farm activities and various agricultural and agro-forestry activities, and subsequently calculate a measure of income diversity. Then we use Multi-Nomial Logit regression to evaluate household factors affecting the level of dependence on cash transfers.

The analysis provides insights regarding rural livelihood systems and the influence of cash transfer programs on these systems. Through this research we are able to (1) demonstrate the distribution patterns of value and share of cash transfer programs in total household income, showing the heterogeneous outcomes from cash transfer programs; (2) with the identification of households having different dependence levels on cash transfers, we can inform more efficient intervention and support practices for target groups in this region; (3) design resilience practices. Our research can be used as a basis to estimate the potential livelihood changes under different cash transfer policies and subsequent changes of their vulnerability to socio-economic and environment stressors.

3.2 Method

3.2.1 Caboclos, the environment, and cash transfer programs

Studies of livelihoods are given additional meaning when they are interpreted within their broad situational context (Angelsen et al., 2011, p. 71). Our study area is in the Amazon estuary region, which is located in a network of channels that runs to the Atlantic Ocean (Figure 3-1). Specifically, this study focuses on the Abaetetuba municipality in the State of Pará, and the people there known as *Caboclos*. With an area of 1,610 sq km and 147, 846 residents in 2012, Abaetetuba is located at the mouth of the Rio Maratauíra and is connected to the nearby city of Belém by both river and road networks. Abaetetuba was chosen as the municipality to survey due to its proximity to the urban center of Belém, which has easy access to markets and the presence of *Caboclos* people. The small farming households who have occupied the delta region for centuries with a variety of livelihood activities that include shifting cultivation, palm fruit/wood/oil extraction, and fishing and shrimping; among which, açaí is the most significant product (Figure 3-2 and Figure 3-3).

The Amazon delta region, where Abaetetuba is situated, can be subdivided into two areas defined by the coverage of tidal floods: high soil quality floodplains (várzea) and lower soil quality uplands (terra firme). Each area has its own vegetation and soils, which are the primary factors affecting the heterogeneous development of livelihood activities (Zarin et al., 2001). This heterogeneity in environmental conditions also restricts households' choice of certain livelihood activities. For instance, growing açaí is favored in várzea, whereas annual crops are often grown in terra firme (Murrieta et al., 1999).

Açaí, the fruit of a native palm tree (*Euterpe oleracea*) has been a subsistence food for the *Caboclos* for centuries. Since the 1970s, the demand for açai has increased exponentially and it remains as a key source of income for *Caboclos* (Brondizio, 2004). Abaetetuba is the second largest producer of açai in Pará, with over 90 % of households in the region engaged in some level of açaí production (Brondízio, 2008). Remote sensing data show that land cover type PALM (dominated by açai) increased by 157 % from 1976 to 1991, 69 % of which was converted from VARZ (relatively diverse várzea forest) in the tidal floodplain in Amapá (Zarin et al., 2001). Consequently, agricultural production of other traditional staple foods, such as manioc flour and rice, has decreased.

Within this region and more broadly across the Brazilian Amaon, several cash transfer programs have been applied (Table 3-1): (1) *Bolsa Familia* targets poor families with children and provides a monthly allowance based on the number of school-aged children attending school. Thirty-seven percent of households receive *Bolsa Familia* in Abaetetuba. (2) *Aposentadoria* provides a minimum wage pension for males older than 60 and females older than 55. The average pension is almost seven times the average agricultural production income according to our survey data. (3) *Seguro Defeso* is an insurance benefit established in November 2003 that is paid to fishermen for voluntarily giving up fishing for certain species during a four month period every year. One third of the farmers in the várzea areas receive this payment[8].

[8] However, this program was cancelled by the Brazilian Federal government in Dec 2015.

Figure 3-1 Study area

Figure 3-2 Caboclos and their house, boat, and garden. (a) Caboclos live in wooden house that is built on the floodplain. The water level fluctuates hourly and the high tides sometimes reach the floor of their house. The extreme high tides are called lancentes, and are observed with an increasing frequency and duration over the past three decades. Caboclos also manage the forest around their house intensively. The house garden usually contains acai trees and some other fruit trees (e.g., lemon, papaya, banana). (b) Caboclos travel in their boats. The traditional boat is a canoe, like the one in the photo. Nowadays most families have a boat with a motor which significantly increases the travelling capacity. (c) Traditionally Caboclos rest and sleep in hammock, which consumes no space at all. Nowadays, some family can afford big and nice house with a normal bed inside. All photos were taken by author during fieldwork.

Figure 3-3 Major livelihood activities that Caboclos conduct. (a) Farmers sell acai berry in a local market. Acai is sold in a basket called saco, one saco is approximately 60kg. (b) A Caboclo lady puts the traditional shrimp trap (matapi) in water. When the tide is gone, they retrieve matapi with shrimp trapped inside. Most times the shrimp captured is for domestic consumption; however, it is becoming popular among urban consumers. (c) A girl showing the agricultural plot on upland. Caboclos can grow annual crops such as rice, manioc, potatoes on upland. Usually it is still slash and burn land use strategy. However, the necessity of managing an upland plot is reduced by the revenue from selling acai: Caboclos can afford these food items from the market. Moreover, the knowledge of how to manage annual crop in a transition area between upland and floodplain is disappearing between generations, since young people are not interested in labour-intensive farm work anymore. (d) Caboclos also rely on fishing to fulfill their food demand. Shrimp and fish are the main protein source in Caboclo’s diet. Depending on the capacity of the

household, they can go fishing in the nearby water area, or travel far away to the ocean for a fishing trip.

Table 3-1 Main Cash Transfer programs

	Pension
Benefit (per month per person)	R$ 545 (~ $275 USD in 2012)
Age requirement	female > 55, male > 60
Other requirement	live in rural dwelling
Coverage	90 % of elderly in rural areas receive this pension, almost 7.5 million beneficiaries in 2008 (Barrientos et al., 2010).
Cost	around 1.5 % of annual GDP in 2008 (Barrientos et al., 2010)
Effective date	It was first weakly financed in 1936 to provide medical services in rural area and is upgraded to a pension fund in 1963. With a few significant changes over the year (e.g., the age is reduced from 70 to 65, and then 60, the pension is raised from half the minimum wage to 100 % of the wage), now this rural program is providing a wide and significant coverage to rural households with the latest adaptation in 2015[9] (Lloyd-sherlock and Barrientos, n.d.).
Impacts	reduce vulnerability of households containing elders (Barrientos et al., 2003); reduce the likelihood for these households experiencing poverty, compared to those who do not have elders in the house (Barrientos et al., 2003)
	Bolsa Familia Program
Short-term goal	ensure youth school attendance and health, and reduce direct poverty
Long-term goal	increase human capital among the poor to reduce inequality and poverty across the society
Benefit (per month per person)	R$ 32 (~ $13 USD), might change based on the number of children in one household
Age requirement	< 18
Income condition	household per capital income < R$ 140 (~$56 USD)
Coverage	nearly 14 million households (around ¼ of the population)
Cost	0.5 % of GDP per year
Effective date	November, 2003. It is an integration of a few previous programs that targeting on education, nutrition, and health of children in poor families.
Impacts	increase children's school attendance and performance in poor households, especially on girls (de Brauw et al.,

[9] http://www.brasil.gov.br/economia-e-emprego/2015/11/aposentadoria-especial-para-trabalhador-rural-esta-assegurada-com-novas-regras

	2014); contribute to poverty alleviation (Hall, 2006).
	Seguro Defeso Program
Short-term goal	offers support for artisanal fishermen during a certain period of the year that they withdraw their income from fishing
Long-term goal	enables protection of the fishing and other aquatic species and ecosystems
Benefit (per month per person)	minim wage R$ 545 per person, up to four months
Condition	member of the local artisanal fishing association
Coverage	647,700 beneficiaries in the year of 2011
Cost	1892.54 million RS in 2012 (<0.05 % GDP)
Effective date	started in 1992
Impacts	lacking of environment impact assessment; the coverage of beneficiaries leaks to non-fishermen

3.2.2 Conceptual model of livelihood

To guide and constrain our analysis of livelihoods we use the “sustainable rural livelihood” (SRL) conceptual model (Figure 3-4, developed by Chambers and Conway, 1991). The SRL provides advantages over the others, such as the Sustainable Livelihoods Framework (Development Study Group, 2002), which include: (1) it highlights the internal components of livelihood and their connections; (2) it simplifies the complexity of livelihood dynamics to a relatively static description, allowing us to identify the significance of current cash transfers relative to total income, and (3) the livelihood capabilities contains the livelihood strategies, which emphasizes households as human actors.

In the SRL model, a livelihood refers to people’s means of constructing basic necessities through a set of activities and adapting to the environment using the natural and social resources in their possession. It is no longer merely the outcome from conducting agricultural activities. On the contrary, a livelihood comprises people, their capacities, and finally their strategies of living. The purpose of a livelihood is to construct a living as well as to survive in a crisis, which is often reached by increasing the livelihood capacity that allows people to conduct more favorable activities. The main components that determine the livings of households are people, tangible assets, and intangible assets (Figure 3-4). Tangible assets are the resources and stores that are commanded by a household, including food stocks, cash savings, land, water, trees, livestock, and farm equipment. Intangible assets are claims, which are often made on relatives and communities at times of shock or stress, and access, which is the opportunity to use a resource or service. We replaced the claims and access component in this model with a cash transfer component, because our focus is not on responses to shock or stress and cash transfer is a type of government service. Together tangible and intangible assets provide the material and social means for people to construct a living.

In the SRL model, people in the households provide more than simple labour, instead, they are actors with the capacity to conduct livelihood activities through their skills, knowledge, and creativity. The capacity of people in the households is acquired as indigenous knowledge, which is crucial for farmers to live in a complex environment, or more formally through education that increases the expertise of the workforce for non-farm activities. The livelihood strategy chosen by a household is a function of household's capabilities and assets, as well as the consequences of their previous livelihood strategies.

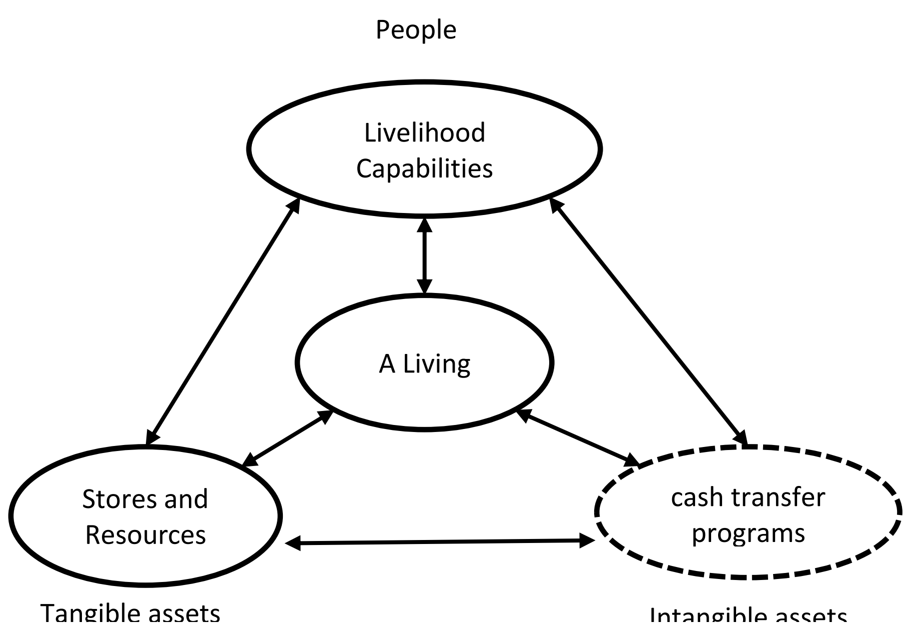

Figure 3-4 Conceptual model of household livelihood: components and connections in a livelihood, Adapted from (Chambers & Conway, 1991)

3.2.3 Data collection

A survey of 634 households was carried out in 50 communities within the Abaetetuba municipality in Pará, Brazil, in 2012. Of the 50 communities, 43 communities with 407 households on terra firme and seven communities with 228 households in the várzea were surveyed following a stratified random sampling strategy (i.e., upland and floodplain are the two groups). Households in each community were chosen randomly. Comprehensive information on household demographics, government cash transfers, asset ownership, and the household's income from agriculture, fishing, or other activities was collected. Surveyors were familiar with the study area, spoke the local language, distributed the questionnaire, and coded the data in collaboration with the authors. Subsequent statistical analysis was conducted using the R statistical package (Ripley and Venables, 2016).

3.2.4 Methods

Data from the household survey was analysed in four steps (Figure 3-5). In the first and second step, we classified the sampled households into different groups and cohorts based on the percentage of cash transfers out of their total household income and the amount of cash transfers; in the third step, we described the combinations of household livelihood activities in each group; in the last step, we identified the factors influencing the dependence level of households. Using the absolute value and share of cash transfers in the total income, 634 sample households were cross categorized.

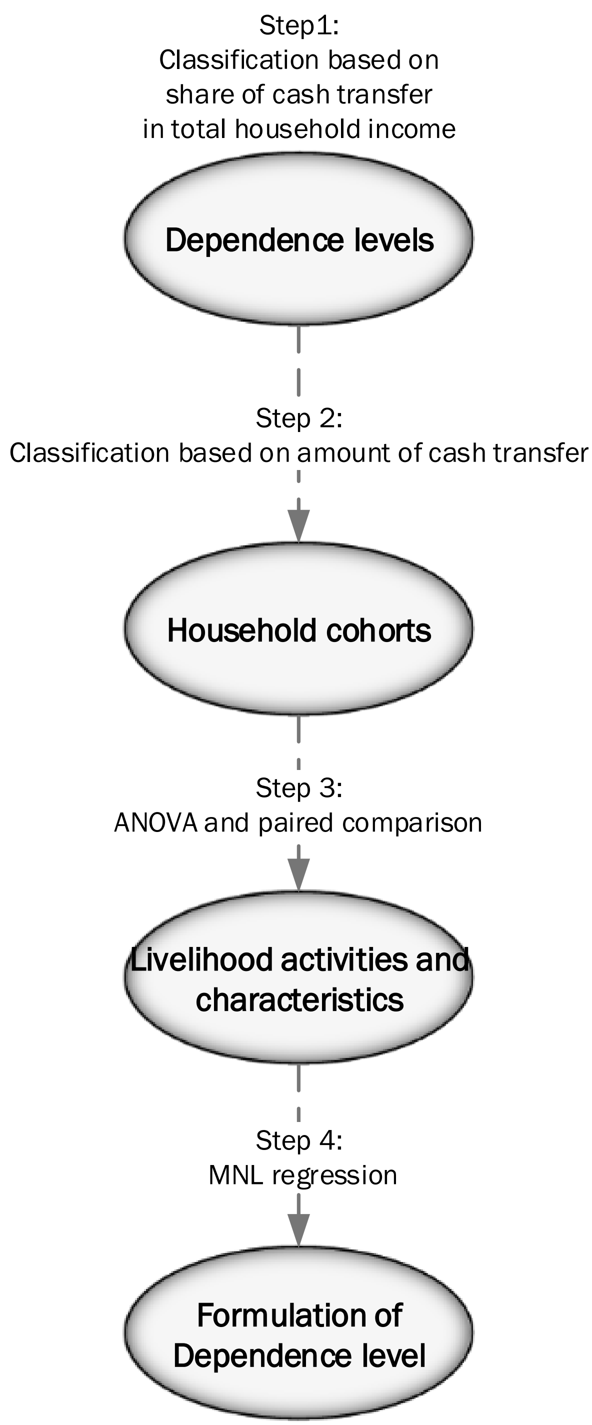

Figure 3-5 Four steps to classify sampled households and identify significant activities and factors

In *Step 1*, groups were classified based on the percent of total income represented by cash transfers. Quartiles were chosen as thresholds instead of other cluster analysis approaches[10], to classify households and to simplify the analysis; hence four distinct dependence levels were obtained (DLs) as: (1) DL1 "not-dependent" on cash transfer income; (2) DL2 "less-dependent" on cash transfer income; (3) DL3 "moderately-dependent" on cash transfer income; (4) DL4 "highly-dependent" on cash transfer income.

In *Step 2*, cohorts were identified based on the absolute amount of cash transfer (CTA, as CTA is short for cash transfer amount). Unlike other livelihood incomes, cash transfer is a passive income that households receive without much labor or capital investment. Due to the wide range in cash transfer amount that households receive, the degree of dependency is not simply determined by household livelihood strategies. Households that receive a high amount of cash transfer can be passively dependent on this income when it becomes too difficult for them to generate more livelihood incomes to match the cash transfer. Cross categorization enables us to identify livelihood strategies that households select "actively" in relation to the cash transfers that they receive "passively". To keep consistent with the classification of dependence levels, we also use lower quartile, medium, and upper quartile of amount of cash transfers to classify four cohorts[11] CTA: (1) CTA 1 "no" cash transfer income[12]; (2) CTA 2 "low" cash transfer income; (3) CTA3 "moderate" cash transfer income; (4) CTA4 "high" cash transfer income. Cohorts are then cross-categorised within livelihood strategy groups (DLs).

[10] K-means cluster (four clusters) shows similar results: DL1 has 169 households, DL2 has 95, DL3 has 229, and DL4 has 141.
[11] To distinguish from group of households using the same livelihood strategy (DL), we use the concept "cohort" to describe a group of households that receive similar size of cash transfer (CTA).
[12] We use "no" cash transfer to describe the first quantile of CTA group for the simplicity and recognition of difference to other groups.

In *Step* 3, ANOVA and paired comparison were used to compare the means of income and household characteristics from the three components in the livelihood conceptual model. ANOVA provides a statistical test of whether or not the means of more than three groups are equal, and paired comparison provides the results between every pair of groups. The null hypothesis is that the difference in mean value of group A and the mean value of group B is zero:

$$H_0 : \mu_A - \mu_B = \Delta 0 \qquad \text{Equation 3-1}$$

If ANOVA and paired comparison reject the null hypothesis, it indicates the group means and their associated variation of several groups are not equal.

Income diversity was also calculated using the Shannon-Wiener index. The Shannon-Wiener index, a popular index to calculate diversity in the ecological literature (Börner et al., 2007), is often adopted to analyze land use or rural livelihoods (Hanazaki et al., 2012); it is most often calculated in the following format:

Equation 3-2

$$Div = -\sum_{i=1}^{n} per_i \ln(per_i)$$

Where per_i is the proportion of the total income represented by the *i*-th activity among all livelihood income. This value quantifies both the abundance of each income source and the share of it. Typical values are generally between 1.5 and 3.5 in most ecological studies. However, in our case, we have limited activities up to four, which makes this number rather a relative comparison between different households.

Logistic regression is often used in land use sciences and econometric studies to identify and determine the relevant weights of independent drivers affecting a dependent variable of interest (An et al., 2005; Babulo et al., 2008; Verburg et al., 2002). In *Step 4*, we used multi-nomial logistic (MNL) regression to the effects of household characteristics on the relative likelihood of being in a specific dependence level compared to the highly-dependent level that is set as base category in MNL analysis. The reason we use multinomial instead of logistic is because there are multiple dependent variables (four groups with different dependence levels on cash transfers). The model is written as following:

$$prop_{j,j\neq 1} = \frac{e^{\beta X}}{1+\sum_{j=2}^{J} e^{\beta X}} \textbf{ and } prop_1 = \frac{1}{1+\sum_{j=1}^{J} e^{\beta X}} \qquad \text{Equation 3-3}$$

Where *prop* is the probability of being in a specific dependence level, *j*=1 is the base category among *J* alternatives. *X* is the vector of variables in the three components of livelihood conceptual model; *β* is the vector of corresponding coefficients. A household is more likely to be associated in the highest likelihood dependence group. This analysis can identify the significant characteristics for households in each dependence group. The coefficients from the MNL can be used directly to assist a household's move to a more favorable position (e.g., moving from highly-dependent to less-dependent on cash transfers). Most households in CTA1 are in the same not-dependent level (DL1), hence we exclude analysis of household dependence levels in CTA1 and MNL is only applied in CTA23, and CTA4 since there is only one group in MNL analysis The characteristics of households in DL1 will be later analyzed by the paired comparison.

3.2.5 Terms and assumptions

Livelihood activities: livelihood activities are means that households can utilize to produce goods and other outcomes to maintain a living. Seven livelihood activities were identified and their associated income was calculated: (1) government cash transfers (including the three main types: *Aposentadoria* (pension), *Bolsa Familia,* and *Seguro Defeso,* and several other benefits including: *Bolsa Verde*, *Beneficiacio Saúde*, *Bolsa Jovem*); (2) off-farm employment; (3) growing and selling açaí; (4) aquatic (income from fishing and shrimping); (5) agriculture, income from farming crops such as manioc, rice, and beans; (6) livestock; and (7) miscellaneous (other non-agricultural but on-farm activities generating cash, such as handicrafts, family industry, farinha production and açaí juice).

Livelihood components (Table 3-2): Livelihood components include the capacity of households and their assets that one can utilize to produce a living. Ten factors in livelihood capacity, tangible assets, and cash transfer programs from the conceptual model (Figure 3-4) are selected from the questionnaire for the subsequent analysis.

Table 3-2 Name and definition of the variables

Asset	Name of variable	Definition of the variable
Livelihood capacity	S_HHD	The total number of people in household, including husband, wife, children, children under 12 years old, and relatives
	ML_HHD	Total number of male labour in household
	A_HUS	Age of husband in household
	E_HUS	Education of husband in household
	AE_M	Average education year of male house members
	AE_F	Average education year of female house members
	N_C	Number of children who are younger than 12
Tangible assets	MOB	The boat capital in household, boats are assigned different values based on the distance they can operate and normally use for
	LT	The type of household's land, várzea or terra firme, 1= terra firme, 2= várzea
	LS	The size of the land that house owns (in sq m)

Assumptions: (1) The gross value of each agricultural and agroforestry income is used to simplify the uncertainty that caused by incorrect memory and small fluctuation of price: Households barely keep track of their subsistence consumption and the amount sold to the market, therefore we estimated the total annual production from agricultural and agroforestry sectors for raw income without distinguishing the subsistence and market amount. (2) Price is set universally and seasonally: although households may sell products at different prices, considering the relatively small geographical range, we use a universal price for each product. The price is estimated based on the response from the survey. The seasonal variation is implemented by using different seasonal prices since the price varies between on and off seasons. (3) The flows of cash and food between households are not counted: household size is calculated only using people who live in the house; remittances from relatives and off-site family members are not counted since it is not captured in the survey.

3.3 Results

3.3.1 Description of cash transfers and dependence patterns

Using the absolute value and share of cash transfer in the total income, 634 sample households were cross categorized. Cross categorization enables us to identify livelihood strategies that households select "actively" in relation to the cash transfers that they receive "passively".

3.3.1.1 Classification and description of households with different levels of dependence

The distribution of dependencies on cash transfer is shown (Figure **3-6**). The green vertical lines indicate the lower quartile, medium, and upper quartile. Hence we use four distinct dependence levels (DLs). The peak values are at no dependence (0.0) and total dependence (1.0).

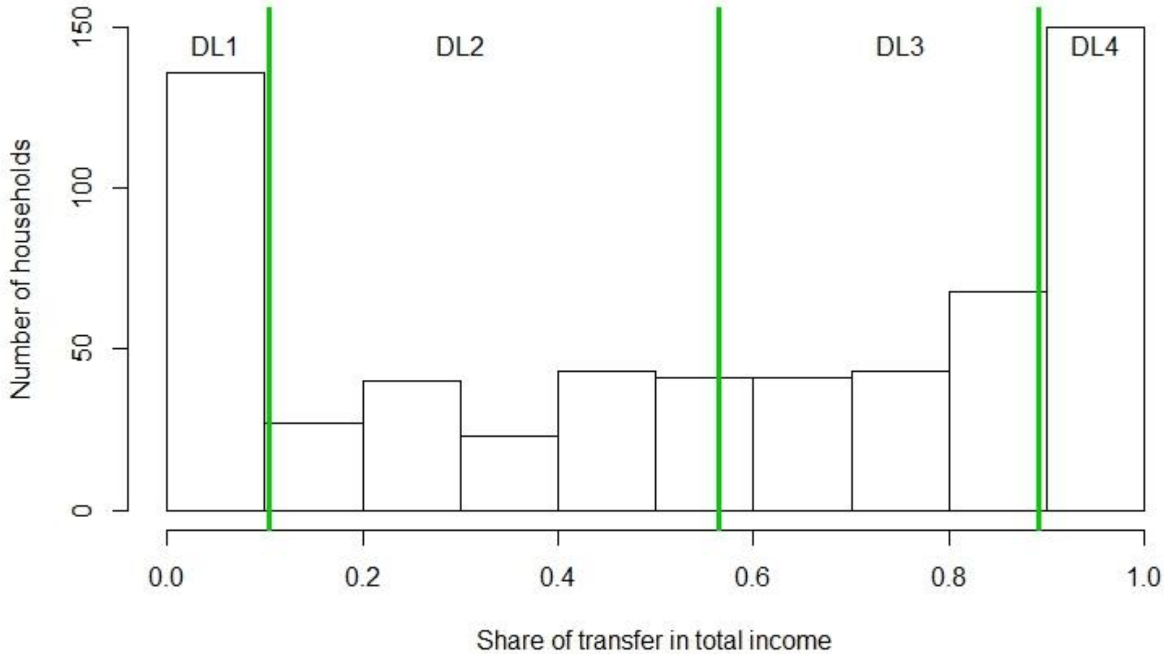

Figure 3-6 Distribution of the dependency on transfer (share of cash transfer to total income). The x-axis is the percentage of cash transfer in total income and the y-axis represents the number of households. Green vertical lines are the thresholds where quartiles are classified.

The overall average share of cash transfers in total household income is 53.56 %, with a standard deviation of 37.3 %. The first quartile, DL1, represents households that are not-dependent on cash transfers. The average proportion of cash transfers for this group is only 2%, and households in this group employ a salary dominant strategy, with mixed agricultural and açaí production income as well. The second quartile, DL2, has households that have a low dependency on cash transfers. Households in this group have an average cash transfer percentage of 36 %, with the remaining two thirds of their annual income generated from livelihood activities. The third quartile, DL3, represents households that are moderately-dependent on cash transfer (an average of 73.9 %) since they generate some household income from all activities.

While the fourth quartile, DL4, represents households who have a high level of dependence on cash transfer. The average percentage of cash transfers in their total income is 96.4 %.

Table 3-3 Summary statistics of dependency, amount of cash transfer and total income (in R$)

	Dependency		**Cash Transfer Amount**				**Total Income**			
	Range	Mean	Mean	SD	Min	Max	Mean	SD	Min	Max
DL1	<=10.5%	1.7%	99	358	0	2560	5649	7391	0	50200
DL2	(10.5-56.5%]	35.8%	4078	3475	384	19620	11394	6964	1384	39680
DL3	(56.5-89.1%]	73.9%	6567	4608	540	21600	8887	6441	700	37200
DL4	(89.1-100%]	96.4%	7816	4567	720	22070	8108	4761	720	23660

Total mean income has an increasing trend from not-dependent group to highly-dependent group, except the highest total income is in DL2, less-dependent group (Table 3-3). The variation of total income is decreasing from not-dependent to highly-dependent groups. There is also an increasing trend in the amount of cash transfer from not-dependent to highly-dependent groups, which is from average R$ 99 in not-dependent group to average R$ 7816 in the highly-dependent group. This almost 80 times difference in the amount of cash transfer is likely to affect the dependence level, which should not be neglected.

3.3.1.2 Classification and description of cohorts of cash transfer amount

We classified households into four different cohorts using the amount of cash transfer, so that the comparison of household characteristics between different dependence levels is conducted within the same cohort, the summary statistics of which are presented (Table **3-4**). As we mentioned above, when there is a large amount of cash transfer, it is more likely for households to become “dependent”, because households need to make a large income to become “less-dependent”. Thus there are no households in “not-dependence” when they receive moderate or high cash transfer (CTA3DL1 or CTA4DL1). Likewise, there are only three and five households that are moderate or highly-dependent on cash transfer when they receive "no" cash transfer (CTA1DL3 or CTA1DL4).

Table 3-4 Cash transfer amount and number of household in each category

	Cash transfer (R$)					Number of households				
	Range	DL1	DL2	DL3	DL4		DL1	DL2	DL3	DL4
CTA1	<=840	**25**	788	740	816	CTA1	**151**	11	3	5
CTA2	(840, 3216]	1487	**1963**	2172	1977	CTA2	8	**81**	49	24
CTA3	(3216, 6990]		5357	**5427**	5711	CTA3	0	42	**46**	55
CTA4	(6990, 22040]		10483	11321	**11695**	CTA4	0	24	60	**75**

3.3.2 Heterogeneity in household livelihood activities

Households are classified into 14 groups by the amount of cash transfer they receive and their dependency on it. To simplify the analysis, we exclude four exceptional groups that have few households, which are CTA1DL2, CTA1DL3, CTA1DL4, and CTA2DL1, and collectively account for less than 4.5 % of the sample. In this section, the heterogeneities in livelihood activities are presented.

3.3.2.1 Major livelihood income among different groups

Three primary livelihood activities in all household groups are shown (Figure 3-7), to represent the major activities that appear in the different dependence on cash transfer. We only examine the representative activities because: (1) although *Caboclos* engage in a large number of activities, there are few significant ones (an activity is considered "significant" if its share in income is larger than 5 % or it is the top three activities in the share); (2) the pattern is clear with the most significant activities.

1) Income from off-farm salary stands out in all not-dependent and less-dependent groups, especially in CTA1DL1 with a highest share of 67.3 %, and in households at CTA2DL2 and CTA3DL2 with a share more than 40 %. Non-farm income is also one significant income for CTA4DL3, with an average share of 6.6 %. The two highly-dependent groups (CTA3DL4 and CTA4DL4), and the two moderately-dependent groups (CTA2DL3 and CTA3DLDL3) don't have any salary income.
2) Agriculture is the next most prevalent livelihood activity that generates income, including growing manioc, rice, and beans. Although income from agriculture is not as significant as salary, households in almost every group have some level of agricultural activity. Overall, agriculture is important in the low cash transfer cohort, regardless of what dependence group a household belongs to (all CTA2 groups). It is also an important activity in moderate and highly-dependent groups in moderate cash transfer cohort (CTA3DL3 and CTA3DL4), and plays a crucial role in CTA4DL4. The range of its share in these groups is from 2 % to 13 %. Households in not-dependent group also have agriculture as one of their significant livelihood activities, with a share of 5.5 %. Opposite to salary, households in every highly dependent class also participate in agriculture activities, and agriculture is one of their top 3 income sources, although the share of agriculture is less than 1 %. However, agriculture is not significant in CTA4 groups, except CTA4DL4. The reason might be that there is less available labour input for agriculture activities.
3) Açaí is a major income source among households in cohort CTA2, CTA3, and CTA4. The share of açaí is above 5 % in most cohorts (except CTA3DL4 at 0.7 %). Only in

CTA1DL1, which is the no cash transfer and not-dependent cohort, açaí is not in the top three income source but still has a share of 4.3%.

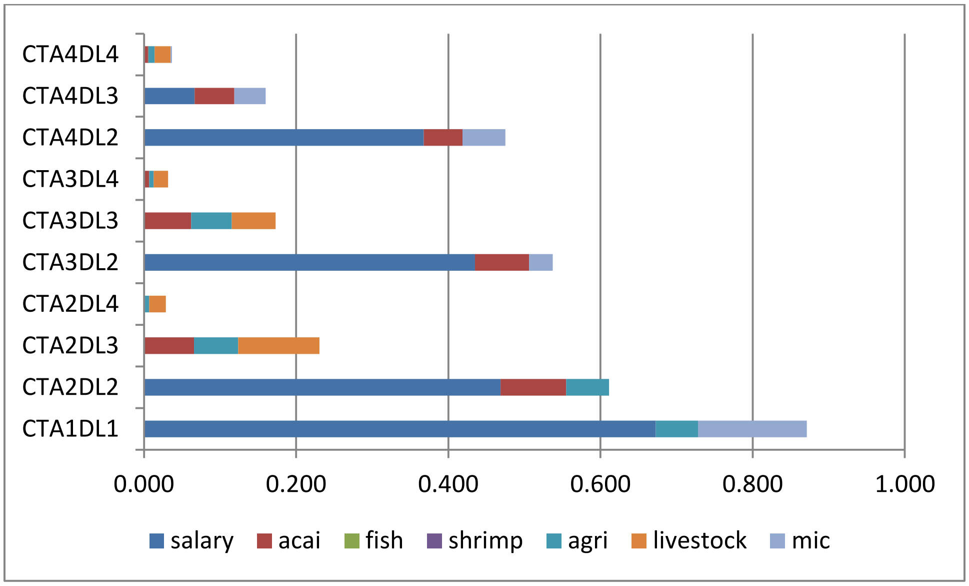

Figure 3-7 Top 3 livelihood incomes in household cohorts. Note: the percentage in this figure is the livelihood income (exclude cash transfer); only the highest three income are shown. Income from livestock exists in all cohorts and is significant in most of the moderately and highly-dependent households; miscellaneous income is not a significant income for households in moderately and highly dependent groups, but is a significant source of income for less-dependent households; fishing and shrimping are rarely significant in most groups.

Overall, even with the difference in the absolute amount of cash transfer that households receive, it is clear that households which are less dependent on cash transfers pursue a livelihood strategy that is focused mainly on non-farm activities (including salary and miscellaneous activities). The moderately-dependent households gain a mixed income from açaí, agriculture, and livestock activities. The highly-dependent households get their income from mixed agriculture and livestock activities. Having non-farm income is a common feature among households who are less-dependent on cash transfer, which may suggest a connection between off-farm employment and ample livelihoods. Therefore, instead of only offering a transfer as "food at the end of some dusty road", being able to sustain an economic environment that provides prosperous opportunities for substantial work could be an alternative option for rural poverty reduction (Standing, 2008).

3.3.2.2 Heterogeneity in livelihood diversity among groups

We use livelihood diversity to represent the abundance and evenness of livelihood activities. Livelihood diversity is calculated using the income of each livelihood activity by using the Shannon-Wiener Diversity Index (Equation 3-2). The highest diversity, 0.568, is among households who receive a moderate amount of cash transfer and are moderately-dependent on it (CTA3DL3); meanwhile, the lowest diversity, 0.045, is in households who have low cash transfer but are highly-dependent on it (CTA2DL4). In general, except for the no cash transfer group (CTA1), the average income diversity decreases with the increasing amount of cash transfer, which drops from 0.412 (CTA2) to 0.357 (CTA4). However, among dependent groups, the average income diversity first increases to its highest at DL3 and drops to its lowest at DL4 the most dependent group. The trend of income diversity from less or moderately-dependent households is the outcome of applying diversified livelihood activities.

3.3.3 Household characteristics

In this section, we compared the livelihood components between different groups using ANOVA and identify the critical ones that determine households' dependence level using MNL analysis, so that cash transfer programs can be effectively utilized and vulnerable households can be identified.

Table 3-5 Livelihood diversity among groups of different amounts and dependence of cash transfer

	diversity of livelihood activities					
	DL1	DL2	DL3	DL4	Mean	SD
CTA1	**0.244**				**0.244**	0.348
CTA2		**0.462**	0.479	0.045	**0.412**	0.394
CTA3		0.488	**0.568**	0.129	**0.376**	0.390
CTA4		0.440	0.550	**0.176**	**0.357**	0.266
Mean	**0.244**	**0.470**	**0.527**	**0.134**	**0.348**	
SD	0.341	0.400	0.409	0.382		

Note: number in bold indicates the highest diversity among the same DL category.

3.3.3.1 Heterogeneity of household characteristics between cohorts that receive different amounts of cash transfer

This section demonstrates the difference among household characteristics in cohorts with different amounts of cash transfer (CTA) (Table 3-6, only the characteristics with a low correlation are chosen).

Households in CTA4 are the largest and oldest among the four cohorts, with an average household size of 6.33 and an average husband age of 55. The household heads are the least educated, with an average schooling year of 3.39 which is 1.34 years less than the overall mean. But these households have the largest land holding (with an average size of 21,958 sq m, almost double the average size in the total sample). Cohort CTA1 (no cash transfer cohort) has the smallest household size (4) among the four cohorts and the youngest husband with an average age of 36.

Table 3-6 Summary statistics of household livelihood characteristics (by cash transfer cohorts CTA) (refer to Table 3-2 for variable names and definitions)

	Size of household (5.04)				Number of children (1.02)				Age of husband (43.14)			
	Mean	CTA2	CTA3	CTA4	Mean	CTA2	CTA3	CTA4	Mean	CTA2	CTA3	CTA4
CTA1	3.96	**	**	**	0.86	**			36.29	**	**	**
CTA2	5.01			**	1.18			**	38.43			**
CTA3	4.74			**	1.05				43.00			**
CTA4	6.33				1.06				54.85			
	Average female education level (3.69)				**Husband education (4.73)**							
	Mean	CTA2	CTA3	CTA4	Mean	CTA2	CTA3	CTA4				
CTA1	2.67	**		**	5.84	0.07	**	**				
CTA2	3.85			**	5.09			**				
CTA3	3.19			**	4.40			**				
CTA4	4.87				3.39							
	Boat capacity (20.16)				**Land size (12215)**							
	Mean	CTA2	CTA3	CTA4	Mean	CTA2	CTA3	CTA4				
CTA1	8.31	**	**	**	7880			**				
CTA2	23.77				9004			**				
CTA3	27.2				9274			**				
CTA4	20.6				21958							

Notes: (1) H_0=null hypothesis that the factors in different cohorts have the same value; H_a= the alternative hypothesis that households who receive different cash transfer have different characteristics. If P-value is larger than 0.05, accept null hypothesis, meaning the factor in two cohorts has the same value; otherwise reject null hypothesis, meaning the factor in two cohorts is different. (2) The correlations between paired variables are weaker than 0.5. (3) Asterisks represent significant difference between two groups

In general, households who receive higher amounts of cash transfer are composed of larger and older families in the estuary, where the household head tends to have less education. This result also proves the intention of the cash transfer programs: aid elders and young children in the family. The four cohorts are significantly different from each other in most cases, except between the low cash transfer cohort (CTA2) and medium cash transfer cohort (CTA3). All variables show no significant difference between the two cohorts, which appears that the two cohorts are similar in household characteristics (in Table 3-6). Therefore, we combine these two cohorts in MNL analysis, to ensure a relatively bigger sample size for logistic regression with a simpler classification.

3.3.3.2 Significant household characteristics that determine its dependence level

The respective coefficients of each explanatory variable measure the log likelihood of one being in a specific dependence level, according to MNL analysis, comparing with the highly-dependence level since we are interested at how to not be highly-dependent. One finding from the ANOVA analysis is that most factors between different dependence levels (DL groups) are not significantly different from each other, except for husband education in both CTA23 and CTA4 cohorts and amount of cash transfer in CTA23 cohort.

However, most factors affect the likelihood of a household being in a specific dependence level over highly-dependent level. In CTA23, the increase in husband education, land size, as well as having access to várzea respectively will significantly increase a household’s likelihood of being in the less-dependent and moderately-dependent level over the highly-dependent category; while the increase of number of children and amount of cash transfer will decrease the likelihood of a household being less or moderately-dependent compared to the likelihood of being highly-dependent. The change of household size and husband age only has significant impact on the likelihood of a household being in less-dependent over highly-dependent, but has no significant impact on the likelihood of being moderately dependent.

In the high cash transfer (CTA4) cohort, each increment of husband education, husband age, and average female education will significantly increase the likelihood of a household being in less or moderately-dependent group oppose to being in the highly dependent group (e.g.., if husband education increases one year, a household is more likely to be in less-dependent with a log likelihood of 0.470 compared to being in highly-dependent level). The increase of household size and the cash transfer amount a household receives, however, is more likely to decrease the household's likelihood of being in the less or moderately-dependent level compared to the high-dependent level.

It is worth noting that often the same factor that drives the likelihood for a dependence group in a certain direction will drive other dependence groups in that same direction (e.g., the size of household in CTA23 has positive impacts on the likelihood of both the less-dependent and moderately-dependent level, and the husband's age has negative impacts on both less-dependent and moderately-dependent levels) when it is in the same cohort. However, the same factor showing a positive impact on the likelihood in CTA23 may have negative impact in CTA4 (e.g., the size of household affects the likelihood of a household being in less and moderately dependent level negatively when it is in moderate cash transfer cohort, but it decreases the same likelihood in high cash transfer CTA4 cohort). It again shows the necessity to classify not only dependence levels, but also the amount of cash transfer, due to the different impacts from factors on dependence level between two cohorts.

Table 3-7 Multinomial Logit regression results

cash transfer cohort	CTA23 (79)					CTA4 (75)				
dependence level	ANOVA	DL2 (less dependent)		DL3 (moderately dependent)		ANOVA	DL2 (less dependent)		D3 (moderately dependent)	
hhd number		123		95			24		60	
		coef	p	coef	p		coef	p	coef	p
(Intercept)		10.503	**	4.155	**		11.819	**	4.354	**
S_HHD		0.054	**	0.048			-0.020	**	-0.134	**
N_C		-0.049	**	-0.053	**		0.522	**	-0.059	**
E_HUS	*	0.180	**	0.020		*	0.470	**	0.286	**
AE_F		0.027		-0.046			0.159	**	0.035	**
A_HUS		-0.033	**	-0.014			0.052	**	0.018	**
factor(LT)		0.164	**	1.098	**		-1.472	**	-1.054	**
LS		0.000	**	0.000			0.000	**	0.000	
MOB		0.004		-0.002			0.006		0.016	**
log size of cash transfer	**	-1.260	**	-0.450	**		-2.070	**	-0.595	**

Note: Base category is DL4 in each absolute amount cohort. Refer to Table for variable names and definitions. Significance: <=0 .01' **', <= 0.05'*'

In general, the likelihood for households to be in a specific dependence level is based on the size of cash transfer, human capital, and assets. Husband education is consistently and significantly able to distinguish the dependence level: it is a priori expected that the higher education is associated with the possibility to participate in off-farm labour activities. Having more children will make households more likely to depend highly on cash transfer; and having a bigger household size will do the same if a household receives high cash transfer. Household assets have contradictory effects for the dependence level in two cash transfer cohorts. In medium cohort (CTA23), the access of várzea will provide households more access to various livelihood activities, therefore it is easier for a productive household to become less dependent; however, when a household receives high cash transfer with a relatively bigger household size and older household head, access to várzea indicates more cash transfer (seguro defeso) and less production of fishing, hence it makes a household more dependent.

3.4 Discussion

3.4.1 Outcome of cash transfers

In this study, we examine the significance of cash transfer programs on the livelihoods of small farming households in the Brazilian Amazon estuary region. Several cash transfer programs have been conducted in this region, including *Bolsa Familia* that aims to increase children's education, an old age pension, and a closing fishing compensation. Together, they constitute a major income source for impoverished farming households facing increasing stress from both nature and society (e.g., more frequent and more severe tidal floods, crop price oscillation).

Overall, transfer programs constitute half of households' annual income and almost ten percent of all households rely solely on cash transfers. Although most programs are designed for children and seniors, this cash income may play an important role in household's decision making, e.g. investing in a bigger boat for fishing. It is also possible that this may create a dependence on cash transfers as shown by other studies (Bertrand, 2003; Kassouf and de Oliveira, 2012). Aside from the possibility of dependence, this investment of cash transfer on *Caboclos* may have reduced their vulnerability to potential shocks. However, if there is a growing dependence on this money, *Caboclos* may lose their capacity to adapt to disturbances and challenges therefore becoming less resilient. The impact of cash transfers on livelihood will vary depending on the resources and assets of a household and the livelihood strategy being utilized.

Our analysis shows an overall comprehensive coverage of cash transfers in our study region, compared to other regions in Brazil or other developing countries. For instance, basic food security is still a concern in other locations with no or little cash transfer. Food insecurity examples include the farmers in the uplands of Laos and Vietnam in southeastern Asia where the provision of alternative options are restricted, and fishermen in the Caiçara of Coastal Brazil (Cramb et al., 2009; Hanazaki et al., 2012). Yet among *Caboclos* such an issue has not been observed since households are able to purchase manufactured foods because of the ample cash transfer. Only about 18% of households in Caiçara, Brazil claim pension income as their main livelihood, while the proportion of cash transfer accounts for more than half of the households' annual income in the Amazon estuary. Northern Brazil has suffered from regional unequal development (Azzoni, 2001), but the adoption of cash transfer programs has assisted its regional development.

The results of our study demonstrate a substantial variation in the amount of cash transfer that households receive and its share of total household income (summarized as dependence level in our study). The level of dependence (less-dependent, moderately-dependent, and highly-dependent) among households that receive similar amounts of cash transfer also varies. This finding correlates other studies that show heterogeneous outcomes of cash transfer programs (Sadoulet et al., 2001) and offer us a possible direction to improve the efficacy of cash transfers by investigating the causes of such patterns.

The relationship between the amount of cash transfer and its significance in total household income suggest that some households more than others are more vulnerable to shocks affecting livelihoods: households who receive no cash transfer have to be able to generate enough income to sustain their subsistence requirement and to face external risks; or households who receive a relatively large size of cash transfer but depend on this transfer highly due to their limited capacity to generate other livelihood income. Such households deserve more attention to improve the outcome of cash transfer programs. The role of cash transfer to assist the poor should change from traditional assistantship to a more dynamic and comprehensive treatment by targeting these households and tackling the cause of such a difference.

With the demonstration of heterogeneous dependence levels on cash transfer, a follow-up question to ask what can be done besides cash transfer to improve the highly-dependent or moderately-dependent households' livelihood. Our results corroborate studies that show that non-farm income can contribute to poverty alleviation and sustainable rural livelihood development (De Janvry and Sadoulet, 2001; de Janvry et al., 2005; Padoch et al., 2008). All less-dependent groups in this study have substantial off-farm income generating activities and significantly higher education. With an educational advantage, it is easier for these households to get a job in nearby urban areas or to start a small business. Hence, they will be more likely to have higher income and become less dependent on cash transfers. Furthermore, promoting access to and enlarging job markets is also an integrated approach to sustain poverty relief other than exclusively through a stipend.

3.4.2 The role of livelihood strategy

It is a challenge to explain, not to mention quantify, human decisions. Households, rather than only maximize economic profit, take into account other livelihood criteria and uncertainties and choose livelihood strategies accordingly. This livelihood strategic decision making is a main component of our livelihood model. Although regression analysis shows significant overall effects from variables being chosen, it is still hard to capture the complex nature of human decision making. For example, people's attitude towards the role of cash transfers can vary substantially from household to household. One family told the author that next year they will expand their açaízal (plot of açaí trees) with the pension. Another family, which was only ten minutes away from the first household by boat, said that the cash transfer doesn't change their way of life at all, they are still poor and can't afford much. From the regression analysis, we might be able to explain their choices by household variables, but it is human agency that makes choices and determines livelihoods. Some household assets or resources can limit certain livelihood options(as shown in the conceptual model in Figure 3-4), which is usually the focus of other livelihood studies and programs of poverty reduction (Mamo et al., 2007; Sadoulet et al., 2001); however, the results from the ANOVA and regression in this chapter (i.e., no significant difference in most household factors between different dependence levels) suggest that there might be space for livelihood strategy to play a role in increasing the livelihood. When all the resources for households are the same, the choice of different livelihood strategies may affect the household livelihoods and the share of cash transfer in total household income, resulting in different dependence levels.

An individual household is the basic unit that applies a livelihood strategy to interact with natural resources and human institutions to generate a living. The theory from a Russian economist Chayanov indicates that demographic change in a rural household is the driving force that affects the strategies and thus the livelihood outcome, because both the consumption needs and available labor are determined by the number and the age/gender structure of the household

(Harrison, 1975). The consumption needs of the household and the available labor in the household change when a young household grows bigger to become a multi-generation family. This might be the reason for the opposite relations between household size and the dependence level on cash transfers in the two cohorts of CTA23 and CTA4. Households that are in CTA 23 might have more family members who are not able to produce any output; conversely, the large number of household size means more adult working labour force in CTA4 since the household head is older.

In addition to the household internal consumption and labor balance, moving from traditional agriculture to a modern rural livelihood also includes the access to off-farm jobs and a different life style. The living condition and social stature of *Caboclos* have improved in the estuary region, evidence of which includes the higher education level in younger households compared to the older generations from our results (i.e., the average education years is lowest in CTA4, increases to CTA23, and becomes highest in CTA1). Our results, along with other studies, suggest that the improvement in education among the young generation make them more likely to participate in non-traditional activities (de Janvry et al., 2005).

The importance of education is widely recognised in the community as well. For example, a household head, who is the father of three children, told the author that he is going to send all his children to college. Moreover, the modernization of rural livelihoods, such as smartphones and internet access, raises rural population’s interests in urban life and thus has weakened young families’ preference for labour intensive agriculture and agroforestry. For instance, a teenage girl in one household that we interviewed added one author on Facebook, and describes her ideal job would be a manicurist. The increased participation in non-farm activities creates a new household norm known as “multi-sited” (Padoch et al., 2008). This type of households continue rural production yet also receive off-farm incomes (Padoch et al., 2008).

3.4.3 Livelihood diversity

Diversity is considered as an essential attribute for resilience when faced with external risks and disturbances (Biggs et al., 2012). It is believed that preserving traditional knowledge and livelihoods can ensure the community’s resilience towards the increasing climatic risks in the delta region (Vogt et al., 2016). Our calculation of livelihood diversity suggests that households that are less and highly dependent on cash transfers have a lower livelihood income diversity compared to the moderately-dependent group. Indeed, less-dependent households have their income mainly from off-farm activities when moderately-dependent have a variety of activities including non-farm income, agro-forestry, and agriculture. When experiencing a shock on a specific income, households with higher income diversity may be more likely to digest the negative impacts and continue to thrive.

3.4.4 Limitations of this study and future work

There are limitations in this chapter that we would like to address in future studies. First, a survey at a single point in time is not sufficient to fully capture livelihood dynamics. By comparing cohorts with different amounts of cash transfer (CTA cohorts), it shows a growing pattern in the demographic condition: from young and small households in CTA1 to multigenerational households in CTA4. What is more interesting is that households in cohort CTA1 don’t have heterogeneity in assets and dependence levels; however, as households receive more cash transfers and grow bigger, they start showing heterogeneity in livelihood and asset accumulation, which may be caused by the livelihood strategies that they adopt. The heterogeneity is also possibly caused by options that households have. Nevertheless, a diverging livelihood trajectory is not able to be drawn using only one survey.

Second, we are only displaying the patterns of significance of cash transfer in the total household income. Further research should track how beneficiary households adjust their behaviors because of the cash transfer, so that we could quantify the influence of cash transfers on their livelihood strategies and inform the design and implementation of cash transfer programs with such influence.

Besides multi-nominal regression model, other regression models can also be used in this analysis to interpret the relation of cash transfer amount and dependence levels, such as order-logit models that has dependence levels in an ordered manner or a continuous model that has cash transfer as a continuous variable instead of using the dependent levels. However, we choose the MNL among all regression models even though it may lose certain predictable power due to the conversion from continuity to four discrete levels, because the results from this analysis can answer our research questions well: what characteristics are significant for households to become less-dependent or moderately-dependent over being highly-dependent when they receive similar amount of cash transfer.

3.5 Conclusion

In light of the above analysis and discussion, what picture emerges from this study? We demonstrate a pattern with substantial variation in the amount of cash transfer that households receive and in the share of cash transfer in household total income, classified as CTA1 to CTA4 cohorts (including no, low, medium, and high cash transfer cohorts) and DL1 to DL4 groups (not-dependent, low-dependent, moderately-dependent, and highly-dependent). Off-farm activities are found in not-dependent and low-dependent households no matter which cohort households are at, and moderately-dependent households have the highest livelihood diversity including income from non-farm, agro-forestry, and agricultural income.

There are significant differences in most household characteristics between cohorts that receive different amounts of cash transfer (e.g., household size, husband age), but no significant differences between different dependent groups, except husband education. A few characteristics, such as education and access to várzea, can increase the likelihood of a household being in a specific dependence level compared to the highly-dependent level. Results from our study show the heterogeneous outcomes of cash transfer programs, diagnose the more vulnerable households that policy makers and institutes should pay more attention to, and identify characteristics or possibilities that can be improved to increase the utility of cash transfer programs, which contribute to the deeper understanding of rural livelihood and the influence of cash transfers.

Chapter 4 Understanding rural farming systems with agent-based modelling and decision making ensembles—a case study in the Brazilian Amazon estuary

4.1 Introduction

According to the World Bank[13], nearly half of the global population is rural residence and the main source of their income is from agriculture. Rural farmers in developing and least developed countries face a multitude of challenges, including the degradation and depletion of land and water resources (Foley et al., 2005; Grey and Sadoff, 2007), food security and scarcity of rural labour(Cohen and Garrett, 2010), the increased variability of crop production due to climate change (Wei et al., 2014; Zinyengere et al., 2014), and the transition to a more market-oriented economy with commercial agriculture and wage employment (Padoch et al., 2008; Tittonell, 2014). The inherent uncertainty created by the complexity in the dynamics of rural livelihoods, however, requires more innovative efforts to bring insights for solving these challenges.

Despite the importance of empirical methods and other approaches in studying livelihoods of rural households, the availability of greater computational resources and modelling techniques has allowed researchers to conceptualise, simulate, and analyze this linked human-environment systems (Berger and Schreinemachers, 2006; Deadman et al., 2004; Parker et al., 2008; Verburg et al., 1999). In developing these models, experiments are posted to represent different conditions in household characteristics and different socio-economic and climatic scenarios (e.g., Le et al., 2010; Parker et al., 2003; Robinson, 2009). By manipulating experimental conditions and analyzing model outcomes in a flexible way that is limited by empirical and analytical

[13] http://data.worldbank.org/topic/agriculture-and-rural-development

studies, modelling moves our understanding of the complexity in coupled human-environment systems a step further. Yet, these computer models can also bring sources of errors and uncertainties during simulating households' interactions with the environment and socio-economic context to generate livelihood dynamics and patterns (Brown, 2010; Evans, 2012; Messina et al., 2008).

Among the modelling attempts to represent the livelihood dynamics of small farming households, agent-based modelling (ABM) has proven to be an effective bottom-up tool, and has been utilized by analysts who wish to explore agricultural systems and other coupled human-environment systems (e.g., Cabrera et al., 2012; Deadman et al., 2004; Parker et al., 2008; Schreinemachers et al., 2010). With agent attributes, environment, and decision-making rules formulated, individual agents and other decision making units interact with the environment and with each other which form system-level patterns.

However, for such models to be capable of representing human-environment interactions comprehensively, there is uncertainty possibly being introduced throughout the modelling process: the conceptualization of the system, the utilization of key assumptions, the choice of model structure and components, the initialization and calibration, and the interpretation of results all must be considered and weighed rigorously. Studies have been careful to resolve the uncertainties among parameter heterogeneity (Brown and Robinson, 2006; Huang et al., 2013), agent typology (Rounsevell et al., 2012; Valbuena et al., 2008), components (Parker et al., 2008, 2006), and key driving forces by meta-analysis (Magliocca et al., 2015). The fundamental uncertainties associated with the choice of behaviour assumptions, however, are widely acknowledged yet poorly investigated.

Agent-based modelers often choose one decision making mechanism within the research questions, research context, and their preference, and develop the rest of the model components based on the behavior model (An, 2012; Schreinemachers and Berger, 2006a). For instance, Cabrera et al., (2012) andDeadman et al., (2004) used LUCITA (Land Use Change in the Amazon), a heuristic decision mechanism, to simulate land use dynamics of annual and perennial crops operated by small farming households, and discovered that large households may result in higher deforestation rates compared to small households. Magliocca et al (2014) compared land use changes across sites with a generalized ABM, and identified common driving factors from environment and demographic sections that are important constraints on agents' land use choices at four of six sites. The choice of decision making methods largely alters model outcomes (Cabrera et al., 2010). Moreover, bringing its own structures and processes with the underlying behaviour assumptions, each model makes comparisons and cumulative learning challenging (O'Sullivan et al., 2015), and also makes policy and governance evaluation problematic (Brown, 2010). Therefore, it is essential to consider a variety of plausible outcomes for a wider coverage of possibilities when it is the same scenario setting.

Within the climate modelling community, treatment for the fundamental uncertainty of model choices have involved aggregating various models into a hierarchical group known as the ensemble approach (Collins, 2007). Using this approach allows researchers to create representative concentration pathways, to cope with uncertainties arising from initialization, parameterization, and structural formulation in climate simulations. Since IPCC AR4, the representative concentration pathways are based on results from a group of individual models as ensemble members. The ensemble approach treats uncertainty explicitly as an inherent product of conducting research rather than an "information deficit" (Brown, 2010).

The current trend in ABMs, however, is to compare different decision making approaches (e.g., An, 2012; Schreinemachers and Berger, 2006a) and choose a main one for single-valued prediction. Given the decision strategy being a major source of uncertainty, showcase alternatives of decision making in the choice helps to avoid misleading or unfair decisions, and can also help abate persistent conflict and indecision occurring as a result of making a single choice. Therefore, in this chapter, we use an ensemble approach focused on the decision making component in an ABM to present alternative behaviors. Sensitivity analysis, which measures the impact of model parameters on model outcome, is also a widely used method to quantify uncertainty (Ligmann-Zielinska and Sun, 2010). Being integrated with the ensemble approach, sensitivity analysis may bring further understanding to the uncertainty of the systems.

In this chapter, we report on the construction of an agricultural household decision making ABM in which an ensemble approach is taken to account for alternative household decision making strategies. Sensitivity analysis is used to evaluate the impact of key socio-economic and demographic variables and circumstances regarding to different decision regimes. Building on the work from Cabrera et al.(2010), we explore alternative decision making strategies that represent the diverging livelihood patterns of local small farmers in this region of the Brazilian Amazon estuary, using data derived from the aforementioned household survey.

We focus the analysis on selected characteristics and decision regimes of this complex system and initialize the model, differentiating the following variables: (1) household characteristics related to livelihood assets, including initial capital, land types, and available labour, (2) the amount of cash transfer households receive, and most importantly, (3) the decision making mechanism ensembles, which are “Max Profit”, “Max Leisure”, and

“Subsistence First”. We want to identify the role of different livelihood variables and decision assumptions by using a sensitivity analysis at community and household scales.

The ultimate question that we want to answer by these analyses is: What are the impacts of government cash transfer on rural households and communities in the Amazon estuary? To answer this question, the following specific questions are posted: ***Q-1:*** To what degree does the way household agents make decisions affect the livelihood outcomes and impacts from cash transfers? ***Q-2:*** What demographic and socio-economic parameters significantly affect the outcomes of individual households or communities? ***Q-3:*** How does the significance of the aforementioned factors change when different household decision strategies are employed?

By answering these questions, we are able to (1) establish an ABM that includes the main livelihood components of rural households in the Brazilian Amazon estuary region; (2) represent uncertainties in human-environment interactions using an ensemble approach; (3) identify the most significant factors for the livelihoods and well-beings of communities and individuals under different cases, thus informing policy makers more effectively.

This chapter is organized as follows. Section 4.2 describes the study area, the Brazilian Amazon estuary region, and some of the cash transfer programs applied in the region. Section 4.3 lists the steps of our methodology, and explicitly explains the three steps: (1) presenting concept model and the main modules in our ABM model, (2) reviewing decision making used in current small farming ABMs and describing the three decision strategies as ensembles in our model, and (3) introducing our experiment designs and sensitivity analysis method (Tukey HSD and PAWN) used at community level and household level. Section 4.4 will demonstrate our results from different experiments and decision ensembles. In the final section, we will summarize and conclude the results.

4.2 Background and cash transfers in study area

This section outlines the human-environment system of the Brazilian Amazon estuary, as the background for our ABM. We also introduce the cash transfer programs of the Brazilian government that are important in this region, especially *Bolsa Familia* and *Aposentodaria*, in this section.

4.2.1 Study area and *Caboclos*

To decode household livelihoods and the decision making mechanisms behind it, a household survey was conducted in Abaetetuba, Pará, Brazil (1°43’4’’S and 48°52’58’’W). Abaetetuba is located in the estuary region of the Amazon River near the city of Belém. Living in this frequently flooded land, *Caboclos* as native but non-Indian population have established a life-style combining agriculture, agroforestry, and other means of productions that adapt to the tidal floods. Nowadays, they are also exposed to urban-life styles and market influence. For example, açaí has been a staple food for Amazon households over a hundred years before the 1970s, when it became a fashionable food in markets at the national and international scale due to its “magical flavor” (Brondízio et al., 2003). The popularity of this food has encouraged Amazon households to expand and intensify their açaí plots while reducing the production of traditional agricultural products such as manioc. The various types and sizes of cash transfer programs that have been implemented in this region are also shaping these households’ livelihood within the dynamic delta environment. For instance, households show different degrees of reliance on cash transfers in the survey results, details of which can be found in Chapter 3.

4.2.2 Cash transfer programs

There are a few CT programs in this region, such as *Bolsa Verde* for the purpose of reforestation and *Bolsa Jovem* for extremely poor families. The most significant cash transfer programs operating in this region, in terms of both number of beneficiaries and overall size, are *Bolsa Familia* (BF), one of the largest conditional CT programs in the world, and *Aposentadoria* (pension) (Oliveira et al., 2007; Paes-Sousa and Santos, 2009; Soares et al., 2010).

Nearly a quarter of the Brazilian population were covered by this program in 2011[14]. Targeting poor households with school age children, BF mitigates poverty by direct cash assistance and enhances the future human capital in these families by allowing these households to send their children to school. Bolsa Familia has increased school attendance among children aged five to 14 by 5.6 percent (from 92.6% to 98.2%) (Melo and Duarte, 2010). Studies have also confirmed the positive impacts of BF on nutrition, vaccination rates, and education (Oliveira et al., 2007; Paes-Sousa and Santos, 2009). At the same time, worries about reduced household work incentives have not been found (Oliveira et al., 2007).

Government sponsored pensions are also a significant source of income for families in this region. Each pension unit is equal to one minimum wage, and often represents more than half of a rural family's monetary income. This benefit can largely ensure household food security, but it also has unintended consequences in labour participation (Bertrand, 2003). Pensioners from poor households sometimes stop working, which otherwise would not be possible, and this impact can extend to some co-residents, and even their life styles as well (Bertrand, 2003; Kassouf and de Oliveira, 2012).

[14] http://www.worldbank.org/en/news/opinion/2013/11/04/bolsa-familia-Brazil-quiet-revolution

4.3 Method

4.3.1 Livelihood conceptual model

This research draws on literature of sustainable livelihoods and uses an adapted livelihood model as a framework to construct the model and to explore the significance of different livelihood components (Chambers and Conway, 1991). Given two adaptations we made to highlight decision making and cash transfers, the main factors that determine the income of households are livelihood factors (including resources and capacity, as well as available cash transfers) and decision strategies (Figure 4-1). Based on this conceptual model, our ABM will explore the effects of these two components on household livelihoods in a rural agricultural community.

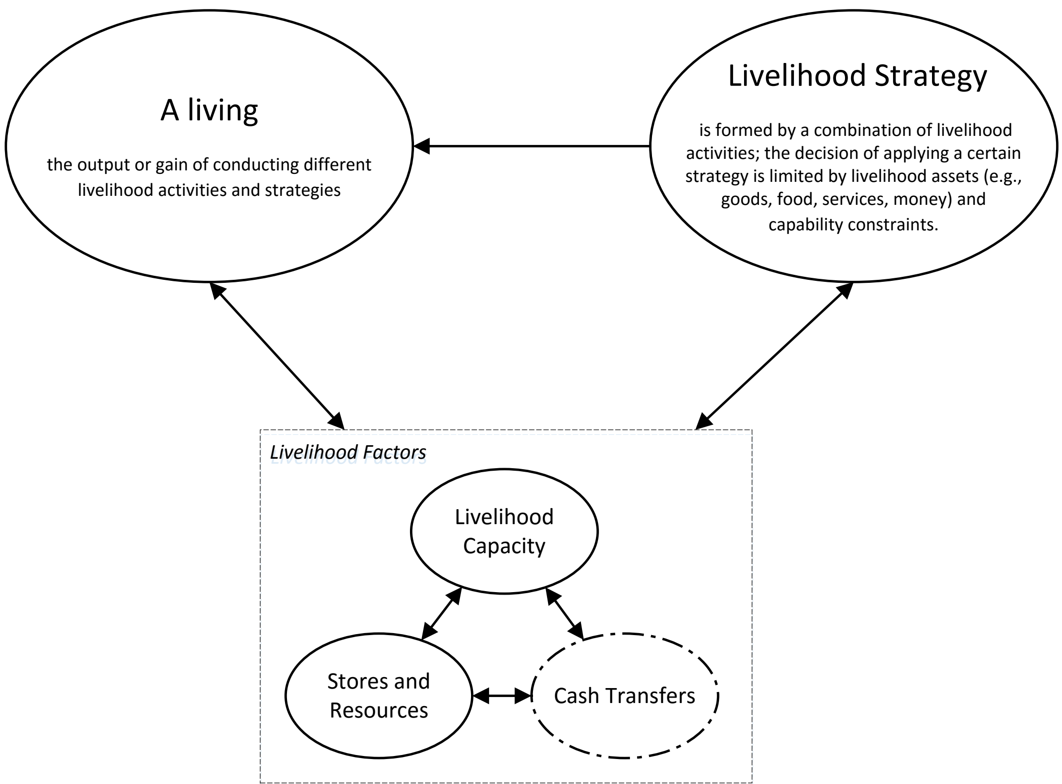

Figure 4-1 Household livelihood conceptual model (adapted from Chambers & Conway, 1991)

We follow the three steps (Figure 4-2) based on the conceptual livelihood model to construct an ABM that represents the rural households in the Brazilian Amazon estuary region and use it explore the impacts of factors and strategies on household livelihood outcomes (e.g., income, reliance on cash transfer). Based on the previous analysis from the household questionnaire (Chapter 3), we (1) selected the significant household factors including demographic, education, property, and capital, (2) identified the key production activities of *Caboclos* that could be represented in the model (with the consideration of data availability), and (3) built the bio-physical and socio-economic environment in the model. The second step was to code the different decision making models and embed them into the decision module in our ABM as ensemble members. This was followed by running the model ensembles under designed simulation experiments, followed by a sensitivity analysis to identify and understand the significance of household factors and decision strategies on household livelihoods.

4.3.2 Model design and process flow

An agent-based model was constructed to represent the households, focusing on their responses to different cash transfers and variety of household characteristics (Figure 4-3). The current model is an updated version of MARIA (Cabrera et al., 2010), which is written in Java using the RePast multi-agent simulation platform[15]. We extended human decision making with respect to cash transfer programs and further developed MARIA's original demographic and environmental modules. More details of the model is explained following ODD (Overview, Design concepts, and Details) protocol (Grimm and Railsback, 2012; Grimm et al., 2010) and can be found in the appendix.

[15] http://repast.sourceforge.net/

To represent the human-environment dynamics, MARIA uses two independent yet interacting sub-systems: the human system and the environment system. The **environment** is represented with a landscape grid composed of 5 m x 5 m cells containing either water or land, with initial land cover classifications (including açaí, agriculture, fallow, or forest) informed by remotely sensed imagery. Land cover transitions occur based on a series of rules derived from previous research in this region (Brondízio, 2008), and also provide feedback to household agents that alter the landscape. **Land cells** affect household decisions based on the following two aspects: (1) the fertility of soil and distance to water determines yield of different crops, and (2) the distance to houses and water impacts agent's land use decisions, for instance, land cells close to houses are more likely to be developed earlier than land cells further away.

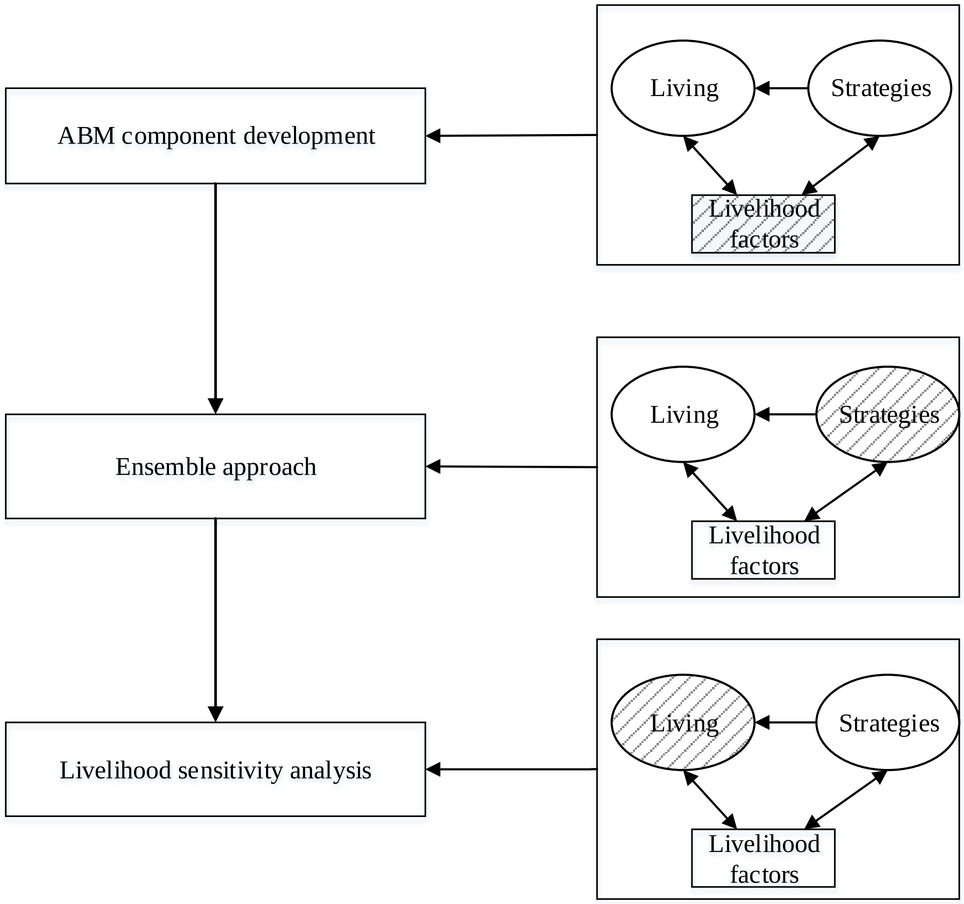

Figure 4-2 Construction of ABM based on the conceptual model

There are also policy, commodity market, and job market forces that indirectly influence land use changes through agents (the upper layer of Figure 4-3). For example, if the price of a specific crop increases due to external market forces, household agents will have a greater economic incentive to select the crop for cultivation and sale, creating an economic driver of land cover transition. By examining the relationships between different system components, we are able to study how household agents and community income and equality evolve in response to different socio-economic and environmental conditions.

The initial conditions of each model run begins with the **initialization module** that creates household agents, landscape and land properties, and other important parameters, such as population structures, cash transfer amounts, and crop price. The model then engages other modules on an annual step basis after the initialization. With each time step, the model begins with an update of policy and market information (1.1), such as the unit of cash transfers, number of available off-farm job offers, and price of each commodity. All this updated information then passes to agents for them to make decisions. Households also update their demographic conditions, (1.1) including the age of each family member and the birth or death of family members. Land use decisions (2.1), including maintaining existing crops and expanding and growing new parcels, are addressed by household agents to land cells based on their resources and crop production, which will be discussed later. The **Land module** is then launched to adjust the land cover transitions and soil quality (3.1). After this, the land system integrates with the human system by updating the crop yield and land use changes.

Our model includes two types of cash transfer programs: *(1) Pension: w*hen a male family member becomes older than 60 and a female family member is older than 55, they fulfill the pension plan and receive a minimum wage per month, which is R$ 545 in 2012[16]. *(2) BF:* If the household monthly income is lower than R$ 140 per capita, each child (<16 years old) within this family receives around R$32 per month (based on specific children age and household income), with the verification of school attendance. Each household can have maximum five children in the BF program. The purpose of the BF program is not solely in improving education, but also childhood vaccination and nutrition. In our model, however, we will only represent the impact on education improvement.

[16] http://agencia.previdencia.gov.br/e-aps/servico/348

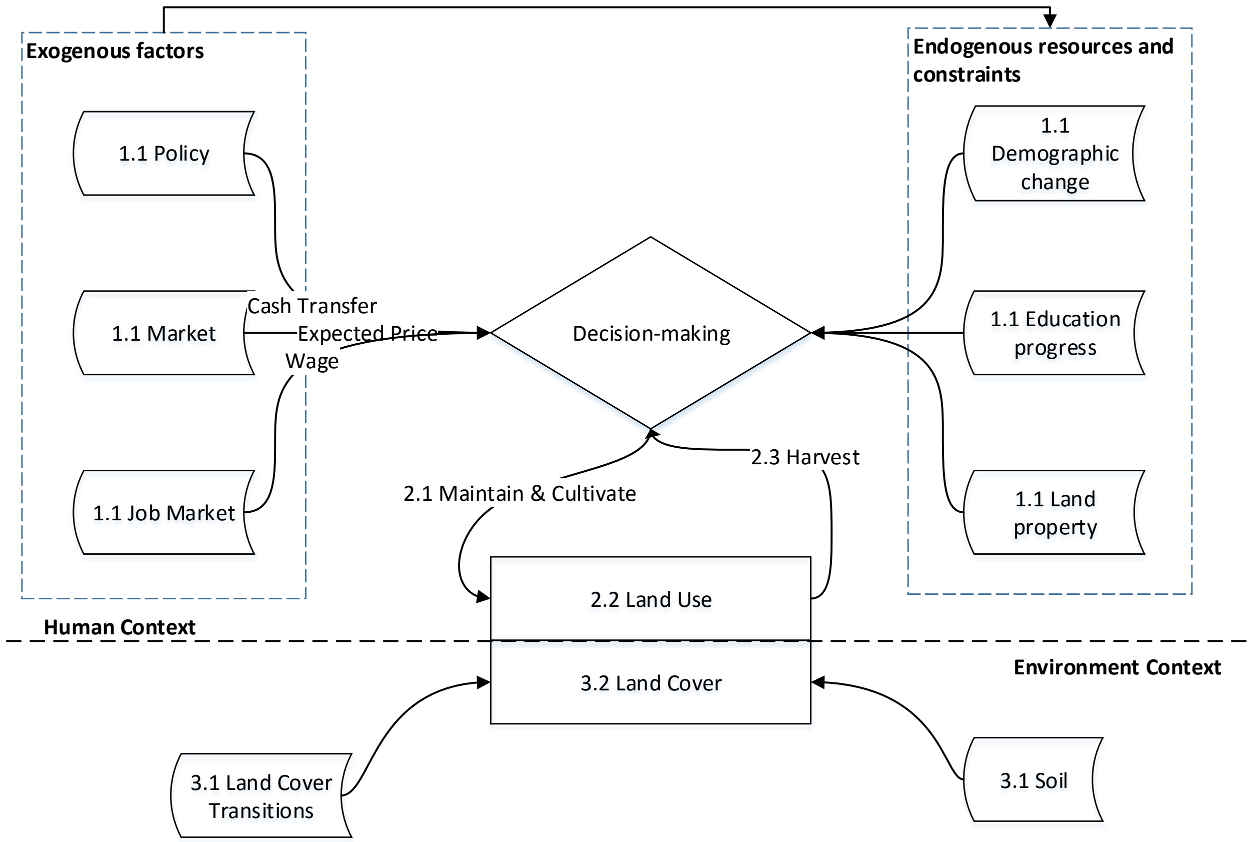

Figure 4-3 Human-Environment interactions in ABM (adapted from Cabrera, 2011)

4.3.3 Formulating agent decision strategies

Depending on their demographic and other livelihood circumstances, desire for leisure, and need for subsistence agriculture, households in rural settings use their limited resources to meet their motivations, hence unique behaviors and livelihood outcomes of households are observed. As shown from the 2012 *Caboclos* household survey, households with equivalent socio-economic characteristics (with the exception of education) may choose different production activities resulting in different income and dependence on cash transfer programs (e.g., the highly dependent group doesn't have many activities going on, while moderately-dependent households who share the same characteristics with this highly-dependent group have the highest diversity of activities including labour intensive agriculture and acai). The evidence of a variety of livelihood goals and strategies is conceptualised in the decision making module of our ABM, and a range of different, potentially conflicting decision-making mechanisms have been applied in extensive ABM cases.

In residential location choice ABM, which is another sub-field of ABM, utility maximization is usually the most often used method. Residential agents choose a housing location in urban center or suburb regions, concerned with factors such as location accessibility and housing price using Cobb-Douglas function format (Brown and Robinson, 2006; Huang et al., 2013; Magliocca et al., 2011; Robinson and Brown, 2009). Farming household agents consider questions such as how to allocate their labour force to the cultivation of each crop, how many new plots to open and how many plantations to maintain, or which crop to plant in which plot. The various factors and their relations during farming process lead to a temporal and spatial complexity, which makes utility calculation end in multiple layers of decisions compared to one standardized residential location choice with multiple factors.

The utility in agricultural decision making has been endowed different meanings, such as economic outcome, profit with respect to risk attitude, and ecosystem provisions and well-beings. It is easy to assess and construct a utility function when there is only pecuniary term, but the utility function can also be multi-attribute when farmers evaluate more dimensions than just monetary income. For example, in Evans and Kelley's model, agents make decisions to optimize their utility that has a non-pecuniary utility such as forest aesthetic besides the pecuniary utility (Evans and Kelley, 2008; Kelley and Evans, 2011). Or ecosystem service, which is not a usual utility component, has been added in decision makings too (D. Murray-Rust et al., 2014).

However, none of the models has used labour as a variable in the utility calculation, which is addressed in our Max Leisure strategy.

Many ABMs also adopt heuristic decision making methods, such as LUCITA (Cabrera et al., 2012; Deadman et al., 2004), PALM (Matthews, 2006), NEA (Mena et al., 2011), ABM-Virtual Laboratory (Magliocca et al., 2014, 2013), and PAMPAS (Bert et al., 2011). For example, when decide to change land use types, both NEA and PAMPAS have the mimic strategy, which is to copy what the agent's physical neighbour's land use type. However, the few reviews of decision makings in ABM focus on the different mechanisms of decision making methods, rather than the theoretical basis and in rural settings, in ABM applications (An, 2012; Bousquet and Le Page, 2004; Kennedy, 2012). For instance, An (2011) summarizes nine decision making methods that can be used in ABMs to represent complex human-environment systems (e.g., microeconomics model, participatory agent-based modelling, and evolutionary programming). Some authors mention classification in their articles and the popular one is "satisfactory or optimizer" (Manson et al., 2012; Schreinemachers and Berger, 2006b; Villamor et al., 2012), or heuristic, mathematic, and cultural-theory (Robinson et al., 2012).

Here, we review seven decision strategies that have been commonly used within other rural household ABMs (in Table 4-1). Moreover, we select three representative theories in rural livelihood literature as representatives of livelihood strategies and use them as ensemble members in this study.

Table 4-1 Decision strategies that used in other ABMs

Model	Authors & Date	Decision making strategy
LUCITA	Cabrera et al., 2012; Deadman et al., 2004	Heuristics : subsistence requirement met
MP-MAS	Schreinemachers and Berger, 2011; Schreinemachers et al., 2010; Wossen and Berger, 2015	Optimization: maximize utility of consumption and savings at three budgeting stages
LUDAS	Le et al., 2012b, 2010, 2008	Livelihood topology: Stay with the most similar livelihood group
FEARLUS	Gotts and Polhill, 2009; Polhill et al., 2013, 2010	Economic return: adopt neighbours' crop selection if the land yield aspiration is not met
LUCIM	Manson and Evans, 2007	Optimization: actors maximize the land use utility based on land portfolio and their preference
K-E	Evans and Kelley, 2008; Kelley and Evans, 2011	Risk adjusted utility (including pecuniary and other outcome) from labour allocation to activities
CRAFTY	D. Murray-Rust et al., 2014	(by default) Cobb-Douglas function: optimal production and ecosystem provision
APORIA	D Murray-Rust et al., 2014	An intermediate level of decision recommendation in this framework is a utility function including economic returns and ecosystem service by choice

(1) Maximizing Leisure (ML)

Labour is generally used as a constraint when one tries to allocate resources and it is never considered as part of the goals. In some heuristic ABMs, farmers always convert as much land as possible until labour and available resources are fully utilized (Deadman et al., 2004; Mena et al., 2011). The motivation for agents in many farming ABMs is profit maximization that is the same as industry enterprises (e.g., MP-MAS, LUCIM).

However, traditional households do not always operate as enterprises, and their utility is not solely profit. In economics, utility is defined as "the satisfaction that a person receives from his or her activities" (Nicholson, 2004, p. 55). It is a construct and a proxy that measures an individual’s expressed preferences for outcome alternatives. As Chayanov (Chayanov, 1966; Ellis, 1994; Harrison, 1975) has concluded from intensive survey of Russian farmers: the household goal is to seek optimal utility of both family income and labour-surplus, so called drudgery of work. Defined as voluntary unemployment, labor surplus implies that farm households can eat and work as much as they want. Therefore, leisure should be one of the utility terms when farm agents make decisions about labour allocation among different activities.

Rooted from Russian peasantry, Chayanov’s work has becoming increasingly influential even in modern rural economics. His theory, such as agricultural intensification and household dependency on demographic structures, has been applied to several land-use modelling studies as well (Caldas et al., 2007; Kaimowitz and Angelsen, 1998; Magliocca et al., 2013). His model is a theory of utility maximisation, which explains the subjective decision with respect to the amount of family labour to commit to farm production in order to satisfy its consumption needs (Chayanov, 1966; Ellis, 1994). Households face two opposing objectives: an income objective which requires labour input, and a work-avoidance objective which conflicts with income generation. The central elements of Chayanov’s labor-consumption balance theory are illustrated (Figure 4-4).

Households with leisure time have been considered in a few ABM examples (Huber et al., 2013; Magliocca et al., 2013). However, the leisure time is used as a reduction of labour input and is not a consideration in calculating utility. Here we treat the leisure time as part of households’ objective: agents maximize the leisure time as long as the subsistence requirement (Y_{min}) is met. We are not saying households would adopt such extreme strategy, but by making the case extreme, we can investigate the representatives of households and measure the boundaries of such strategies.

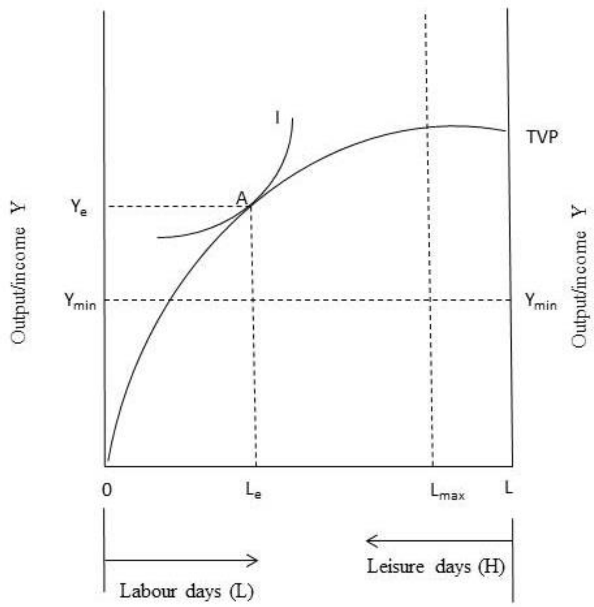

Figure 4-4 Indifference curves of income and leisure for farmers. TVP is total value product curve that is a function of labour input (L). The output of the farm, which equals the income, is measures on the vertical axis as Y. The horizontal axis measures the total labour time available to the household, which can be allocated either to farm work (which is measured from left to right as OL), or to other activities ('leisure') (counting from right to left as LO). The I curve is the indifference curve, every point on this curve produces the same utility. The highest utility happens at the tangent point (A) of the indifference curve and the total value production line. Point A puts the farm utility as Y_e and leisure days of (L-L_e).

(2) Maximizing Profit (MP)

This is based on economic optimization that quantifies monetary returns to all factors of production (Barlett, 1984, p. 140; Colman and Young, 1989). Optimization has been widely adopted by ABMs that simulate farmers' decision making, such as MP-MAS and LUCIM (Manson and Evans, 2007; Schreinemachers and Berger, 2011). In this strategy, households seek for the highest possible net income according to market prices. It considers farm households similar as enterprises that seek for the highest revenue which are different from traditional smallholders. In our case, the main crops of *Caboclos* are açaí and manioc, while the market price of açaí has been increasing for the past thirty years and the price of manioc has been relatively low. Therefore most households switch all their resources to grow açaí and purchase manioc from the market.

(3) The Subsistence First strategy (SF)

This is based on simple rules or heuristics that are observed in the field and/or implemented in ABMs (Barlett, 1984, pp. 45–86; Mccracken et al., 2002; VanWey et al., 2007). Farm households use simple rules or special procedures for dealing with a highly varied environment. For example, farming households in the frontier region of the Brazilian Amazon make decisions of agricultural crops and other production based on family age and gender structure (Entwisle and Stern, 2005; VanWey et al., 2007). Other heuristic decisions describe contextual behavioral tendencies, such as risk averseness (Ellis, 1994) and livelihood (income and assets) diversification (Brown et al., 2013; Ellis and Allison, 2004; Ellis, 1998), have also been explored.

It is becoming an international trend that small farm households are switching from traditional self-sufficient strategy to a more market-exposed strategy (Vongvisouk et al., 2014), but studies also suggest the existence of different farming strategies with subsistence-orientation (Tittonell, 2014). Despite the fact that manioc is more labour intensive and less profitable in the market than açaí, there are still households who prefer growing manioc domestically to fulfill their subsistence needs without purchasing from the market (Brondízio et al., 2003; Vogt et al., 2016). To reflect this documented strategy, we use this subsistence-first strategy as one ensemble member in our ABM simulation.

4.3.4 Modelling and sensitivity analysis strategy

We conduct two experiments for each of the four major components that influence livelihood dynamics (i.e. land type, household capital, labour, and cash transfer) where the probability distributions used to set the initial values of the tested variable are altered between experiments and the other variables are identical to baseline. We then apply these experiments to the initialized model and ensemble members to simulate household livelihoods.

Accordingly, the experiments are organised as follows (Table 4-3): the baseline (Experiment BL) is established as the empirical distribution (uniform distribution, or discrete distribution following the probability); the rest of the experiments highlight different factors including *land types* (Experiment V+), *initial capital size* (Experiment C- and C+), *family size* (Experiment F- and F+), and *pension units* (Experiment CT-0 and CT+). One example is that Experiment C- has a higher probability in smaller capital regimes when initializing the households in the community while Experiment C+ has a higher probability in high capital, and Experiment F- has more family members compared to the baseline. Each experiment is run under all three decision making ensembles.

The experimental results are analyzed at both the individual level (representing single households) and aggregate level (representing the whole community) to understand the effects from these experiments on livelihoods with our model outcomes. To quantitatively measure these effects, we choose six individual level metrics and two community level metrics for sensitivity analysis (Table 4-2). Using metrics from two scales can also give insights on parameter effects at different levels.

We selected six household level indicators to give us a full measurement of household level livelihoods: annual production income, annual total income, household wealth, household reliance on cash transfer, and production/ income diversity for PAWN[17], the sensitivity index. The two aggregate level (community level) output metrics are the Gini index and Poverty Gap index, which are widely used by both researchers and policymakers to evaluate community development capacities in terms of the income inequality and poverty aspects respectively (de Janvry et al., 2005; Kajisa et al., 2007).

The **Gini index** measures the inequality of income or utility distribution, the value of which ranges between 0 (perfect inequality) and 1 (perfect equality). For instance, the Gini index has been used to compare the levels of income inequality of 264 households in six villages in Bangladesh, the Gini index for total income is 0.38 but it is 0.52 for households who obtain income from forest resources (Mohammad Abdullah et al., 2016). Brown and Robinson (2006) used Gini index to measure the utility disparity of households' location choice.

The **Poverty Gap index** quantifies the poverty intensity by measuring the average poverty gap in the population as a fraction to the poverty line. It builds up on the proportion of the local population that has income below the poverty line and is formatted as a percentage of the poverty line ranging between 0 and 100%. One example of the usage of Poverty Gap index is to study the relationships between rural income distributions and changes in environmental conditions in India between two time periods (Bhattacharya and Innes, 2012) where Poverty Gap index was 0.25 in 1994 and reduced by 0.03 in 2001 (i.e., the average aid needed to pull the whole community out of poverty is to give 25 % of the amount of poverty line times for every

[17] PAWN was derived from the creators' names (Pianosi and Wagener, 2015).

household in the group in 1994 while the amount of money needed was reduced to 22 % of poverty line). We calculated each of the metrics with and without cash transfers to compare household livelihood outcomes based on their decision strategies.

At a household level, global variance-based sensitivity analysis has been widely used in the development and analysis of environmental models as an effective tool (Ligmann-Zielinska and Sun, 2010; Pianosi and Wagener, 2015; Saltelli et al., 2010; Thiele et al., 2015). Among other variance-based approaches such as Sobol (Ligmann-Zielinska and Sun, 2010; Nossent et al., 2011) and FAST (Chan et al., 1997), we use the PAWN method (Pianosi and Wagener, 2015; Wagener et al., 2015) to identify the influential demographic and other factors on the livelihood of individual households. We choose PAWN for this study because it (1) characterises output distributions by the cumulative distribution functions (CDF) that are easier to derive than probability density functions used by other methods; (2) the output distribution can be multi-modal or highly skewed; (3) it has lower computational costs and can be operated directly with the output results (Pianosi and Wagener, 2015).

The essence of PAWN sensitivity index is the Kolmogorov-Smirnov statistic (Equation 4-1) as a measure of distance between unconditional and conditional CDF:

$$KS(x_i) = \max_y |F_y(y) - F_{y|x_i}(y)| \quad \text{Equation 4-1}$$

while the PAWN index T_i picks a statistic, such as the median or the maximum, over the maximum values we get from the range of x_i (i.e., we get a set of corresponding max value from changing x in its range, PAWN index uses a median or mean from this set of value). In general, the range of T_i is between 0 and 1, and lower the value of T_i, the less influential x_i is. The two equations are illustrated (in Figure 4-5).

$$T_i = \underset{x_i}{stat}[KS(x_i)] \qquad \text{Equation 4-2}$$

In the two equations, $F_y(y)$ is the unconditional CDF and $F_{y|x_i}(y)$ is the CDF when $x=x_i$. The *max* operator in Equation 4-1 means the biggest distance between the unconditional and conditional CDFs. The operator *stat* in Equation **4-2** suggests the choice of a statistic metric for all the possible KS when x is the value of x_i.

At community level, we use an analysis of variance (ANOVA) and Tukey's honest significance test (Tukey's HSD) to compare the outcome from each experiment to baseline experiment. The impact of changing each variable could be quantitatively measured by the change of Gini and Poverty Gap index relative to baseline in each decision regime. ANOVA is useful for comparing means of the indicators among more than two groups for statistical significance and Tukey's HSD is a post-hoc analysis to find means that are significantly different from each other. ANOVA has been commonly used in ABM simulations to confirm the stability of outcomes or to compare the impacts of experiments (Le et al., 2012b; Ligmann-Zielinska and Sun, 2010). Tukey's HSD is also a suitable alternative method for comparing more than two data sets, and has often been used in the evaluation of experiment impacts (Ezzine-de-Blas et al., 2011). In conjunction, ANOVA and Tukey's HSD allows us to identify experiment conditions (e.g., more small families, larger capital to start with) that have a significant impact on the income inequality and poverty alleviation affecting communities.

Table 4-2 Output Metric

ID	level	output metrics	Variable/ Equation	Definition
1	household	household wealth	HW	the family accumulated wealth over year of a household agent
2	household	annual production income	PI	the annual income of a household agent from all production activities
3	household	annual total income	TI	The annual income of a household agent, including cash transfers
4	household	reliance level on cash transfer	CT_R	the percentage of cash transfer income out of total income in a household agent
5	household	income diversity	$ID_k = \sum_{i=1}^{N} p_i ln p_i$	the average income diversity. We use this equation to calculate both production income diversity (without cash transfer income) and total income diversity (including cash transfer income).
6	community	Gini Index	$G_k = \frac{\sum_i \sum_j \lvert income_i - in}{2 \sum_i \sum_j incom}$	A measure of income distribution of a population. It is the mean absolute difference between individual values divided by the average. The value theoretically can range from 0 (complete equality) to 1 (complete inequality). income i and income j represents the individual income of household agent i and j.
7	community	Poverty gap Index	$PGI_k = \frac{1}{N} \sum_{j=1}^{q} (\frac{z - income_i}{z})$	The average positive shortfall from the poverty line, expressed as a percentage of the poverty line. This index gives how much money government needs to invest to pull people out of poverty line. N is the total population, q is the number of household agents who are living at or below the poverty line z, income i represent the income of household agent i. If a household income is above the poverty line, it has a gap of zero.

Note: These **metrics** are all calculated with values when tick =30. The choice of 30 ticks shows no significant difference at these index compared to when there are more ticks. Poverty line is defined by international standards: people living on less than $1.9 a day[18]. Indices of No.6 and 7 are **calculated** (notice it's calculated, not meaning the scenario doesn't have cash transfers) in two forms:

[18] http://povertydata.worldbank.org/poverty/country/BRA

without cash transfer (pure production income) and with cash transfer (consider cash transfers as a type of income).Notice the variable here for Gini and Poverty Gap is income; but in the next chapter we use household capital to analyze poverty trap.

Table 4-3 Experiment Design

ID	Experiment	Form	Initial capital	Land type(upland or várzea)	Community size	CT unit	Decision method	Experiment Rep
1	base	BL	U(1000-4000, 0,25, 4000-7000, 0.5, 7000-10000, 0.25)	M(Upland-0.66, V-0.33)	120	BF: 50, Pension: 1000	M(ML, MP, SF)	384(128)
2	more várzea	V+	U(1000-4000, 0,25, 4000-7000, 0.5, 7000-10000, 0.25)	M(Upland-0.33, V-0.66)	120	BF: 50, Pension: 1000	M(ML, MP, SF)	384(128)
3	small capital	C-	U(1000-4000, 0.75, 4000-7000, 0.25)	M(Upland-0.66, V-0.33)	120	BF: 50, Pension: 1000	M(ML, MP, SF)	384(128)
4	big capital	C+	U(4000-7000, 0.25, 7000-10000, 0.75)	M(Upland-0.66, V-0.33)	120	BF: 50, Pension: 1000	M(ML, MP, SF)	384(128)
5	small family	F-	U(1000-4000, 0,25, 4000-7000, 0.5, 7000-10000, 0.25)	M(Upland-0.66, V-0.33)	80	BF: 50, Pension: 1000	M(ML, MP, SF)	384(128)
6	big family	F+	U(1000-4000, 0,25, 4000-7000, 0.5, 7000-10000, 0.25)	M(Upland-0.66, V-0.33)	160	BF: 50, Pension: 1000	M(ML, MP, SF)	384(128)
7	no CT	CT-0	U(1000-4000, 0,25, 4000-7000, 0.5, 7000-10000, 0.25)	M(Upland-0.66, V-0.33)	120	BF: 0, Pension: 0	M(ML, MP, SF)	384(128)
8	higher CT	CT+	U(1000-4000, 0,25, 4000-7000, 0.5, 7000-10000, 0.25)	M(Upland-0.66, V-0.33)	120	BF: 70, Pension: 1400	M(ML, MP, SF)	384(128)

Notes: (1) U, uniform distribution, with probability on different ranges, for continuous variables including capital, labour, pension; for instance, U(1000-4000, 0.25, 4000-7000, 0.5, 7000-10000, 0.25) means the probability of a capital value in 1000-4000 is 0.25, the probability of a random value in 4000-7000 is 0.5, and a value in 7000-10000 is 0.25; M, probability mass (discrete) function defined with category values: probability of upland type is 0.66, and probability of várzea type is 0.33.

(2) Each experiment we run the model with 384 repetitions to diminish the random error. The number is determined by (2k+2) 2^(4+j) (Ligmann-Zielinska and Sun, 2010), k is the number of independent factors, which is 5, and we set j=1 to reduce the computational cost. This amounts the model executions per experiment to 384.

(3) For each experiment, we keep capital, land type, and household size following certain distributions rather than regulating all households to one size. The community is more likely to have all sorts of households rather than only with one type. Therefore, governance polices or strategies, such as encouraging the movement to várzea or upland or having smaller sized households in one community, is more practical to inform policy makers. Certain types of households and cash transfers will be analyzed with different methods at a separate scale.

(4) We adjust each experiment by 40% δ away the mean value, which keeps a similar degree of change for each variable.

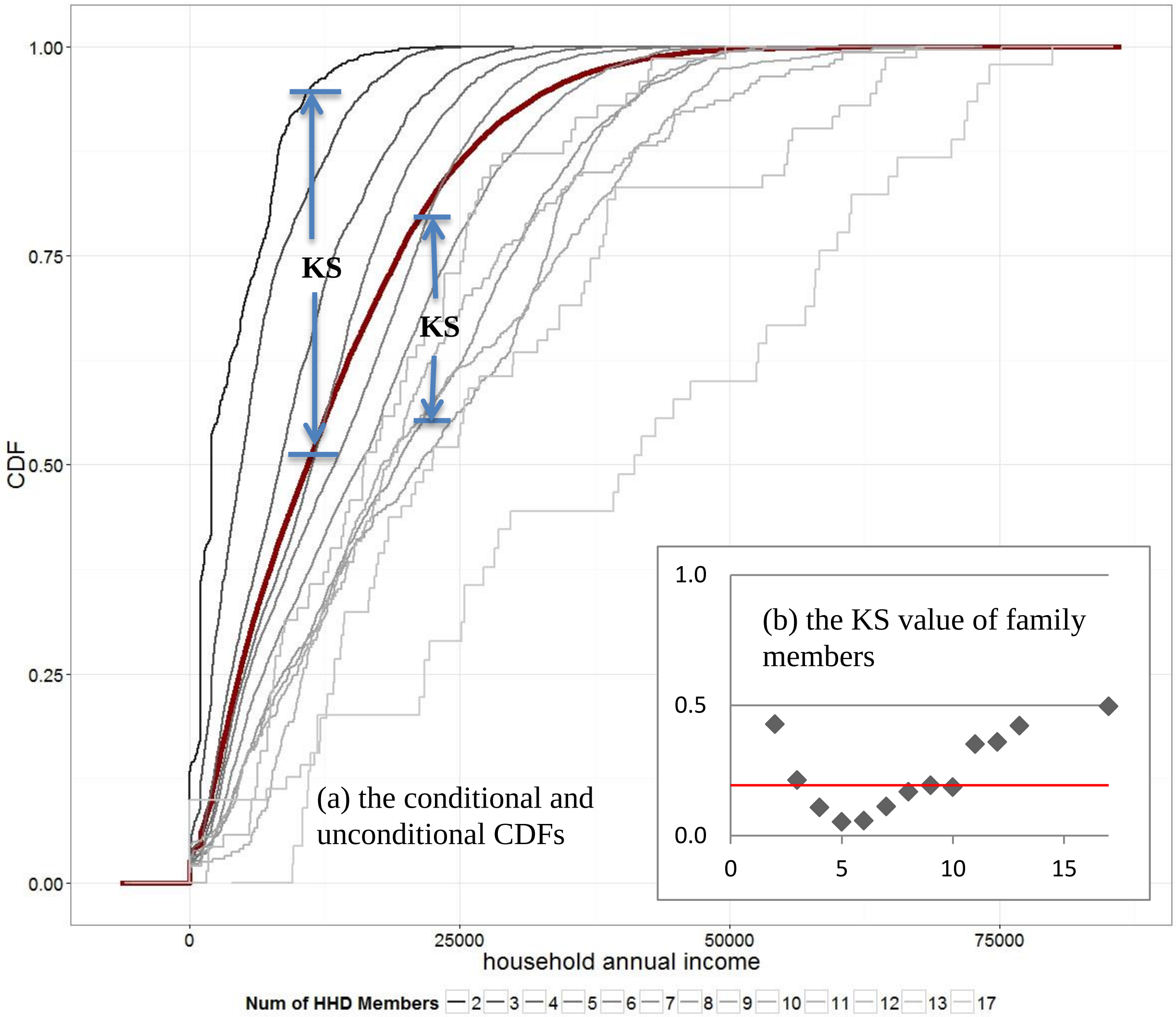

Figure 4-5 Example of KS and Ti from experiment output. We use household annual total income (including cash transfer) with Max Profit decision strategy as output and the variable is household member, which ranges from two to 17. The red line in (a) is the unconditional CDF, and the grey scaled lines are conditional CDF. Each grey line corresponds to one value from the range of family members (i.e., there are fifteen grey lines and the family member values are from one to fifteen). KS measures the maximum distance between unconditional CDF and the conditional CDFs (as shown by the vertical red line). Dots in (b) represent the KS of all possible values for this variable (family size), which are estimated by Equation 4-1, while the horizontal red line is the median value based on Equation **4-2**. In this case, the median of household member KS is 0.193.

4.4 Results

In this section, we examine the simulated livelihood outcomes from different experiments at the household level by the PAWN method (the overall impacts from decision strategies and within each decision strategy) and at the community level by ANOVA and Tukey HSD analysis (the overall impacts of all experiments, and between each experiment and specific decision). We report on the results at the community level, the Gini index and Poverty Gap index purely calculated using production income and these two index calculated including cash transfers.

4.4.1 Household livelihood outcomes

We applied PAWN sensitivity (median) for seven model parameters on six outputs, the results of which are first represented over all decision making ensembles (Table 4-4) and then within each decision regime respectively (Figure 4-6). The first section answers the first research question and quantifies the significance of decision strategies among other characteristics. The second section addresses the third research question by measuring the significance of every factor in each decision regime.

Table 4-4 Median of PAWN index over all decision ensembles (bold indicate the highest value in the column)

Ti-Median	**production income**	**total income**	**CT reliance**	**household wealth**	**production diversity**	**income diversity**
family member	0.152	0.193	0.106	0.215	0.041	0.146
No. pensioners	0.040	0.056	**0.187**	0.066	0.026	**0.152**
decision strategy	**0.228**	**0.231**	0.162	**0.264**	**0.126**	0.093
having várzea	0.206	0.205	0.145	0.231	0.061	0.083
pension unit	0.055	0.067	0.117	0.079	0.018	0.085
husband education	0.053	0.046	0.065	0.047	0.079	0.060
initial capital	0.043	0.045	0.085	0.085	0.028	0.094

4.4.1.1 PAWN among all decision ensembles

The median index indicates that decision strategy, which dominates how farmers allocate their resources and activities, is the most influential factor for almost all livelihood outcomes except income diversity and CT reliance (Table 4-4). This is consistent with us proposing the adoption of an ensemble approach with multiple decision strategies. Whether it is production income, total household income, or household wealth, decision strategy is the most influential among all the parameters (e.g., it is almost five times more influential to income compared to the number of pensioners).

For income diversity, the number of household members who are eligible for pension payment becomes the most influential factor, the reason of which is that cash transfer payment is part of income diversity and its amount can be substantial. This is also the same reason that the number of beneficiary is also the most significant factor when it comes to the cash transfer reliance. The second highest index is having várzea that hovers closely to the decision strategy, except for production diversity that várzea may have a negative impact on diversity since it'll mostly be acai. The next important one is family member which is particularly important to family wealth and production diversity.

4.4.1.2 PAWN within each decision making strategy

For each decision strategy, we found that the most influential factors are different (Figure 4-6). For the Max Leisure strategy, the most influential factor is the number of eligible beneficiaries in the household for all outcome indicators except income diversity, which is opposite to the results from the overall sensitivity analysis. This might be households pursuing more leisure time may not produce much income when mostly relying on cash transfers. Having várzea is least influential for four out of six livelihood indicators (i.e., cash transfer reliance, income diversity, production diversity, and production income) and husband education is least significant for household wealth and total income.

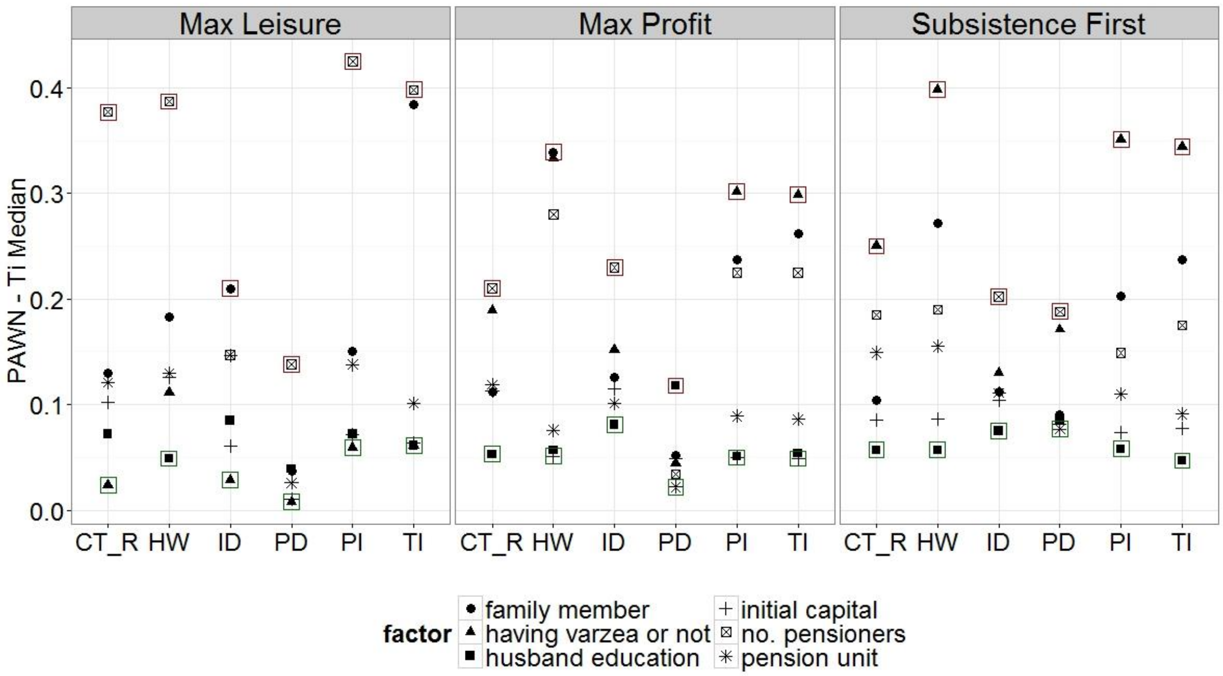

Figure 4-6 PAWN (Median) index for six factors across three decision regimes. Six model output are: (1) CT_R, CT reliance, (2) HW, household wealth, (3) ID, income diversity, (4) PD, production diversity, (5) PI, production income, (6) TI, total income. The factor with the highest sensitivity is circled by red square, and lowest sensitivity is highlighted by green box.

However, for households that maximize profit, having várzea or not is the most influential factor for production income and total income, since income size is likely associated with income from açaí. How many family members are eligible for pension is most important for the percentage of household's dependence on cash transfers and their income diversity (as the overall significance). The most influential factor for production diversity is the level of husband education for what determines the household's probability of getting an off-farm job. Household wealth is mostly influenced by the number of family members, which determines the available labour.

Households that ensure their subsistence requirement first are sensitive to the land type of várzea and number of pensioners. The four out of six indicators, the production income, total income, cash transfer reliance, and household wealth, are mostly influenced by households' land type. If in upland, it might be easy for a household to fulfill its subsistence requirement of manioc and then easily pursue market value, which makes a household sensitive on land type. The diversity of production and income is mostly determined by the number of elders in a household.

Overall, the most significant factor for Max Leisure is the number of family members who are eligible for pension, while for Max Profit and Subsistence First is having várzea along with the beneficiary number. They have the highest PAWN index across most of the outputs. For production diversity, husband education is the most significant for Max Profit regime. Initial capital is a less significant factor, particularly in Max Profit regime.

4.4.2 Community livelihood outcomes

When measured aggregate outcome using the two community-level indices of income inequality and Poverty Gap that are calculated with and without cash transfers, ANOVA results show significant differences in the community outcomes across eight experiments and the three decision strategies (Appendix A). Since the significance of decision making ensembles has been presented in the above analysis, here we show the overall impacts from eight experiments first (Figure 4-7) for ***Q-2*** and report the impact of every experiment within each decision strategy (from Figure 4-8 to Figure 4-11) for ***Q-3***, at the community level.

4.4.2.1 Impacts of eight experiments on all decision strategies

The mere presence of cash transfers generally reduces both the average income inequality and poverty in all experiments (e.g., the average income inequality without cash transfer is 0.551 and with cash transfer is 0.397 in baseline experiment), among which the average Poverty Gap, the gap between community income and poverty line, greatly reduced by 90% in the baseline experiment. The presence of cash transfer also reduces the ranges of these two indices (the lengths of bars in the boxplot are shorter of index with cash transfer) compared to without it.

However, comparison through Tukey HSD shows that not all experiments have a significant influence on community income inequality and poverty (Appendix B). For example, initial capital (Experiment C- and C+) and land cover (Experiment V+, with exception of inequality under cash transfers) are not significant factors in affecting community income inequality or poverty. By contrast, family size is a significant factor: communities with more large families (F+) result in lower Gini index with CT, although F+ shows higher poverty and inequality when only considering production without CT. Smaller family sizes (F-) may contribute to higher poverty over production income, and higher poverty and inequality for total income including cash transfer.

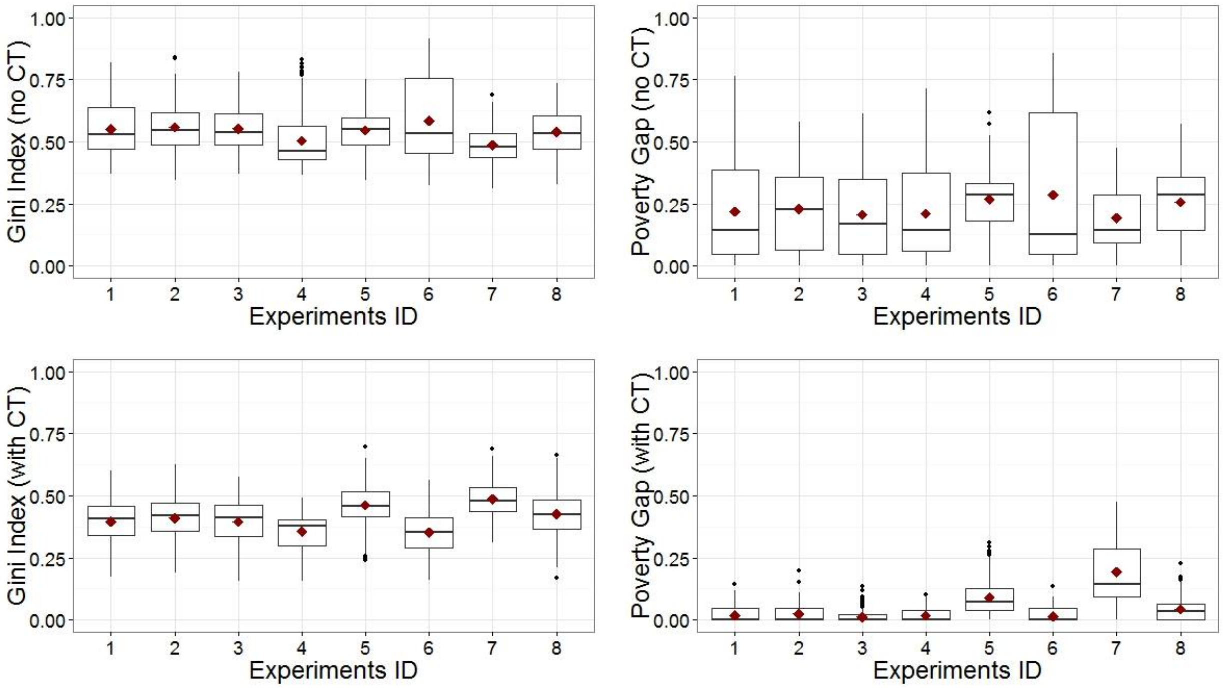

Figure 4-7 Community Level Livelihood Outcomes of Eight Experiments. From 1 to 8 are: 1-baseline, 2-more várzea, 3-small capital, 4-big capital, 5-small family, 6-big family, 7-no CT, 8-higher pension. Outcomes are the aggregated from all three decision ensemble members. Red dot is the mean value. Notice the index value is the same for 7-no CT, because the calculation of index when with CT is the same as without CT.

4.4.2.2 Impacts of eight experiments on each decision strategy respectively

The means of four indices between each experiment and the baseline in every decision ensemble were compared to show the impacts of these experiments in different decision strategies (from Figure 4-8 to Figure 4-11, details of which can be found in Appendix C).

(1) Gini index calculated without cash transfers

The mean Gini index within each experiment, when calculated purely based on production income without cash transfers, can be ranked from highest to lowest among the Max Leisure, Subsistence First, and Max Profit decision strategies respectively (Figure 4-8). A similar pattern is also found in the variation of this index, Max Leisure has the largest variation, Subsistence First follows, and Max Profit has the lowest variation.

Within the **Max Leisure** decision regime, the experiment of more várzea (V+), more small family (F-), no cash transfer (CT-0), higher pension (CT+) all decrease the Gini index, which is the income inequality. Among these, CT-0 actually decreases the inequality most by 0.207. Experiment F+ is the only experiment that increases the income inequality (from 0.668 to 0.789) compared to the baseline. The small (C-) or big capital (C+) experiments do not show significant change on Gini index. For **Max Profit**, V+ and CT-0 improve the average income equality and C+ decreases it in comparison with baseline. The rest of these experiments do not have significant impacts over income inequality for Max Profit decision makers. Within **Subsistence First** decision strategy, except V+, the experiments of C-, F-, CT-0, or CT+ increase the income inequality. Overall, land cover várzea is an influential factor for income inequality, having more of which (V+) improves the equality of income distribution across all three decision strategies.

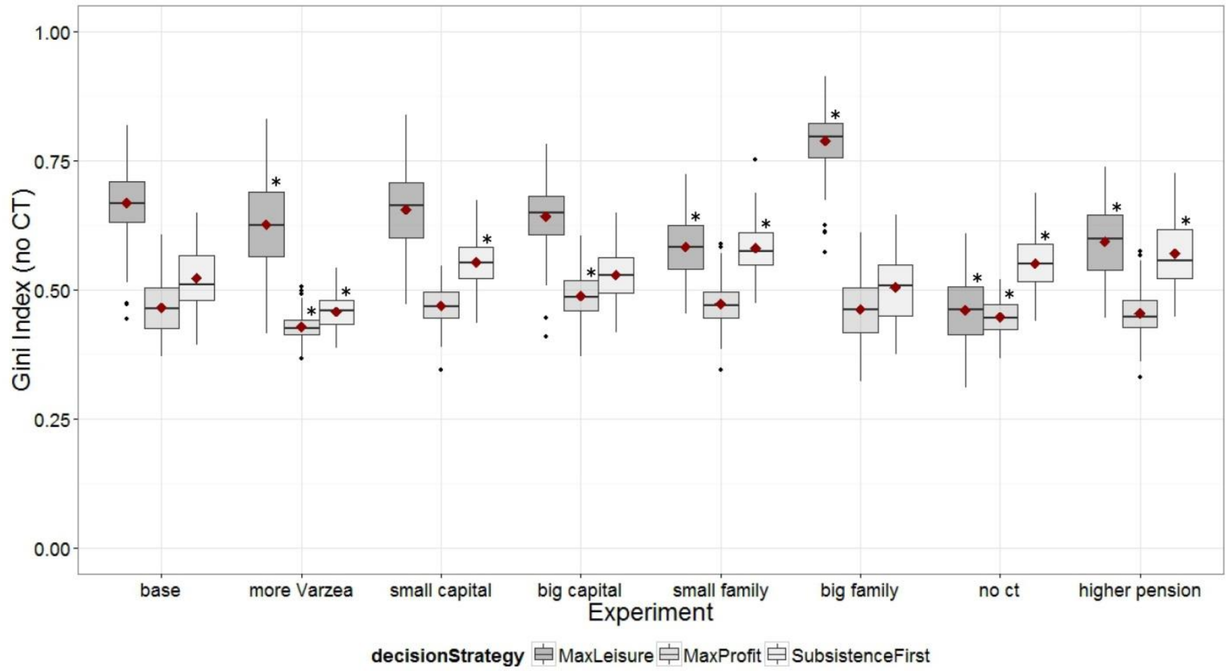

Figure 4-8 Gini Index of each experiment in three decision ensembles. Red dots indicate the mean value, stars show a significant difference of the sample distribution compared to baseline.

(2) Gini index calculated with cash transfers

When calculating gini index with cash transfers (Figure 4-9), a drastic change in the overall pattern occurs. First of all, Max Leisure now has the lowest value across all eight experiments and Subsistence First has the highest value of Gini index. Including cash transfers have a bigger impact on Gini index value in Max Leisure and relatively small impact for Max Profit and Subsistence First. Most experiments change the average Gini index to the same direction compared to baseline (e.g., V+ decreases income inequality with or without cash transfer in all three decision strategies), except that F- and F+ experiments have opposite directional impacts on Gini index with and without the presence of cash transfers. Under all decision strategies, V+ and F+ can decrease the income inequality with the presence of cash transfer. Moreover, the results of Gini index have a smaller variation with the presence of cash transfers, especially for Max Leisure.

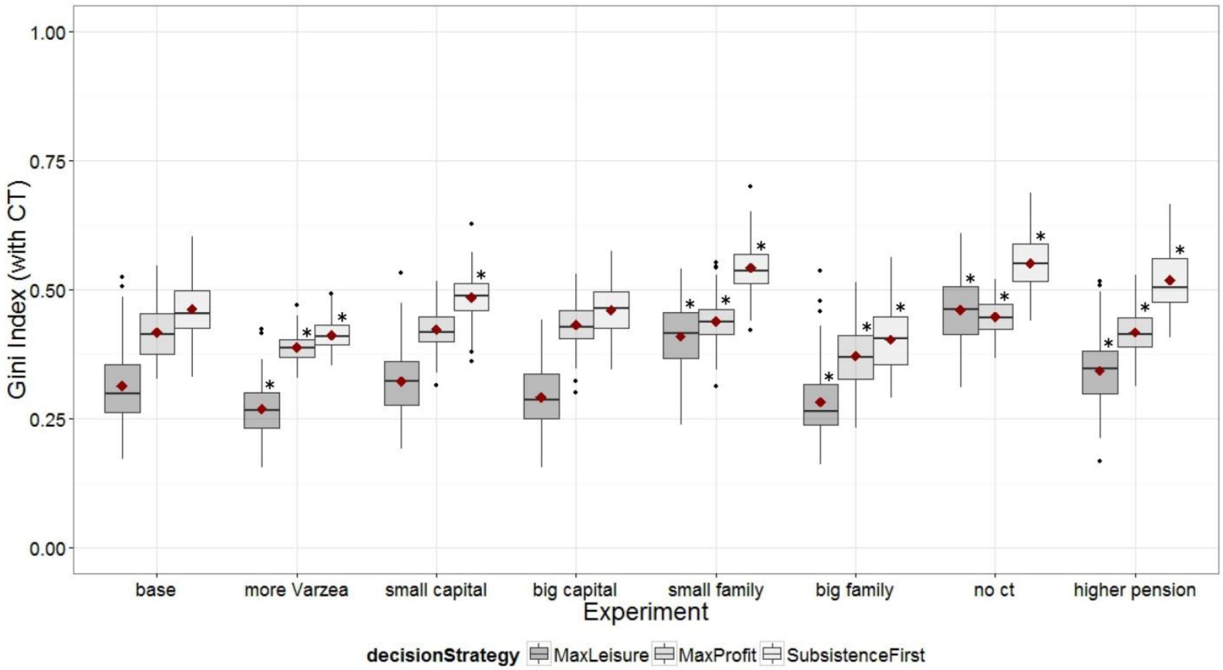

Figure 4-9 Gini Index with Cash Transfer of each experiment in three decision ensembles. Red dots indicate the mean value, stars show a significant difference compared to baseline.

(3) Poverty gap without cash transfers

The Poverty Gap index that calculated without cash transfer (Figure 4-10) indicates that among the three decision making strategies, Max Profit has the lowest average Poverty Gap across all experiments while Max Leisure has relatively high average Poverty Gap, except for experiments of F-, CT-0, and CT+ where Subsistence First has higher value. Max leisure also has the widest range of distribution (showing by the length of the bar) in Poverty Gap among the three decisions, while Max Profit produces the most consistent results within each experiment.

For **Max Leisure** regime, the most influential experiment is no cash transfer (CT-0), which decreases Poverty Gap from 0.455 in baseline to 0.127. Having bigger family (F+) is the only experiment that increases the Poverty Gap. All other experiments with the exception of the more várzea scenario (V+) significantly affect the Poverty Gap. Under **Max Profit** decision, small family experiment (F-) has the biggest negative impact on Poverty Gap, increasing the value from 0.044 in baseline to 0.14. Experiment F+, CT-0, and CT+ also increase the poverty issues. For **Subsistence First** decision regime, F+ can improve the Poverty Gap from 0.159 in baseline to 0.116. In addition to F+, having C-, F-, CT-0, CT+ all increases the Poverty Gap, which is similarly to their impacts in Max Profit.

Across the three decision regimes, having more várzea is no longer an influential factor in any ensemble case for Poverty Gap, on the contrary to its significance in Gini index. The experiments of family size (F- , F+) and pension settings (CT-0, CT+) significantly affect the Poverty Gap differently across all decision regimes (e.g., the cash transfer experiments improve the poverty situation in Max Leisure, but deteriorate it in Max Profit and Subsistence First).

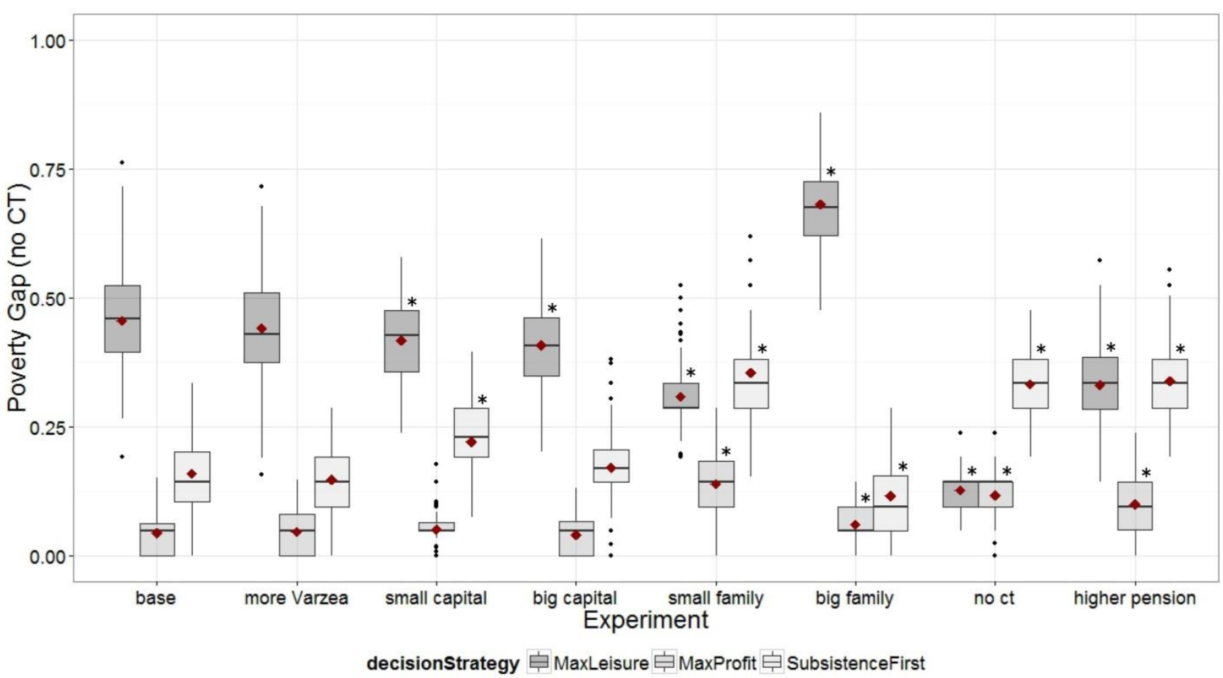

Figure 4-10 Poverty Gap of each experiment in three decision ensembles. Red dots indicate the mean value, stars show a significant difference compared to baseline.

(4) Poverty gap calculated with cash transfers

The Poverty Gap calculated with cash transfer across three decision regimes (Figure 4-11) shows that the mere presence of cash transfers plays a significant role in poverty alleviation, which largely decreases the Poverty Gap among all decision regimes and across all experiments. For instance, the Poverty Gap index calculated without cash transfer for households that maximize leisure in baseline is 0.455 and only 0.017 when considering cash transfer, and it is nearly zero for Max Profit at baseline experiment. When comparing the seven experiments to baseline, only small family (F-) and no cash transfer (CT-0) are significant to the value of Poverty Gap.

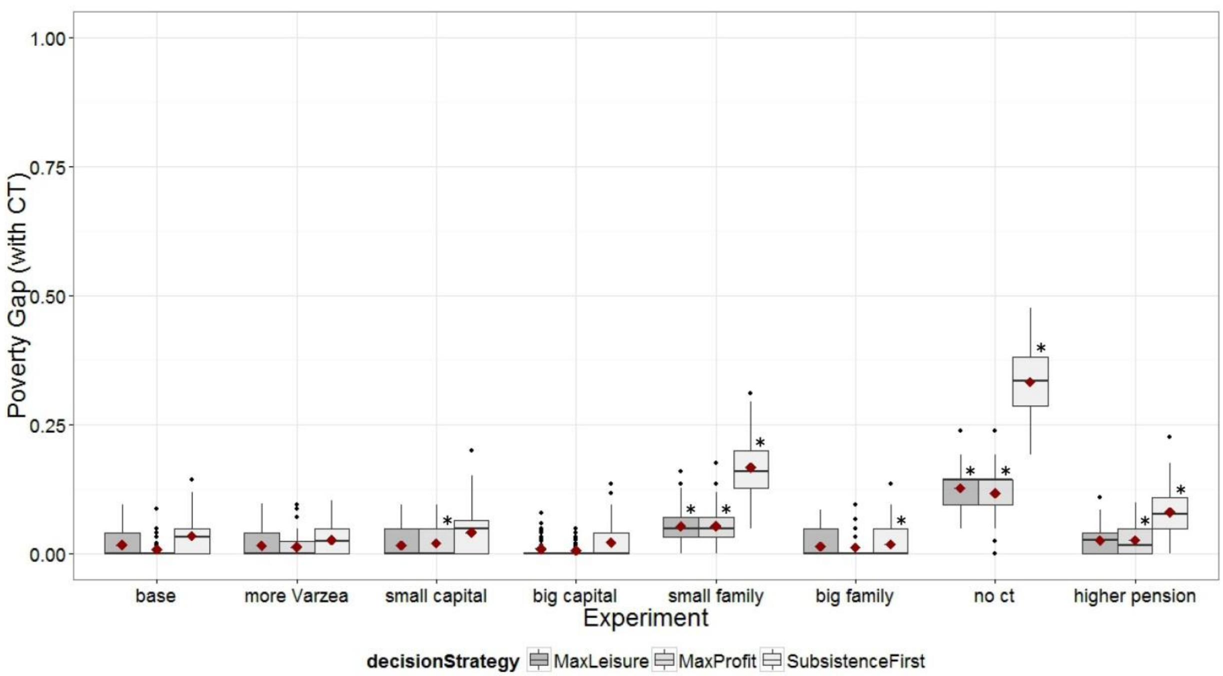

Figure 4-11 Poverty Gap with Cash Transfer of each experiment in three decision ensembles. Red dots indicate the mean value, stars show a significant difference compared to baseline.

For **Max Profit** households, C-, F-, and CT experiments increase poverty severity in relation to baseline experiment. Having F+ improves the poverty condition for Subsistence First regime, while F- experiment has opposite impact. Overall, a greater demographic of smaller families increases the Poverty Gap index regardless of human decision-makings. However, having more big families experiment can improve the Poverty Gap in Subsistence First experiment.

There are a few overall patterns found in the results. The first is that the presence of cash transfers largely improve the equality of income distribution and degree of poverty (the comparison between Gini index with and without the consideration of cash transfers, and Poverty Gap with and without cash transfers), especially the Poverty Gap, which has been largely reduced across all three decision regimes. Among three decision strategies, the presence of cash transfers has most drastic impacts on Max Leisure regime.

The second overall pattern is that the application of cash transfer programs has a negative impact on the production income equality and poverty severity (the comparison of indices without cash transfers between no cash transfer experiment with baseline). Yet having higher pension does not produce a consistent impact.

The third one is that experiments that are influential on the outcomes are different across decision regimes. Max profit decision regime is least sensitive to these experiments while Subsistence First regime is more sensitive to many experiments. The experiment of having more várzea has no significant impact on aggregated community outcomes, but does improve the income equality and poverty condition in relation to the baseline scenario across all three decision regimes. Another important factor to community outcomes is family size. Larger families may improve the overall equal distribution of income and poverty reduction for all three decision regimes. However, family size appears to have different impacts on economic indices with and without cash transfer in Max Leisure regime. For instance, smaller families reduce the

Gini index and Poverty Gap index without cash transfers, but increase the indices with cash transfers (and vice versa). The capital size (C-, C+) is not a significant factor for all indices across all three decision regimes. These results answer our questions regarding to the impact of cash transfers and particularly their different impacts on characteristics.

4.5 Discussion

4.5.1 What is the influence of the decision regime, cash transfers, and the household characteristics on rural livelihoods?

By applying post hoc analysis on the experiments and decision regimes of our agent-based model we were able to evaluate the effects of factors and decision regimes on household and community livelihood outcomes. Results from both household level and community level suggest that decision making regime is the most influential factor compared to other components in the rural farming system. Cash transfer programs, as a substantial income for rural households, can significantly reduce poverty and income inequality. However, the impacts of cash transfers vary across different decision making regimes. The overall distribution of certain household characteristics can influence the community livelihood outcomes, but this influence also varies across decision making. The different influence indicates that having a full picture of the outcomes from decision alternatives can enhance the confidential level when informing decision makers and making policy suggestions.

At the individual level, results from sensitivity analysis suggest that for households that maximize leisure, the number of eligible pensioner in a family is the most significant character for all individual livelihood indicators that we tested in this study, except income diversity. This type of households, or at least having the tendency of such decision strategy, might be able to explain the highly-dependent level that we found from the survey in 3.3.1.1 . However, this characteristic is not significant for most livelihood outcomes in Max Profit and Subsistence First strategy (except the diversities of production and income, which is because cash transfer also contributes largely as an income source). Having várzea is more important for Subsistence First and Max Profit households, especially for the production income and total income, due to its fertility for cash crop açaí.

Communities adopt the same decision strategy usually have similar livelihood outcomes no matter which experiment it is, particularly Max Profit that has the lowest variation. Clearly the influence of decision strategy is so significant that we should not neglect it when understanding the livelihood dynamics and evaluating policy impacts by a modelling approach. For instance, the same cash transfer program may be twice as effective on Max Leisure as Subsistence First strategy when we consider poverty reduction. It may direct the conclusion to a wrong way if only one single decision making is formed in the ABM, rather than exploring possibilities in outcomes with multiple decision ensembles. Therefore, besides the efforts to solve uncertainty by methods including agent heterogeneity (Huang et al., 2013), agent typology (Valbuena et al., 2008), and sensitivity analysis (Ligmann-Zielinska and Sun, 2010), it is important to incorporate decision strategies as part of inherited uncertainty in the modelling process for all circumstances.

The definition of ensemble in climate models is “a group of comparable model simulations” (Knutti et al., 2010, p. 2), which can appear in three categories: (1) multi-model ensembles that includes the impact of structural differences, (2) intra-model ensembles that differentiate the initial conditions, (3) perturbed and stochastic physics ensembles that sweep the internal model parameters within plausible range. On the contrary to the first ensemble that involves a group of different models, the latter two are within one single model and aim to estimate single model uncertainty systematically. Therefore, when transplanting the ensemble approach to agent-based modeling field, it is reasonable to argue that what we did in this chapter is also an ensemble that estimates the uncertainty systematically within this single model by having plausible decision strategies.

The influences of cash transfers on community livelihood outcomes are different across decision regimes and with different demographic and socio-economic experiments. The presence of cash transfers significantly improves the overall income and equality under Max Leisure decision regime; however, it is less influential for Max Profit and Subsistence First regimes. This pattern is consistent with our empirical findings from the survey data, with heterogeneous dependence levels on cash transfers among 634 households. Further the impact from the presence of cash transfers is more significant on poverty reduction rather than income equalization.

The analysis of cash transfer impacts in this chapter is not to quantify the multiplier effect from having no cash transfer to having cash transfer, it compares the effect to production income and the overall income among households that use different decision strategies. Therefore, we can investigate the heterogeneous impacts of applying the same cash transfer programs on household livelihoods. In future research, a cross-section literature review could be conducted to capture the multiplier effect from similar cash transfers that are applied in different regions (e.g., the program in Mexico and pension in South Africa) and to inform our model parameterization, so that improvement on livelihoods of having a stable cash transfer program can be modeled and compared.

However, there can be a built-in assumption from the decision strategies on agents' behaviors when in terms of receiving cash transfers. For instance, it is expected that Max Leisure households may reduce their work hours hence the reduced livelihood outcomes if a household receives cash transfer. However, it is still important to lay out the plausible outcomes from various decision strategies, since different household behaviors may lead to very different results from applying the same cash transfer program that is significant for policy implication.

Changing the overall distribution of certain variables can be influential for community livelihoods, but often it has to be investigated for specific decision regimes. Examples include encouraging bigger family size improves the poverty alleviation and income equality for Subsistence First households; conversely, it increases the Poverty Gap index in both Max Leisure and Max Profit decision regimes. By all means, internal labour is always an important factor in all household studies (Babulo et al., 2008; Cabrera et al., 2012; Tittonell, 2014) but its effect can be complex with the introduction of cash transfer programs. This may be explained as Subsistence First has high demand for labour so with bigger family it is likely for such family to succeed, especially those are big families to start with in the beginning of the simulation

There are also experiments that are significant for all three decision regimes, including more várzea for income equality, and some are usually insignificant no matter the decision regime, such as the initial capital. The impact of initial capital has been further discussed in Chapter 5. These findings are consistent with the land use pattern that found such results for a different region in Amazon (Cabrera et al., 2012). When designing policies or interventions, these factors can be effectively used or, on the opposite, be neglected. The significance of decision strategies and cash transfer also confirms our adaptation of adding these two components to the household livelihood conceptual model as necessary. The current model only tests the dynamics of one generation (simulation length is 30 years) and inheritance for successor will be included as another component to test in the future version.

The livelihood conceptual model we presented shows: small farming households' livelihood is an integrated outcome determined by their characteristics, the decision strategy they use, and the cash transfer programs. Using this adapted conceptual model and ensemble approach, we are able to investigate a comprehensive combination of all three livelihood components instead of focusing on only one. Indeed, potential government policies increasing household livelihood are more effective if it is on household behavior since some characteristics have been shown to be insignificant. The effects of having cash transfer are also more influential than the unit of cash transfer. More importantly, with these ensemble members of decision strategies, we can inform policy makers with more specific suggestions on different communities with targeted livelihood outcome, or a more cost-benefit implementation of existing programs to achieve the same overall goal.

4.5.2 Modelling coupled human-environment systems

To solve the complex issues of coupled human-environment system and the modelling representation, O'Sullivan et al (2015) summarized four approaches including (1) sensitivity analysis, (2) participatory modelling, (3) hybrid modelling, and (4) theoretical engagement. This chapter utilized theoretical engagement to explain the patterns of livelihood that we discovered from empirical analysis and link the pattern-to-process as the foundation of the decision theory in our ABM. We also applied sensitivity analysis to our model by using Turkey HSD analysis and variance-based sensitivity analysis, which helps us understand the coupled system thoroughly and in-depth. The hybrid modelling approach, in O'Sullivan's opinion, is to couple models from different discipline, such as link carbon model and the human behavior model together

(Robinson et al., 2009). We adopt the ensemble approach from the climate change modelling community which is to gather a few models that solve one problem with different assumptions. This ensemble approach can be combined with the idea of modular development in ABM (Bell et al., 2015). Same module but with different ingredients can be used as ensemble members for ABM.

Uncertainty in ABM and coupled human-environment systems has been a long-term challenge that modelers are facing. There have been many advancements in model development and evaluation, such as ODD process for modelers to communicate (Polhill et al., 2008; Schreinemachers and Berger, 2011) model component evaluation (Parker et al., 2006), and meta-analysis (Magliocca et al., 2015). Sensitivity analysis is a commonly used approach, and its explicit assessment of uncertainty can help modelers focus on research questions, lead to proper explanations, and make novel predictions. Nevertheless, this post-hoc analysis might be operated on a wrong fundamental assumption within the model. The ensemble approach, together with sensitivity analysis, treats uncertainty from the outset instead in one direction and a fixed setting, which gives us better confidence and more options to inform policy makers.

Nonlinearity is a significant attribute of any coupled human-environment system (Liu et al., 2007). Our results clearly show that there is no general pattern of the relationship between different features to the livelihood outcome. The initial capital distribution changing from low to high does not cause the community level livelihood metrics to switch from poor to good. The impact of cash transfer is even more distinctive. Having no cash transfer at all and having higher cash transfer unit are simultaneously negative or positive for community income equality and wealth. This has also been observed in our empirical data analysis in Chapter 3 (e.g., the size of household contributing to the likelihood of dependence differently in two cohorts).The baseline experiment has lower total Gini index and Poverty Gap index compared to both the no cash transfer experiment and higher cash transfer experiment. For individual decision regimes, sometimes the baseline has better community performance; sometimes the no- and high-cash transfer experiments have better outcomes. This nonlinearity has also emerged in other ABM simulations, such as the results from FEARLUSS-SPOMM, which suggests against the naïve expectations of more incentives will secure more biodiversity (Polhill et al., 2013), instead, it is a nonlinear relation between incentives and biodiversity. Despite the nonlinearity in cash transfer and capital attributes, labour shows a more consistent effect on the outcome: having more large families tend to make the community wealthier and income more equally distributed.

4.6 Conclusion

Multiple efforts have been put to cope with uncertainty that emerges from modelling coupled human-environment systems, especially the human decision making as a main source for the uncertainty. In addition to current attempts of using ABMs to understand rural livelihood systems, we construct an ABM with three livelihood strategy modules as ensemble members to represent the livelihood dynamics of smallholders in the Brazilian Amazon estuary region, to fully explore the alternative outcomes around different decision making models. The ensemble approach that we presented here is not new in climate modelling community, which has been used as a standard approach to predict future climate trajectories, but it is rather novel for ABMs to incorporate the uncertainty into the structure of the modelling process. With multiple decision makings established as ensemble members, the ABM is capable of investigating the range of livelihood outcomes and the socio-economic and demographic variables that play significant roles in different decision regimes.

Developing ABMs with an ensemble approach (in this case, it is the human decision module) can also provide insights to the different impacts of cash transfers on livelihood income. Results from sensitivity analysis suggest that a household's livelihood strategy is the most influential to livelihood outcomes at both the community level and individual level. Cash transfer programs largely improve the income and its equal distribution, but the influence changes with the decision strategy (e.g., the most drastic impacts are on Max Leisure households). Further, it suggests that policies that target at different livelihood factors (e.g., land type, family size, education) will also have different impacts for household agents who use different decision making models. For example, improving education is significant for Max Profit adopters but not so much for households with Subsistence First or Max Leisure, where the demographic structure plays a significant role. As such, the integration of the ensemble approach in ABMs offers the chance to cope with uncertainty that inherited in coupled human-environment systems and emerged in the modelling process, which allows us to evaluate more possible outcomes from policies and better inform future policy changes.

Chapter 5 Through the lens of development resilience: using agent-based modelling to explore rural livelihood resilience

5.1 Introduction

It has been estimated that at least one billion inhabitants of rural settings are poor, which accounts for 75 per cent of the world's poor and food insecure people[19]. Poor households that rely on agricultural and natural resources for their livelihoods are increasingly exposed to threats from climate change, economic unpredictability, disease epidemics, and political instability. One example occurs in the Brazilian Amazon estuary region, which has experienced slower development for decades compared to other regions in the nation (Azzoni, 2001). The per capita gross domestic product (GDP) of State of Pará in this region is 52 per cent of the national average and its Human Development Index ranks 24th among the 27 Brazilian states[20] in 2012. This region has experienced increasing climate variability in the past few decades and more severe droughts and floods (Pinho et al., 2014). The vulnerability of poor rural populations to these climate threats was exacerbated by the abrupt cancellation of the *Seguro Defeso* fishing insurance program in December 2015, affecting 590,851 beneficiaries[21].

The impacts of the climatic and socio-economic changes stand to disproportionately affect rural households because of their limited ability to absorb shocks and cope with changes (Carter et al., 2007). Therefore, it is urgent for scientists to assess and study the resilience of rural livelihoods. The insights of resilience dynamics that emerge from such studies can be used to inform policy-makers on how to address these challenges effectively, which would also be

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[19] http://www.fao.org/resilience/background/en/
[20] http://www.pnud.org.br/atlas/ranking/Ranking-IDHM-UF-2010.aspx
[21] http://www.previdencia.gov.br/2015/12/beneficios-inss-estabelece-procedimentos-para-a-concessao-do-seguro-defeso/

advantageous for major donors such as the Food and Agriculture Organization (FAO) and World Bank, who can work to implement resilience practices that achieve sustainability in rural livelihoods.

Financial and resource destitution is the fundamental cause of rural households' vulnerability to increasing climatic and social risks (Carter et al., 2007). Households that fail to maintain minimal subsistence are unable to build up their productive assets, generate income, or adequately feed or educate their children. Being unable to fully sustain themselves on a regular basis makes it that much harder to come out from a disaster unscathed. Due to the challenges created by the rural poverty, any initiative to help improve resilience to disasters for these households must first tackle the poverty trap, which is the position that will cause further livelihood degradation.

Figuring out how to move people out of the poverty trap is a problem that has occupied development economists for many years (Barrett, 2008; Carter et al., 2007; Thomas and Gaspart, 2015). Development theory, with its focus on poverty dynamics, bears a strong resemblance to resilience theory. For example, resilience theory's "basin of attraction" concept suggests that a system may remain in a basin (poverty) if the endogenous factors of a system are between thresholds that define a basin. In development theory, the "poverty trap" likewise is a critical minimum threshold of assets and income earning capacity below which families are unable to maintain a basic livelihood or well-being over time (Barrett, 2008; Carter et al., 2007; Enfors and Gordon, 2008). Moreover, both fields share the goal of helping rural households achieve self-sufficiency. Despite the above-mentioned similarities and the possibility of mutually beneficial relations between resilience and development theories, few scholars have viewed poverty through the lens of resilience. Therefore, we use the concept of "development resilience" among our various applications of resilience.

Development resilience is defined as "the capacity over time of a person, household or other aggregate unit to avoid poverty in the face of various stressors and in the wake of myriad shocks" (Barrett and Constas, 2014, p. 14626). That capacity must remain high over time for the unit to be considered resilient. This definition addresses goals from both fields: the avoidance of poverty and the maintenance of the resilience capacity. The case study in this chapter, rural households in the Brazilian Amazon estuary region need to be resilient when facing climatic and market risks. Meanwhile, staying away from poverty must also become a priority for the *Caboclos*, the local households in the region that rely on agriculture, agroforestry, and fishing and shrimping to earn a living. This novel definition of development resilience can guide our case study in this chapter by addressing the two focal points of poverty reduction and resilience enhancement, and can encourage conversation between the two fields to mutually advance both theories, by investigating poverty dynamics through a resilience framework.

Specific interventions and management policies are required to reduce poverty and increase resilience in practice (Biggs et al., 2012; Walker et al., 2010). Government cash transfer programs are a powerful but often controversial intervention. Some have been shown to have a positive influence on children and women's health (Paes-Sousa and Santos, 2009; Paxson and Schady, 2007) and education (de Brauw et al., 2014; Schwartzman, 2005). However, their role in income and livelihood improvement is debatable, as growing dependency on these programs is a major concern (Sadoulet et al., 2001; Standing, 2008). Moreover, few have investigated these programs' impact on development resilience despite the widespread coverage and significance of cash transfer programs in developing countries. Guidance to change livelihood strategies is an approach that can be conducted actively by households. In this intervention, rural households are assisted in a transition from subsistence-oriented to market-oriented behaviours (Cramb et al., 2009; Magliocca et al., 2014). This transition bolsters their income yet results in the loss of traditional knowledge and income diversity, both tools that are valuable for households in adapting to economic and environmental changes (Vogt et al., 2016). We will be looking at these two poverty interventions using development resilience framework.

To date, resilience has been studied from either a theoretical perspective (Barrett and Constas, 2014) or largely based on empirical observations (Cinner et al., 2011; Enfors, 2013; Enfors and Gordon, 2008; Lebot and Siméoni, 2015; Schwarz et al., 2011; Tittonell, 2014; Vogt et al., 2016) and field experiments (Diniz et al., 2015). Such case studies attempt to understand the dynamics of rural livelihood and have concluded that diversification of assets and farmers' experiences with previous hazards can enhance resilience (Carter et al., 2007; Cinner et al., 2011; Vogt et al., 2016). To extend the scope of these empirical and statistical studies, we use an agent-based model to study resilience under shocks and explore the effectiveness of different interventions, based on resilience-informed scholarship as well as the concept of "development resilience".

Agent-based modelling (ABM) is an approach that represents coupled human-environment systems by agents who are programed with decision rules and interact with the environment. It is a tool that has been widely utilized to explore the dynamics of complex systems, yet few ABMs have explored poverty and livelihood dynamics within a resilience framework. Using an agent-based model, we represent the livelihood system of small farming households in the Brazilian Amazon estuary. The flexibility embedded in ABM allows us to test agents' response to various shocks and to evaluate the effectiveness of different interventions for enhancing resilience, both of which are challenging for empirical studies. Using ABM to study resilience can be beneficial in deepening our understanding of both the modelling approach and the resilience concept. With the theoretical foundation, modelling offers us an opportunity to check the credibility of resilience theory.

Simulating small rural households in the Brazilian Amazon by an agent-based model, this chapter takes a resilience approach to investigate livelihood and poverty dynamics. We also investigate the impact of different types of shocks on livelihood dynamics and the influence of interventions, such as government cash transfer programs, on escaping poverty. We argue that cash transfer programs are more likely to increase household livelihood resilience if a large amount of capital is given upfront. We organize our analysis following five steps of resilience assessment, later discussing our findings in relation to theories of development resilience and poverty dynamics. Finally we conclude the chapter by comparing the effectiveness of the various proposed interventions when it comes to escaping poverty and maintaining livelihoods.

This chapter is an attempt to track and reveal poverty dynamics utilizing a modelling approach on a case study. Within the context of development resilience theory, we ask this question: How effective are cash transfer and other interventions for reducing poverty and enhancing resilience? To answer this question, the following questions need to be answered to gain a full understanding of the dynamics: (1) What are alternative states to resilience in rural livelihood systems? (2) What are the impacts of each shock and which shocks have the severest negative influence? (3) What causes households to fall into the poverty trap or stay well-off under all circumstances? How about households in between the two states?

Instead of a single value signifying the resilience measurement, answers to these questions give us insights of the formation of poverty and dynamics of livelihoods. Exploring these questions fully utilizes the agent-based model as a tool to extend the scope of field observations and pure theoretical exploration and to test interventions in poverty reduction. Results built on the ideas of resilience theory reinforce our perceptions of basins of attraction, stable landscapes, and non-linear system behaviors, all contributing towards a more thorough understanding and a pathway towards more accurate theory development. As a pioneering effort, this chapter also demonstrates a resilience framework by using an agent-based model to study poverty and development dynamics. Findings, including the reasons for poverty traps, sources of resilience, and the effectiveness of cash transfer programs, are significant to policy makers looking for effective strategies for resilience-related policy and decision making for rural farming households.

To better structure the assessment, we follow the five steps of the resilience assessment framework (Figure 5-1) and organize this chapter as follows. In next section, we discuss the steps of resilience assessment, including the design of external shocks, classification methods, and the multiple factor analysis to identify sources of resilience; in Section 5.3, we present the results from our agent-based simulation and answer the major questions outlined in the introduction; Section 5.4 outlines the results and compares them with other studies. The last section summarizes the findings of this chapter and explains its usefulness in guiding policy making.

5.2 Methods to assess resilience

5.2.1 Steps of assessing resilience

Resilience has been specified as a property of a complex system, yet it's not clear how it is calculated (Quinlan et al., 2015). In order to rigorously and repeatedly assess resilience as one property of the livelihood system using our ABM, we adapted the five steps of the resilience assessment framework (Figure 5-1) that are suggested in Resilience Assessment (Resilience Alliance, 2010). Most tasks in the first two steps of the assessment have been covered in this chapter (including the definition of resilience) and in the previous two chapters (the identification of key issues, the model development, and multiple reliance states). However, we are not looking for a metric to measure the value of "resilience", rather, the assessment framework provides us the possibility to review the dynamics of this livelihood system. Specifically, following the development resilience concept, more resilience is better since we want to enable the upward development. Therefore, the use of term "resilience" or "be resilient" in this chapter means the system is capable of staying in a favorable state, in our case, a livelihood state.

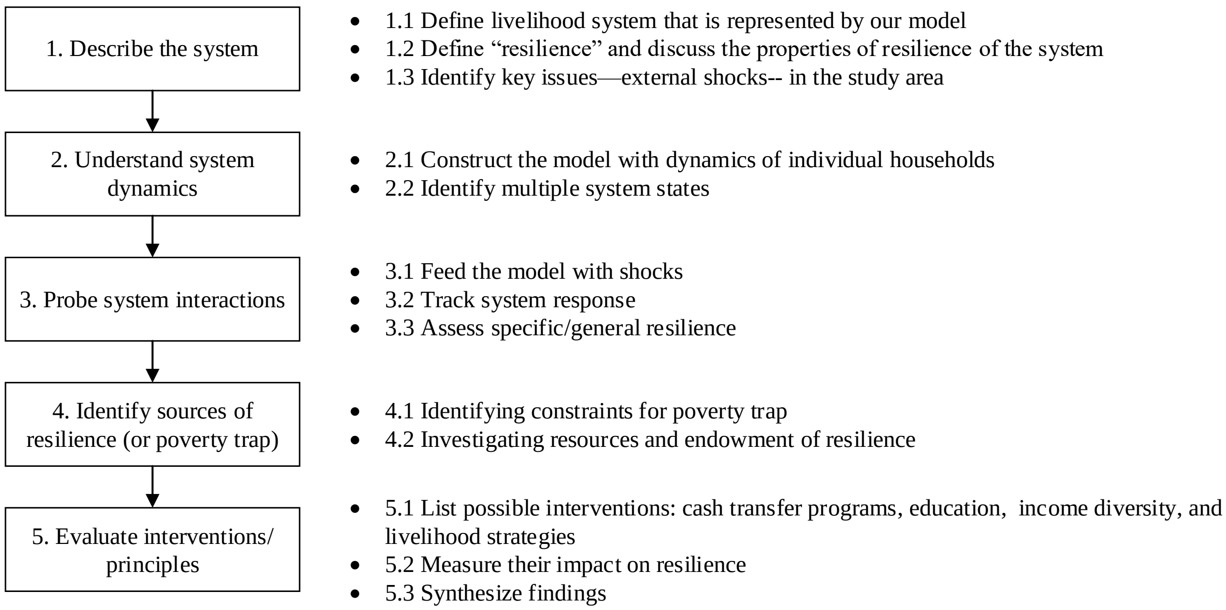

Figure 5-1 Five steps of the resilience assessment framework (adapted from (Resilience Alliance, 2010))

5.2.2 Describe the system using an agent-based model

In our ABM, the agents representing rural households contain household members and resources that are initialized with an empirical distribution. The environment has two categories of land types: várzea and upland. Várzea represents the floodplain areas on which açaí can grow, while uplands areas support the growth of other crops, including manioc. Details of the *Caboclos* rural livelihood can be found in Chapter 3 and design and components of our model can be found in Chapter 4, particularly the three decision making strategies that are embedded in the ABM as an ensemble approach.

In addition to the change from static external factors to dynamic environmental factors, we also changed the expectation variable in decision making strategies to an average three-year window based on households’ memory capability (Brondizio and Moran, 2008). Households agents store the crop price and yield of past three years, and they use the average value of the past three years as expected price or yield for their land use decisions. Each shock scenario (detailed in section 5.2.3) was run under three decision making strategies respectively. 30 repetitions randomized on capital, demography, education, and land property[22], resulting in 90 repetitions for each shock type.

5.2.3 External shocks to system and scenario design

In this section, the design of scenarios of external shocks and cash transfer settings are introduced. The *Caboclos* are facing increasing risks from their coupled human-environment system. To evaluate the impacts of potential shocks and prepare households for them, we simulate three different disturbances: the boom-bust cycle of market crop açaí, climate hazard, and a national economic recession that reduces the availability of off-farm jobs (Table **5-1**). Regulating the disturbances to the same degree in duration (i.e., the shock will last for five years) and severity (i.e., the value of each representing variable in the model drops by 90 %) can help us establish the basins of attraction and compare the impact of different shocks on resilience.

Cash transfer programs have been an important intervention for poverty reduction. However, the cancellation of cash transfer programs is another potential risk. When the nation's economy is in recession, it is possible that the government will cut programs in coverage or amount. For example, the Brazilian federal government has cancelled the *Seguro Defeso* fishing compensation insurance. Therefore, we design three cash transfer settings along with shock types (Table **5-1**) to evaluate the impacts of cash transfers as a social assistance as well as a shock for its sudden cancellation. It is important to consider the full set of possible shocks and to test them in a logical sequenced program for a coherent picture, and the model outcomes of which scenario is analyzed is demonstrated (Figure 5-3).

[22] We choose 30 repetitions because the variation is the same as 50, see Chapter 1Appendix E.

5.2.4 Livelihood state classification

Livelihood systems have multiple output measurements and states. We select individual household wealth (the accumulative capital of a household) as the livelihood output and trace its dynamics to categorize livelihood states, since we are interested in poverty. Barrett & Constas (2014) classified three states in development resilience: humanitarian emergency zone (HEZ), chronic poverty zone (CPZ), and non-poor zone (NPZ). We use per capita household wealth to quantitatively classify the three states. In HEZ, households are in absolute poverty, while in NPZ, they could have a "concave, monotonically increasing function" of livelihood (Barrett and Constas, 2014, p. 14626). The authors also pointed out that the existence of a threshold between the "chronic poverty zone" and the "non-poor zone" is still under empirical study. We have observed such patterns in our model results; hence we imported this "chronic poverty zone", which also adds depth to the analysis. The descriptions are as follows:

- HEZ-0: per capita wealth is below zero, which suggests that households may need immediate humanitarian assistance;
- CPZ-1: per capita wealth is below 6000 monetary units in the model[23]. The threshold of the poverty line in this model can be tricky; however, we used the third quartile of per capita wealth[24] at simulation year 10 as our threshold to divide the chronic poverty and non-poor zones, since the first quartile should usually be the better-off families and is consistent with most field research (Babulo et al., 2008; Carter et al., 2007). Although this value is chosen arbitrarily, it provides an overall threshold to compare between scenarios, which is more effective than relative values such as a rate or percentage;

[23] It is a relative unit, not equivalent to Brazilian currency.
[24] The precise value is 6,278, we round it down to 6,000 for simplicity.

moreover, the standard of living is not supposed to change over time (Barrett and Constas, 2014).

- NPZ-2: household per capita wealth is beyond the threshold, which represents a sufficient household wealth.

5.2.5 Tracking system response

We sample the livelihood state of households at three crucial time points: Pre-Shock (Year 10), After Shock (Year 16), and at the End of simulation (Year 30) to track the system response for shocks, similar to previous field studies (Carter et al., 2007). Therefore, we have three digits to represent the livelihood state of every household in these time points. The form of the digits is X-Y-Z. X is the state for Pre-Shock, Y is the state for After-Shock, and Z is the state for the End of Simulation. The value of X, Y, Z comes from HEZ-0, CPZ-1, and NPZ-2.

For instance, a code of 112 means household belongs to CPZ-1 before and after the shock, and goes up to NPZ-2 by the end of simulation. By comparison, a code of 100 suggests a household was at CPZ-1 before shock but was pulled back to HEZ-0 and remained there over the simulation period. This approach provides us an overall picture of a households' livelihood dynamic and capability to handle shocks with a three-digit code. It also offers us the freedom to investigate household livelihood at any crucial time slot. For instance, we are able to summarize the statistics at the end of the simulation by looking at the last digit of the codes.

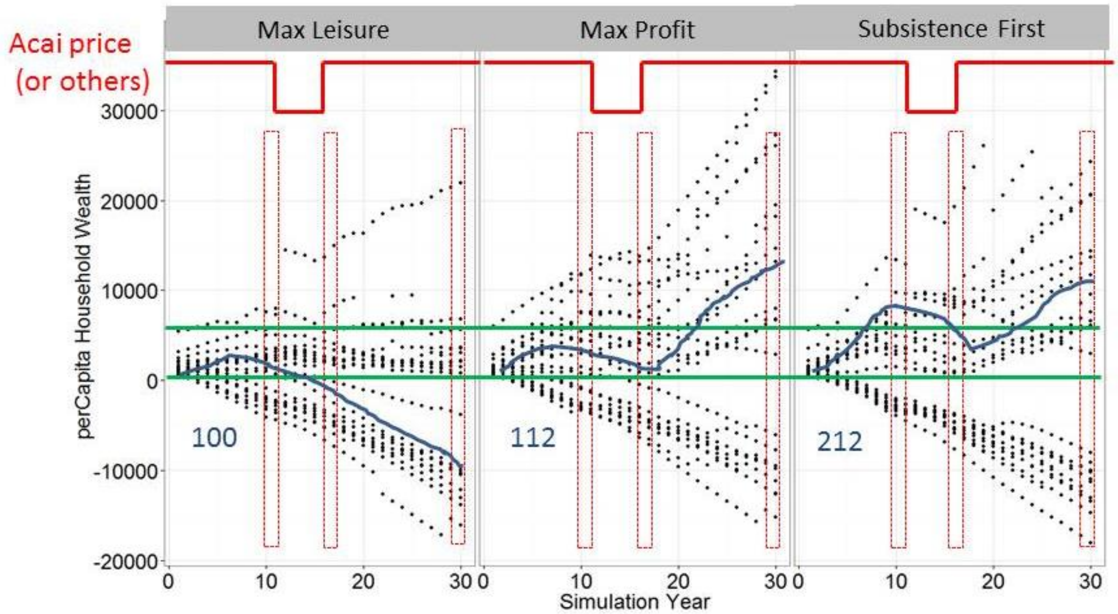

Figure 5-2 Demonstration of the coding system. The x-axis is the simulation year from year 0 to year 30 while y-axis is the per capita household wealth. Three strategies are in three panels. The two green horizontal lines are the threshold to distinguish the three livelihood states. The three red boxes indicate the critical year that we are tracking: pre-shock, after-shock, and at the end of simulation. The red curve on top represents the price of acai and demonstrates the drop from year 11 to year 15. We use the blue lines to give examples of three household trajectories 100, 112, and 212.

Table 5-1 External shocks that *Caboclos* might encounter

Cash transfers	Shock Value	Shock Variable	Açaí Price	Climate	Job Offers	Shock Duration	Shock Magnitude
No, Static, Dynamic	NO_SHOCK	Baseline	Static	Static	Infinite	---	---
No, Static, Dynamic	SINGLE	Açaí Price Shock	Dynamic	Static	Infinite	Yr: 11-15	Açaí price drops by 90%
No, Static, Dynamic	SINGLE	Climate Shock	Static	Dynamic	Infinite	Yr: 11-15	Açaí Yield drop by 90%
No, Static, Dynamic	SINGLE	Job Shock	Static	Static	Dynamic	Yr: 11-15	Available off-farm jobs drop to 10 % of entire population
No, Static, Dynamic	DOUBLE	Açaí & Climate	Dynamic	Dynamic	Infinite	Yr: 11-15	Both açaí price and yield drop by 90%
No, Static, Dynamic	DOUBLE	Açaí & Job	Dynamic	Static	Dynamic	Yr: 11-15	Açaí price drops by 90% and available off-farm jobs drop to 10 % of entire population
No, Static, Dynamic	DOUBLE	Climate & Job	Static	Dynamic	Dynamic	Yr: 11-15	Açaí yield drops by 90% and available off-farm jobs drop to 10 % of entire population
No, Static, Dynamic	TRIPLE	Ultimate Shocks	Dynamic	Dynamic	Dynamic	Yr: 11-15	Everything drops by 90%

Note: every shock scenario has been run with all three decision strategy ensembles and under three cash transfer settings. No cash transfer: when there is no cash transfer during the simulation; Static cash transfer: cash transfer is constant over the whole simulation period; Dynamic cash transfer: when cash transfer is reduced by 90 % as a shock during year 11-15. However, we only present a section of analysis due to the context limitation. We only use static pension setting to compare the impacts of all seven shocks.

5.2.6 Evaluate specific and general resilience

Although the external shocks we applied to households are identical in duration and severity, their impacts on household resilience and states might not be identical. To compare each shock's impact, we use ANOVA and paired-comparison to check if the specific shock would change household livelihoods compared to the baseline scenario. We use the three livelihood states in the baseline scenario as a benchmark to categorize the livelihood patterns in other scenarios, so that we can quantitatively measure the impact on livelihood patterns under different scenarios. The percentage of vulnerable households who are pushed into the poverty trap as compared to the baseline is a quantitative measurement of the impact of each shock.

5.2.7 Investigate resilience resources by multiple factor analysis

We use multiple factor analysis (MFA) to analyze household assets and decision data and observe an integrated picture of the households in the hope of both reducing data dimensions and drawing a typology of households in different livelihood state groups. Principle Component Analysis has been used in the resilience assessment to associate resilience responses or states with system characteristics (Cinner et al., 2011; Lebot and Siméoni, 2015). MFA, a type of PCA, is used to process a set of observations described by several groups of variables, whether quantitative and qualitative.

As the household livelihood conceptual model that we used in Chapter 3 suggests, livelihood is not only the outcome of assets and capabilities, but also livelihood strategies. Therefore, the MFA input includes households' initial wealth (household total wealth, per capita wealth), labour capacity (available labour, total labour, and subsistence requirement, and household size), human capital (husband education and average school year of female members), pension, land type (várzea and upland), and decision strategy (Max Profit, Max Leisure, and Subsistence First). Both land type and decision strategy are categorical data.

Using MFA, we are able to know which assets are important for households to be resilient. The two main components from MFA can represent most of the information required to describe the household characteristics in livelihood states and resilience. The purpose of MFA is not to provide accurate quantitative measurements of the importance of each household characteristic, for which a simple mathematical model can do the job, rendering ABM unnecessary. The goal of the ABM is mainly to point us towards which resources or constraints scientists and policy makers should address for specific types of household or livelihood state.

There are three purposes to applying MFA on household assets and decisions. The first is to identify the constraints on households that are trapped in the poverty zone and the significant resources needed to be in the non-poor zone. We apply MFA on households with pre-shock state HEZ-0 and NPZ-2 in the baseline scenario when there is no pension to fulfill this objective. The second reason to apply the MFA on households is to identify differences between households that are in the Chronic poverty zone, identifying the characteristics of vulnerable households that are moving upwards, for which the MFA on households with pre-shock state 1 from the same scenario is used. The third purpose of the MFA analysis is to determine if pensions are a significant factor in positioning households in the resilience landscape. We performed the same MFA operation but on households in the Triple Shock scenario when there is a static pension (Figure 5-3).

5.2.8 Orders of analysis and answers to research questions

Due to the substantial scenarios that we have simulated to fully explore the impacts from cash transfer and shocks, we report the analysis selectively in representative combinations (Figure 5-3). Details of more analysis can be found in Appendix G-I. We use output from all shock and cash transfer settings for the classification of livelihood state (5.3.1 . The impacts of cash transfers are analyzed in the baseline scenario with no shock treatment (5.3.2.1). The impacts of different shock types on livelihoods are illustrated in a constant pension setting (5.3.2.2). To identify main constraints and resources for households being at different livelihood states, we choose the static pension setting with baseline and triple shock scenario (5.3.3). Out of the two interventions besides cash transfer, the impacts of capital boost are analyzed with all three cash transfer settings in baseline and triple shock scenarios (5.3.4.1), while decision strategies are compared using static cash transfer and all shock scenarios (5.3.4.2).

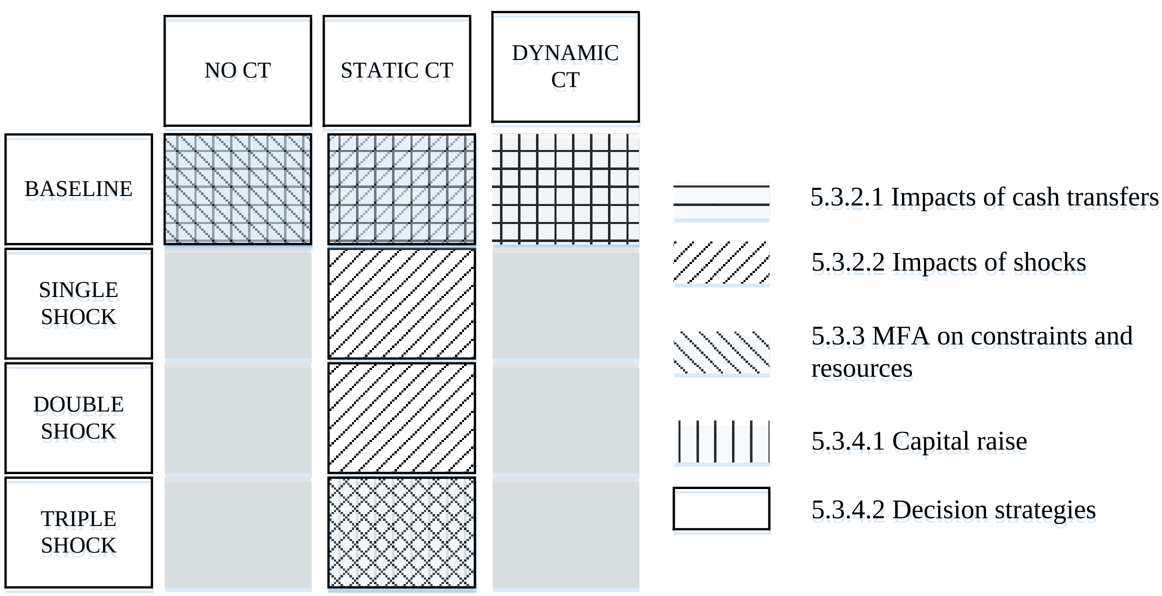

Figure 5-3 Selected scenario combination of analysis. To keep simplicity, certain analysis is only conducted in a specific shock scenario and cash transfer settings, which are indicated by the pattern of the box. For instance, 5.3.2.2 the impact of shocks is analyzed under the baseline,

single shock, double shock, and triple shock scenario with the static cash transfer setting, and the boxes are fulfilled by the left-bottom to right-upper lines.

5.3 Results

5.3.1 Attributes of livelihood state

In this section, we report livelihood states using the classification method, to address the question "*What are alternative states to resilience in rural livelihood systems*". In theory, there should be 27 combinations in our system, with three states at three time slots. However, we only observe 14 out of 27 (Table **5-2**), of which merely eight combinations have a proportion larger than 1 % of the agents in simulation. Households that start with HEZ-0, the lowest measure, always remain in that state over the next two stages (coded as 000). The majority of households in State NPZ-2 right before the shock always bounce back and end up in State NPZ-2, as represented by 212 and 222 (Table 5-2). Once a household has reached NPZ-2, it will always remain in the non-poor zone at the end of simulation. However, households in state 1 can end up in any state.

Table 5-2 Observation of possible combinations of states

possible combinations of states									
0-XX	**000**	001	002	010	011	012	020	021	022
1-XX	**100**	101	102	**110**	**111**	**112**	120	121	**122**
2-XX	200	201	202	210	211	**212**	220	221	**222**

Note: 101, 120, 121, 210, 211, and 221 are Rarely Seen as the proportion is smaller than 1 %, sometimes smaller than 0.1 %. The rest grey shaded combinations are Not Seen in simulation. The rest are considered in analysis as regular cases.

Both exogenous and endogenous processes can lead to changes in the state of a system. In the baseline scenario, when there are no external shocks to the system, households may still switch from State 1 to State NPZ-2 or HEZ-0, due to endogenous processes, including demographic changes and land use changes. Among the 40.79 % of households who are in state 1 right before the shock, 11.4 % of them went down to poverty by the end (5.4 % from 100 and

6.0 % from 110); 48.2 % of households reach State NPZ-2 by the end (from 112 and 122) while 40.4% of households did not move to either state.

5.3.2 Impacts of shocks on alternative livelihood states

We measured the proportional change of each code for each shock scenario from baseline with three pension settings using ANOVA and Tukey-HSD analysis (referring to Figure 5-3 and Table 5-1). This section compares changes of livelihood state proportion that occur with each shock type and vertically between pension settings (Table 5-3). Results show that shocks alter the proportion of each code group, except for 000. Again, these households are already deeply trapped in the poverty zone, hence external shocks only affect their livelihood negatively without changing the categories of these households. Indeed, external assistance is in urgent demand to bump them out of the poverty trap. Pension settings for their part change many, but not all, livelihood states. However, shock scenarios and pension settings do not have interactive effects on livelihood state (Table 5-3). Therefore, we can analyze the impact from shocks and pensions separately.

Table 5-3 ANOVA between shock types and pension settings

	000	100	110	111	112	122	212	222
Shock Type		***	***	***	***	***	***	***
Pension Setting	**	***		**	***			***
Shock Type & Pension Setting								

Note: Null Hypothesis: H_0, the mean of the proportion of each state in every model run is the same for all scenarios. If p-value<0.05, reject H_0. * indicates the significance.

5.3.2.1 The impacts of cash transfers in baseline scenario

This section can help us understand the impacts of cash transfers on baseline livelihood dynamics when there is no external shock. If the pension program remains the same over many years, we can consider pension distribution as an intervention. Such an intervention reduces the proportion of households who are trapped in poverty from the very beginning statistically. However the margin is quite small.

What is important is that when pension removal is introduced as another source of shock, there are more households who end up in the HEZ-0 zone. Surprisingly, without any pension program, more households are able to reach the NPZ-2 state at the end of simulation; when pension removal is introduced as a shock, we observe the lowest number of households that end the simulation in the non-poor zone compared to other scenarios.

Table 5-4 Impacts of pension on livelihood states.

Note: this is the proportion of households in different livelihood states in the baseline scenario under three pension settings. Complete comparison of pension and shock scenarios are in Appendix F.

Proportion of livelihood states								
Baseline	**000**	**100**	**110**	**111**	**112**	**122**	**212**	**222**
No Pension	39.02%	2.19%	2.44%	16.48%	7.43%	12.25%	0.03%	19.33%
Static Pension	38.25%	2.46%	2.26%	18.41%	8.73%	12.14%	0.12%	17.22%
Dynamic Pension	39.42%	5.08%	1.90%	16.72%	7.83%	12.28%	0.16%	16.19%

Although having a pension program may help some households in the poverty trap, the overall household livelihood states are not improved; especially when pension comes as an external shock (Dynamic Pension), the impact is not favorable (Table 5-4). If households grow to depend on pension payments, their sudden withdraw may cause more damage than good to livelihoods. Pushing households out of poverty might also need more than a unit of pension.

5.3.2.2 The impacts of shock scenarios within static pension setting

Now we look at the impact from different shocks (Table 5-6, here we use Static Pension as a demonstration, as other Pension Settings do not alter the results much, referring to Figure **5-3**).

This section answers "*What are the impacts of each shock and which shocks have the severest negative influence*".

We select shocks that are representative (Climate Shock, Climate and Job, Triple Shocks) to compare with the baseline (details of all shock types can be found in Appendix G). By definition, resilience of a household livelihood system is the ability to absorb shocks and maintain system functions. So we count the percentage of households that can stay in the same state after the shock. The first observation from the results is that none of the shocks change the proportion of 000 households. This type of households is determined by their endogenous constraints. The second result is that shocks usually have same orientated impacts on the livelihood tracks. This means that all shocks, if there is statistical significance, increase proportionally to State HEZ-0 towards the end of simulation ending up as 100 and 110. Shocks also move more households from 122 and 222 to 112 and 212 respectively. Some of the households who are in non-poor zone 2 at the after-shock stage might have moved to CPZ-1 state at after-shock stage due to those shocks.

The third observation is that climate shock has more impact than açaí shock. For instance, climate shock moves 4 % additional households to 100 compared with açaí shock at no pension setting; meanwhile, job shock has no significant impact overall. The double shocks, particularly açaí and climate shocks, have an even worse impact than the triple shocks. Overall, the shock with the highest negative impact is climate shock, followed by açaí shock, with the least influential impact coming from the reduction of jobs. It is worth noting that although job shock itself has no significant impact, when added up with other shocks such as climate, it brings an additional negative impact.

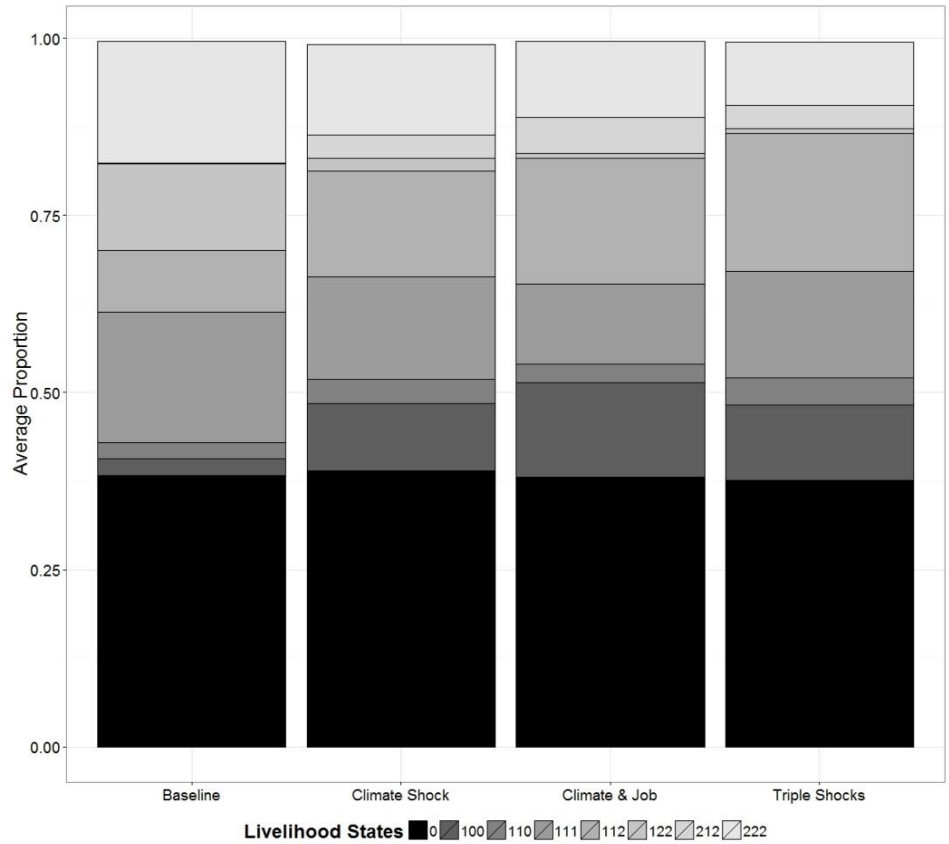

Figure 5-4 Proportion of Livelihood States within different shock types under Static Pension. We choose three representative shock scenarios to compare the proportion of their livelihood with the baseline. The proportion of households in the poverty zone is similar over the four scenarios, but the three shock scenarios have less well-off households compared to baseline**.**

5.3.3 Constraints and resources for households in different livelihood states

In this section, we present the significant constraints and resources for poverty and resilience, which are carried out by a multi-factor analysis (Table 5-5) and interpreted in a geometric way (Figure 5-5).

The analyses are carried out in three steps: First we identify the constraints that trap households in poverty (Livelihood State HEZ-0) and the resources that households have in the non-poor zone (Livelihood State 222) under the baseline scenario, Multiple factor analysis of household assets and decision strategies resulted in two factors that carry majority information.

There were subsequently termed “HEZ-0” and “NPZ-2”, and explained 42.03 % of the variance. The mean values of all variables are presented in Appendix F. Figure 5-5 shows how household characteristics contribute to different livelihood states. The NPZ-2 is reasonably explained by várzea land type and initial capital, while upland type explains HEZ-0. Two decision making strategies – Max Profit and Subsistence First – align with NPZ-2, and Max Leisure is on the same direction with HEZ-0. This analysis answers “*What causes households to fall into the poverty trap or stay well-off under all circumstance*”.

Table 5-5 Summary of four multi-factor analysis on baseline and shocking scenario

	Scenario	**Households in which Livelihood States**	**Examples of latent factors**
Fig 5-5 (a)	baseline	HEZ-0	max leisure, upland
		NPZ-2	várzea, subsistence first, max profit, high initial capital
Fig 5-5 (b)	baseline	CPZ-1 (100, 110)	upland, subsistence first
		(111)	max leisure, high initial capital
		(112, 122)	max profit, average female education,
Fig 5-5 (c)	shock scenario	HEZ-0	upland, high subsistence requirement, total labour,
		NPZ-2	várzea, high initial capital, max profit, subsistence first
Fig 5-5 (d)	shock scenario	CPZ-1 (100, 110)	max profit, upland, husband education,
		(111)	max leisure,
		(112, 122)	subsistence first, initial capital, várzea, hhd size, total labour

Our second step is to identify key factors that distinguish vulnerable and less-vulnerable households that are at bifurcation points (a point where the system is not in a lock-in situation and can move to both sides, such as the livelihood State 1-XX) in the baseline scenario, to address the question “*How about (the resources and constraints of) households in between the* *two states*". The MFA result changes when we move to analyze unstable states. State 100 is usually associated with upland, as well as 110 and 112. Várzea is correlated with 111 and 122. Average female education and a Max Profit decision making strategy can largely explain 122; however, maximizing leisure is the main component for 111.

Our third step is to identify the significant factors for resilience among households who are at bifurcation points under shocks. Looking at the scenario of triple shocks, the two basins of attraction are also significantly explained by the two land types as in step two. The orientation of decision strategy, however, changes compared to the state 1-XX in our baseline. A decision strategy to maximize profit now is associated with the same orientation as 100 and 110, while 111, 112, and 122 are on the same axis as Component 2 with a maximizing leisure and Subsistence First strategy. Pension and the education levels of the head of household can largely explain State 111 and 122. The MFA results can be found in Appendix I.

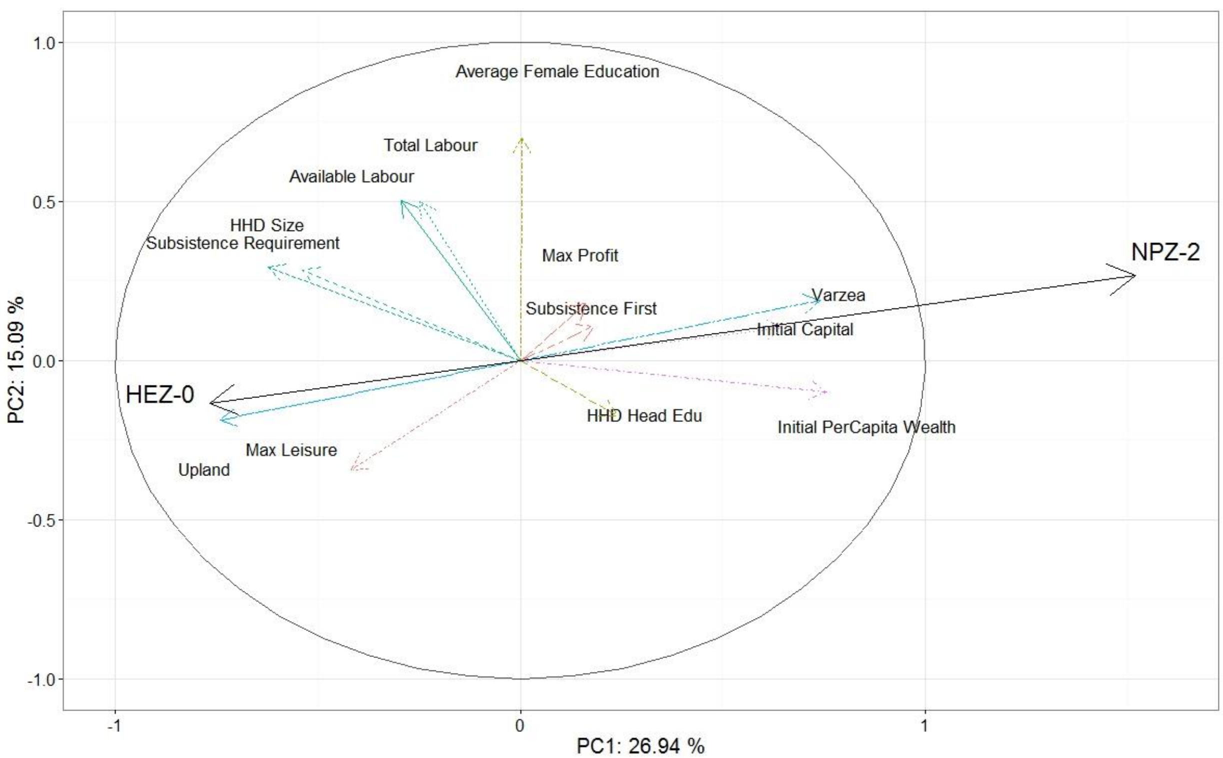

Figure 5-3 (a) MFA of HEZ-0 and NPZ-2 (Baseline Scenario). Each household characteristic can be represented by PC1 and PC2, the colored vectors are household characteristics. Black vectors are the livelihood states. Livelihood states are more likely to be determined by the closer characteristic vectors.

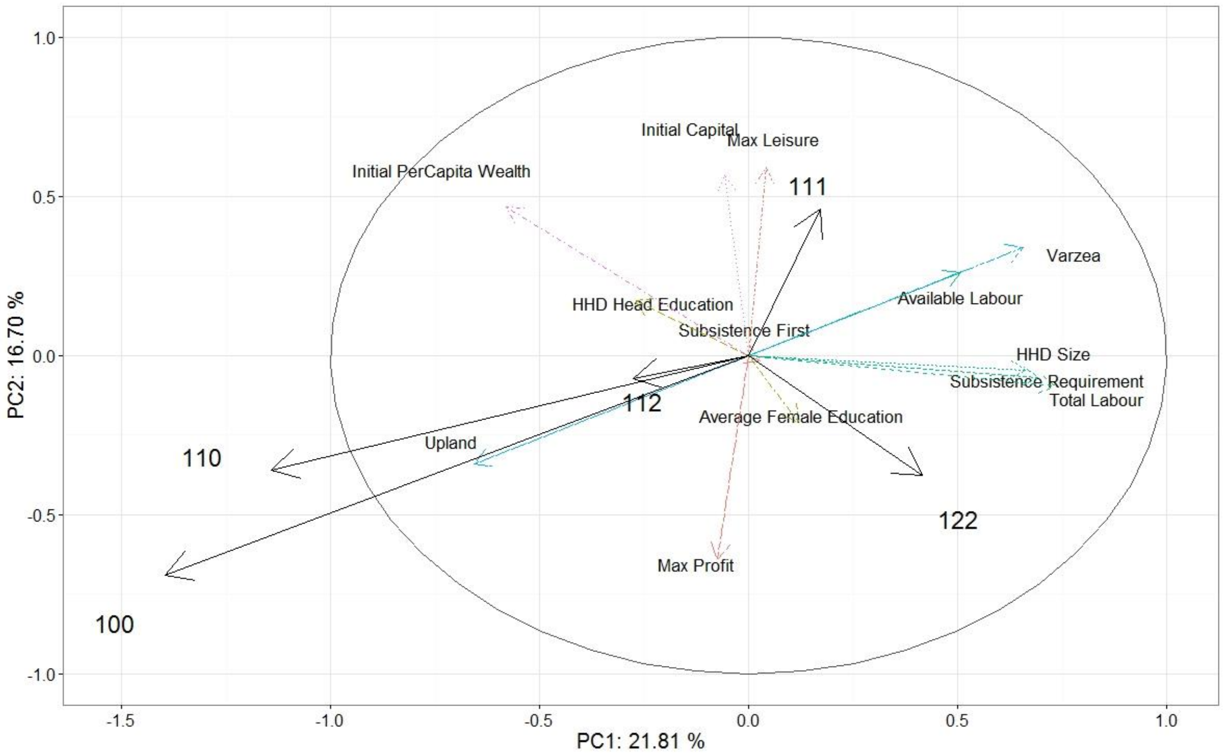

Figure 5-3 (b) MFA of CPZ-1XX (Baseline Scenario). This explains the resources or behaviors that make households in CPZ more likely to reach NPZ-2 at the end or more vulnerable to go to HEZ-0. Livelihood strategies and other resources play bigger role than land type in the poverty trap MFA analysis (compared to a).

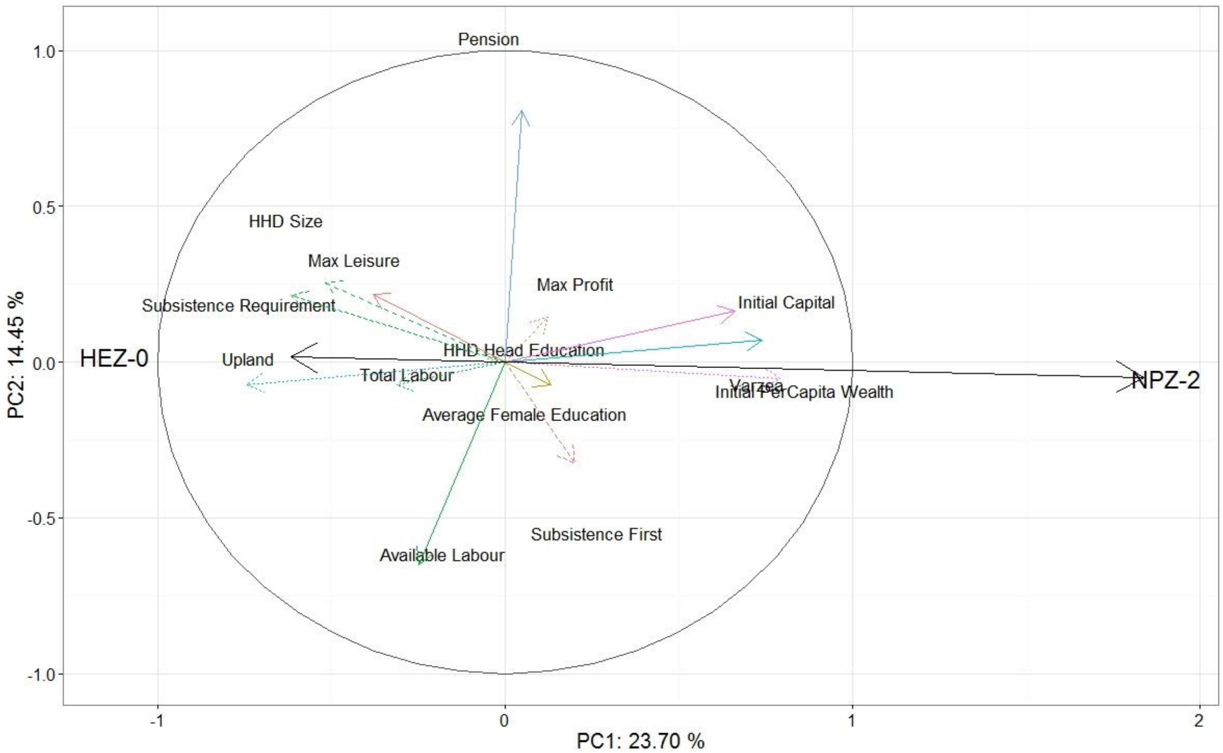

Figure 5-3 (c) MFA of HEZ-0 and NPZ-2 (Triple Shock Scenario), which shows no significant change compared to the baseline scenario in a.

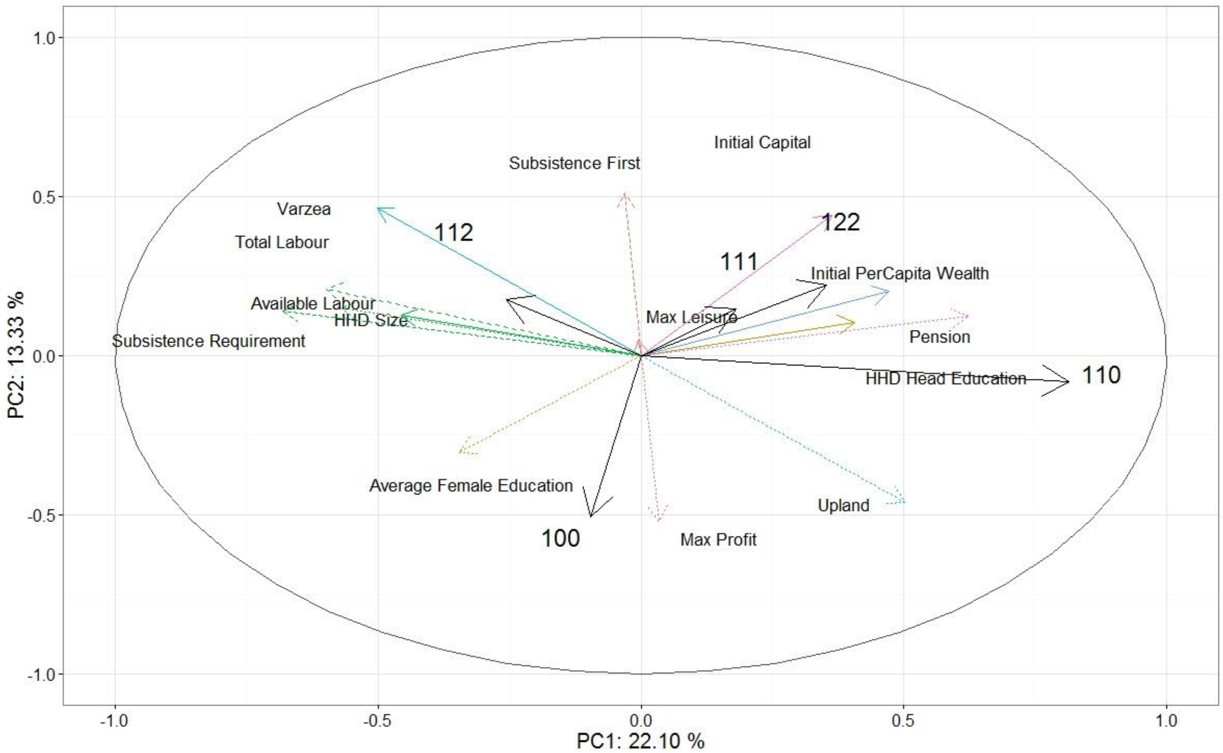

Figure 5-5 (d) MFA of CPZ-1XX (Triple Shock Scenario), compared to (b) the vector of Subsistence First is closer to the states that can reach NPZ-2 at the end (111, 112, and 122) while Max Profit is closer to 100. From baseline to shocks, different factors are significant for different livelihood states**.**

5.3.4 Potential interventions and their impacts

In this section, we investigate initial capital boost and its mixed impact with cash transfer programs, and livelihood strategies as interventions for their impact on poverty reduction and resilience enhancement, addressing the research question that is "*How effective are cash transfer and other interventions for reducing poverty and enhancing resilience*".

5.3.4.1 Boosting household wealth at the beginning

We tested a "financial assist" at the beginning of the simulation, which is a universal payment ten times the annual pension[25]. With this capital raise, the percentage of households

[25] There is a type of government cash transfer to help households improve their housing situation.

being trapped in the poverty zone is significantly reduced and regular pension payments have a more significant impact on reducing the number of households stuck in the poverty trap (Table 5-6). Furthermore, this initial capital endowment significantly increased households in the non-poor zone.

The percentage of households in 222 increased from 19.33 % to 31.69 % in the baseline without pension. Although the percentage of 222 in all three pension settings has been increased, no pension setting has the highest proportion of 222 (31.69 %) compared to the static pension (27.96 %) and the dynamic pension (28.16 %). This pattern is the same when there is no financial boost. However, the overall percentage of households in the end state of NPZ-2 (XX-2) is the same across the three pension settings.

We also investigated the triple shocks scenario (at static pension) to evaluate if a raise of initial capital can increase livelihood resilience. Our first finding showed that triple shocks largely increased the number of households in 112 and reduced households in 122, compared to the baseline. Second, the proportion of households in 212 increased more than five times, from around less than 1 % to 5.4 %. The overall impact of triple shocks is that it moves 6.45 % of households from the non-poor zone to unstable landscape. With a large financial boost at the beginning of the simulation, the proportion of households in the non-poor zone is similar to the baseline with no shock, suggesting that the capital boost can cancel out the negative impacts of shocks.

Table 5-6 Proportion of Livelihood States at baseline under Three Pension Settings

	No capital raise	Capital raise			
	Baseline –No pension	No Pension	Static Pension	Dynamic Pension	Triple shocks
000	39.02	23.44	20.43	21.81	18.78
100	2.19	8.73	8.75	8.82	12.01
110	2.44	4.92	3.88	2.53	5.56
111	16.48	13.60	17.00	16.75	18.57
112	7.43	6.24	8.58	9.29	13.60
122	12.25	9.26	10.85	9.76	1.59
212	0.03	0.32	0.44	0.71	5.40
222	19.33	31.69	27.96	28.16	20.79

Note: We layout the proportion of each livelihood state in the baseline when there is no pension and compare the proportion of each state in baseline scenario with three pension settings with the capital raise, and the triple shocks with capital raise. As shown, the capital raise largely reduces poverty situations, compared to scenarios when there is no capital raise.

5.3.4.2 Adopting resilience-towards livelihood strategies

This section compares the proportion of three decision strategies in each livelihood state (Figure 5-6). All three decision strategies show in state HEZ-0, but the subsistence-first approach has a slightly higher proportion than other interventions. The second is Max Profit and the least proportion is Max Leisure, across all shock types. However, there are only Max Profit and Subsistence First strategies in state 222, showing that no households who use a Max Leisure strategy can reach 222. Majority households who use Max Leisure end up in state 111 and many households fall to 100 or 110 from 111 in shock scenarios, especially in climate shock, climate and job shock, and triple shock scenarios.

In the baseline scenario, the proportion of Max Profit and Subsistence First approaches increases as households move from 100 to 222. Under shock scenarios, there are fewer households who use these two strategies in state 122 and more that use them in 112, 110 and 100. Especially in state 100 and 110, there are more households using Max Profit over Subsistence First strategies. Using climate shock as an example, there is a higher proportion of Subsistence

First interventions in states 122 and 212 than with Max Profit, and the latter has higher incidence in states 100 and 110. Overall, to reach the non-poor zone basin of attraction, adopting a Maximum Leisure strategy is less likely to succeed in comparison to Subsistence First and Max Profit interventions. For households who are in an unstable landscape (1-XX), adopting the Subsistence-First strategy may lead to better resilience towards shocks and ability to avoid descending into the poverty zone.

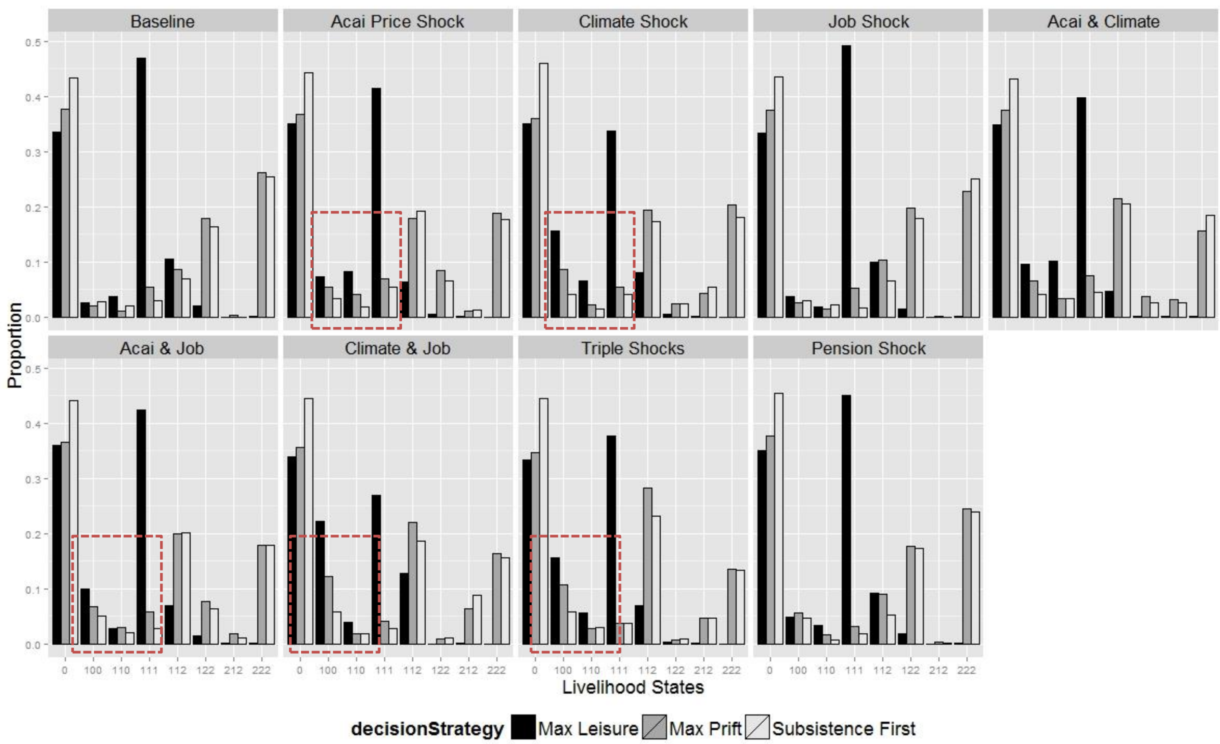

Figure 5-6 Proportion of Three Decision Strategies in Livelihood States. Overall, the Subsistence First strategy has the highest proportion in HEZ-0.Max profit and Subsistence First strategies have similar proportion in NPZ-2. When facing shocks, the Subsistence First strategy seem to be more resilient than Max Profit intervention, since there are more of the latter in the depressed livelihood States of 100 and 110. This also matches with the MFA results.

5.4 Discussion

Our study has found basins of attraction which are consistent with observations from resilience theory and alternative stable states of the system (Walker and Holling, 2004). If households fall into these basins of attraction, it may be difficult or impossible for the system to move into an alternate one. Our results show, only eight livelihood states are observed. Households that start with HEZ-0 in the pre-shock stage will always end in the HEZ-0 state. A household starting at NPZ-2 in the pre-shock stage will more likely be in state NPZ-2 at the end of simulation, even if it may fall to state 1 during the after-shock stage. Therefore, it is reasonable to assume that State HEZ-0 and 2 are the basins of attractions in our system (Figure 5-7).

Sometimes the basin is favorable. Households in state NPZ-2 are already in a favorable basin of attraction. They can be moved out of the basin, but are eventually moved back into NPZ-2. Sometimes the basin is not advantageous: for households in HEZ-0, it simply takes too many resources to pull out of poverty, trapping them deeply in poverty. Between the two states, households in state CPZ-1 are closer to the basin of HEZ-0. This makes them more vulnerable than households that are closer to NPZ-2, making them the households that our interventions and assists should reach to.

We pay close attention to those households who are at bifurcation points (State CPZ-1) because their equilibrium is unstable and they are the ones to easily change state. This approach has also been used in two case-based ecological studies (Dai et al., 2012; Hirota et al., 2011). Households' divergent pattern of moving towards the basins of attraction during the simulation matches our conceptual model extracted from observations in the field. Households end up in very different positions over time in both their overall wealth and reliance on cash transfer.

The existence of basins of attraction in the model results, however, can also be a result of the modeling design rather than the proof of resilience theory. We stimulated the model with various types of shocks, but not the magnitude or the duration of shocks, or the time point when the shock comes. In this sense, it is possible that if we introduce a shock that lasts long enough or severe enough, or the shocks comes early that households have not accumulated enough capital to digest the damage, households may not drop out of the NPZ hence no this favorable basin of attraction. Nevertheless, the poverty trap is presented even in the baseline scenario and its dynamics have been identified, which supports policy implications to move households out of poverty traps to a favorable position.

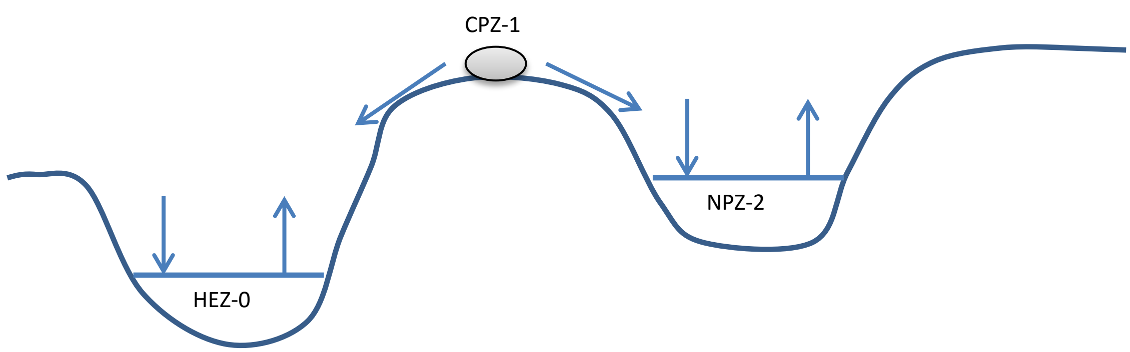

Figure 5-7 Conceptual model of alternative states of resilience. HEZ-0 and NPZ-2 are the basins of attraction, while HEZ-0 represents the poverty trap and NPZ-2 is a relatively well-off livelihood state. Households who are in either of the two states are unlikely to move. Households in State 1, the CPZ-1XX, can move both ways more easily.

The constraints for households in state HEZ-0 are mainly land types: upland or várzea. Past studies have often paid attention to upland deforestation of Amazonia, while studies addressing the livelihoods of *Caboclos* on várzea land have improved very little. The result of intra-regional differences in livelihood is consistent with a great spatial variability in land use patterns found in a larger scale of Amazonia (Aguiar et al., 2007). Although *Caboclos* on the várzea growing açaí are far from being prosperous, many farmers have enjoyed the success of the açaí economy over the past decades (Brondizio, 2004). On the contrary, upland farmers do not profit as much from the boom of açaí economy due to soil and environmental conditions.

If assisted with a higher initial capital, some upland households might be able to jump out of the poverty trap, as shown by our result in 5.3.4.1 . However, this initial push has to be substantial; otherwise the impact is insignificant as suggested by results regarding capital size experiments in Chapter 4. Some effective strategies to move households out of the poverty trap include re-allocating households to várzea or initiating a financial boost project. However, reallocation projects have to consider long-term environmental impact, such as risks of increasing extreme flood.

For households at the bifurcation points, land type is no longer the most significant factor determining their position in the livelihood resilient landscape. Instead, the decision making strategy that households use and education level are more important. Our results also prove that resource constraints are significant in determining the initial position of households on the poverty spectrum. However, behaviour and human capital matter more on households' movement on the livelihood spectrum, for what has also been shown by the conceptual livelihood model and results in Chapter 3 and Chapter 4.

In the MFA plot, the relative position of decisions in the bifurcation livelihood state changes depending on whether or not there is an external shock. Max Profit strategy can be two-fold: it can move households to the non-poor zone (122) and or move them from bifurcation to the poverty zone (100 and 110) if other livelihood characteristics are not sufficiently pursuing market profit (e.g., not enough labour or land type). However, when there is an external shock, the Max Profit strategy is more likely to push households towards the poverty trap (100). On the contrary, the Subsistence First and Max Leisure strategies, under the shock scenario, are more likely to keep households on the bifurcation points or push them towards the non-poor zone. The reason may be that Subsistence First, with agricultural products, is still profiting under the shock;

while Max Leisure simply does not have much production income to be affected by. These findings give us better guidance on how to assist farmers move out of poverty and away from the trap, since different supports and strategies should be provided under different conditions.

Resilience is a property of a system facing external disturbances and shocks. Climate change, economic volatility, and political regime shifting undoubtedly harm the livelihood of poor farmers. Using quantitative assessment, our study evaluates the harmful impacts of several shocks: climate change, commodity boost cycle and political and economic recession. It shows that climate change is potentially the biggest shock to household livelihood, while off-farm job recession is the least harmful. When making decision, households use the average crop yield of price during the past three years to plan current year's livelihood choice. Supposedly, the shock scenario of climate and price should have a similar impact on households' livelihood choice and their resilience. The reason, I suspect, is that crop yield is different across each pixel while price for the same crop is the same across households and land parcels.

The rural-urban migration in the estuary has been complex and accelerated due to the changing economy of Brazil and benefit programs to rural area (Brondízio et al., 2003; Padoch et al., 2008). Despite the significance of off-farm jobs to household income (as also presented in Chapter 3), Amazonian migrants often continue participating in the rural-urban network (Padoch et al., 2008). Furthermore, the types of jobs that *Caboclos* undertake are usually labour-related but still require a certain degree of education that shows as a probability function from our empirical data. The relatively low probability of rural households holding an off-farm job results in a non-significant change under the job shock compared to baseline.

Additionally, it is worth noting that the impact of multiple shocks does not produce a simple additive effect. Job shrinking may not have a significant impact on household livelihoods. However, when coupled with climate or açaí shock, the margin of its negative influence is bigger than the sum of the two single shocks. Unfortunately, some shocks do occur in pairs. For instance, economic recession may cause a chain reaction with pension reduction, shrinking jobs, and boost cycle of the açaí price. We need to prepare for the multiplier effects from these shocks.

Many authors have argued about the controversial effects of cash transfer programs on household livelihoods. The main concern focusses on poor households' growing dependence on cash transfer programs. Certain studies (Rawlings and Rubio, 2003; Sadoulet et al., 2001; Standing, 2008) show the positive impacts of cash transfer programs on human capital and basic income. Other studies show reduced labour endowment from extended family when a pension is received (Bertrand, 2003). Our study shows that having a constant pension does not have significant impact on household livelihoods and that more households could reach 222 without the presence of pension. This may be because households who use Max Leisure are likely to become increasingly dependent on pension payments, which slows household agents increasing production. Particularly if pension comes as a shock (i.e. as under the scenario where pension is removed from year 11 to 15), pensions may cause more harm than benefit.

We found no mixed impact from pension and shock types, suggesting pension may not have significant influence on improving overall resilience. However, pension might increase the livelihood resilience when households receive an initial capital boost, reducing the number of households that are trapped in poverty. But again, the pattern evident for households receiving pension in the non-poor zone is similar to the pattern without an initial capital boost; more households are in the non-poor zone when there is no pension and the fewest households are in the non-poor zone under a dynamic pension. It may be that some households develop a dependency on cash transfer programs, so they cannot cope with sudden pension reductions and thereby move to a poorer state. Our findings are consistent with on-going arguments in literature: pension is conditionally beneficial for households in the poverty trap, but may have the possibility to increase households' dependence on these transfers (Farrington and Slater, 2006).

This study is a first attempt to assess development resilience using modelling. Our main purpose is to provide a framework to apply resilience theory using an agent-based model. Through this work, we hope to gain insights into small farming livelihood dynamics and to better inform decision making in practice. Resilience is a concept that emerges from the study of complex systems. Particularly in our complex human-environment systems, it is not easy to code resilience into a number or reach conclusive results to compare with ecology (Dai et al., 2012; Hirota et al., 2011).

Our study touched on a few properties of a complex system, such as non-linearity and the surprises of pension effectiveness. Nevertheless, there are limitations when we study resilience in a complex system like ours. First we lack representation in the second-level adaptation. There are multiple levels of adaptation and feedback in a complex system. In our model, households follow a static decision making strategy to allocate their resources into different livelihood activities, resulting in livelihood behaviors and income. Their behavior responds to a change in incentives such as crop price and crop yield and do not switch or adjust their decision making for shocks. In our model there is no such adjustment for shocks in decision making. However, it is debatable that households would switch to a new decision making regime due to the experiences of a shock. The amplifying and dampening behaviors that have been observed in the field (Cinner et al., 2011) could be the results of first level adaptation. We only use the first level adaptation in our simulation with classic economic theories as decision making strategies, since we do not have any behavioral information from the field to support second-order behavioural adjustments.

The second limitation of the research is that our external shocks only produce one-directional feedback. The aggregated farmers' behavior does not affect the price of açaí or job availability. On a larger scale, the impact should be bi-directional. For instance, when a climate shock reduces crop yield, the crop price should increase resulting in an incentive for farmers to grow more, which is the opposite of what our model does currently.

The third limitation of the inquiry is that shocks have the potential to cause very different impacts, depending on their timing and severity. For instance, a price shock occurring to the system at a relatively early stage may have a greater impact than if it had occurred in year 20, when households have already reached the non-poor zone and established ample assets and wealth. Conversely, if a shock hits the system at a very early stage, even a job shock, the least influential shock, may produce devastating results for households that have not had the time to accumulate significant adaptive capacity. This scenario can be evaluated in future studies. Despite the complex nature of such system and the resilience concept, our research has to set a boundary for the sake of simplicity and validation. In the future, with sufficient field work results, we may try to overcome these limitations.

5.5 Conclusion

This chapter shows how poverty and livelihood dynamics can be simulated by an agent-based modelling approach within the development resilience framework. The existence of the poverty trap, as a basin of attraction in a resilience framework, is evidenced by simulation results and is largely constrained by the intra-regional socio-ecological environment. Households in the poverty trap are hardly affected by any external stimulation, whether shocks or reductions in cash transfer programs. That said, government cash transfer programs effectively reduce poverty when households are pushed out of the trap first. Households in the chronic poverty zone are at the bifurcation point and can go either towards the poverty trap or the non-poor condition based on largely on their decision making strategies and human capital. If better endowed with resources, such as being located on várzea land and having ample household capital, households are likely to reach the non-poor zone and be resilient to all types of shocks. Based on our findings, policy and livelihood decisions should be made based on household resources and their livelihood states within such a complex system.

Chapter 6 Conclusions and Discussions

6.1 Conclusions and contribution

6.1.1 General conclusion and overall contribution

The overarching goal of this thesis is to explore the impacts of cash transfer programs on rural livelihood dynamics. Using small farming households in the Brazilian Amazon region as an example, this goal is achieved by the completion of three major tasks: exploring, for the Abaetetuba region of Brazil, the patterns of household dependence on cash transfers, utilizing three decision strategies in an ensemble ABM to explore uncertainties and the wide range of possible outcomes in a household livelihood model, and using that model to assess resilience in rural households facing different disturbances. Two main approaches, empirical analysis and agent-based modelling, were adopted in this thesis. The key outcomes of this thesis include: (1) exploring the heterogeneity of cash transfer impacts by using a sustainable livelihood approach, (2) introducing an ensemble approach to agent-based modelling and demonstrating its usage and importance, (3) exploring aspects of resilience by agent-based modelling. The research questions outlined in 1.3 are addressed in the following sections.

6.1.2 Conclusion and contribution related to rural livelihood patterns

(1) What are the patterns of household dependence levels on cash transfer programs in the estuary region at the Brazilian Amazon? With respect to rural livelihoods, what drivers cause the distribution of such heterogeneity, even when some households receive a similar amounts of cash transfers?

Through the classification, a distinctive pattern of cash transfers and the dependence levels was established in Chapter 3. There is substantial variation in the amount of cash transfer that households receive. These households were classified into four cohorts in which they received no cash transfer, low cash transfer, medium cash transfer, or high cash transfers. Four levels of dependence on cash transfers: not-dependent, low-dependent, moderately-dependent, and highly-dependent, were also identified on the basis of the percentage of cash transfers of the total household income. The livelihood activity that is most associated with households who are in the not-dependent and low-dependent groups is off-farm employment activities that generate large amounts of income, for the importance of off-farm activities in rural development has also been concluded in other literature (Barrett et al., 2001; De Janvry and Sadoulet, 2001; de Janvry et al., 2005). However, households in the moderately-dependent group have the most diversified livelihood income (i.e., income from agricultural activities, agro-forestry activities, and off-farm activities), as calculated by a Shannon-Wiener diversity index to measure the livelihood income diversity (Hanazaki et al., 2012). Many studies suggest that maintaining diversity is essential to environmental and socio-economical fluctuations for smallholders (Carter et al., 2007; Hanazaki et al., 2012; Vogt et al., 2015).

Household demographic characteristics, livelihood assets, and resources were explored by analysis of variance and paired comparison, and later by a multi-nomial logistic regression (MNL), to identify the key drivers that inform the variation in cash transfers and the distribution of dependence levels. Between households who receive different amounts of cash transfer, significant differences were identified in all household characteristics (i.e., household size, husband age, number of children, average female education level), except between low-cash transfer and medium cash transfer groups which are similar in all characteristics. Households that receive no cash transfer have the smallest number of family members and the highest husband education level, while the high cash transfer group has largest households and the lowest number of years of schooling for the husband.

For households with different levels of dependence on cash transfers within the same cash transfer cohort, with the exception of husband education level, no significant difference in household demographic or socio-economic characteristics was found. However, most of these demographic characteristics are significant for the MNL results that outline the likelihood of a household being low- or moderately dependent on cash transfers compared to those that are highly-dependent. For example, husband education, land size, as well as having access to várzea significantly increases a household's likelihood of being in the low-dependent and moderately-dependent level over the highly-dependent category. The significance of these factors is later proved in the following analysis in Chapter 4 and Chapter 5, as well as in other rural livelihood literatures (Babulo et al., 2008; De Janvry and Sadoulet, 2001; Thomas and Gaspart, 2015).

Chapter 3 addresses the research question asking the patterns of rural livelihoods. Results from this chapter, firstly, show that the cash transfer payment that households receive is very different in amount, so is the level that households depend on this income. Secondly, the more vulnerable households are identified through the investigation of livelihood composition and household characteristics, so that policy makers and institutes can efficiently target households in need. Thirdly, this chapter is a successful case using sustainable livelihood approach to deepen our understanding of rural livelihoods and the influence of cash transfer. Lastly, this analysis provides an empirical foundation for the modelling and simulation work carried out in Chapter 4 and Chapter 5.

6.1.3 Conclusion and contribution related to uncertainties in agent-based modelling

(2) In the context of an ABM that represents a complex human-environment system, how do we resolve the uncertainty that constitutes the nature of human decision making? What are the significant factors determining the outcomes of household livelihoods? Does the significance of these factors change when human behaviors change?

In Chapter 4, the ensemble approach is explored as a new approach to cope with the uncertainty that comes with human decision making in agent-based models. The results in Chapter 4 provide us with a different perspective on uncertainty treatment, one that traces its roots to this protocol in climate change modelling. We selected three livelihood strategies based on classic economic theories, empirical studies of smallholders, and ABMs in rural livelihoods to represent stereotypes of decision making as ensemble members of our ABM, which are maximizing net economic return, maximizing leisure time after a subsistence requirement is met, and growing subsistence crops first (Chayanov, 1966; Ellis, 1994; Entwisle and Stern, 2005; Evans and Manson, 2007; Schreinemachers and Berger, 2011; VanWey et al., 2007).

The demographic structure of households and their socio-economic conditions, including cash transfers, may play different roles in affecting livelihood outcomes if households are pursuing different strategies. Developing ABMs with an ensemble module of three decision strategies allows us to explore the variation in outcomes associated with particular strategies. In addition with the statistical analysis and global sensitivity analysis, we quantified these differences among decision making strategies.

The results, first of all, establish that we can see very different patterns in aggregate model outcomes when we switch decision making strategies. The presence of cash transfers has a dramatic effect on the outcomes for households following the max-leisure strategy. However, these transfers have a much less significant effect on households following the subsistence-first or max-profit strategies. This is consistent with the heterogeneous dependence levels on cash transfers found by empirical analysis in Chapter 3.

The results also have an important policy implication. Community-level livelihood outcomes depend to a much greater extent on the decision strategy employed by households in the community, rather than the socio-economic and demographic conditions at play. The eight experiments we designed in this chapter has a different distribution of household characteristics (e.g., the household size, initial capital, or the percentage of having access to várzea) or transfer payment. However, no significant improvements were observed between the experiments that change the pattern of characteristics. The outcomes, in fact, largely depend on which decision making the households use. For instance, Max Profit decision regime is least sensitive to our eight experiments that change the distribution of land type, household size, capital, and cash transfer unit; however, the difference in the outcomes from Subsistence First regime is quite observable. Overall, the presence of cash transfer reduces poverty and income inequality, measured respectively by Poverty Gap index and Gini index.

There is a similar pattern at the household level outcomes according to the PAWN index, a global sensitivity analysis that we used. Among all the variables that we investigated at the household level (i.e., number of family member, initial capital, having várzea, husband education, number of family members who are eligible to pension, and unit of pension), the most influential factor for households that maximize leisure is the number of pensioners. However, this variable plays a less significant role on six livelihood outcome indicators when households are using Max Profit (except for dependence level on cash transfer and income diversity) or Subsistence First strategies (except for the diversity in income and production income). Across different decision strategies, the important factors include the pensioner number and access to várzea. On the contrary, the initial capital and husband education is not influential.

Although many efforts have been devoted to exploring uncertainty issues in models of coupled human-environment system (e.g., using agent typology, the scale issues, bounded-rationality)(Evans et al., 2002; Huang et al., 2013; Manson, 2006; Parker et al., 2012; Valbuena et al., 2008; Zimmermann et al., 2009), this chapter is the first case, to our knowledge, that integrates the uncertainty in human decision making by presenting and comparing different decision making strategies. Rather than treating it as a source of error, the adoption of an ensemble approach allows us to understand and explore uncertainty. Using this ABM with ensemble members, we are able to investigate a range of possible livelihood outcomes rather than a prediction of a single-value or single decision regime, which adds confidence to our modelling results and policy advice (Evans, 2012; Messina et al., 2008).

6.1.4 Conclusion and contribution related to resilience assessment

(3) How are poverty and desirable livelihood states formed? Specifically, what demographic structure, livelihood assets, or decision strategies contribute to the formation of such states? Can cash transfers or certain interventions solve the poverty trap or increase the resilience of desirable-livelihood households?

Rural livelihood dynamics were simulated with an agent-based model utilizing three decision strategies. Using the development resilience definition to integrate poverty alleviation and resilience enhancement, we assessed the poverty and resilience properties of household livelihoods among the small farming households. The analysis of livelihood dynamics reveals the existence of a poverty trap (coded as the Humanitarian Emergency Zone-0, HEZ) and a relatively well-off state (coded as Non-Poor Zone-2, NPZ), which is conceptually similar to a basin of attraction in the resilience framework (Barrett and Constas, 2014; Walker and Holling, 2004). Results show that households who are in these two states will most likely stay in these states no matter which external shocks they are facing. Conversely, households who are between these two zones (coded as Chronic Poverty Zone, CPZ) are at the bifurcation points that are more likely to switch towards the poverty trap or the non-poor condition (Dai et al., 2012; Hirota et al., 2011; Walker and Holling, 2004). Upscaling to an aggregate level, although some households are in a relatively desirable condition, the community is still vulnerable to external shocks since a fairly large number of households are trapped in poverty which cannot adapt to shocks.

Having been discussed in Chapter 3 and Chapter 4, rural livelihoods are determined by household capabilities, household assets and resources, and their decision making strategies. Therefore, resilience as one property of rural livelihoods is also the result of these components. As shown in the results of multiple factor analysis, the constraints that trap households in HEZ (poverty) are mainly not having access to várzea where açaí can grow. Having access to várzea and ample capital are more likely to elevate and secure households in the NPZ. Between these two stable basins, having higher education, access to várzea, and the adoption of Max Profit can make households less vulnerable when there are no external shocks. However, when facing an external shock, using Subsistence First strategy may make households more resilient compared to other strategies, since households will undertake less economic loss and have enough subsistence required crops.

We evaluated the effects of cash transfer programs on the poverty reduction and resilience enhancement. Results indicate that a constant pension program reduces the number of households from poverty (less households that are trapped in HEZ) compared to when there is no pension program. However, if there is a constant pension program, there are also fewer households who can become better-off at the end of the simulation (the proportion of households in NPZ is less compared to the no pension scenario). This can be explained by households that follow Max Leisure strategies will stop participating in production activities once their subsistence requirement is secured by the pension payment. Furthermore, the abrupt cancellation of pension might hit household livelihoods and cause negative impacts (e.g., highest proportion of households who end up in HEZ, and lowest in NPZ) more than when there is no pension program.

Cash transfers can be more effective in poverty reduction if they are used together with a boost of initial capital endowment in a hypothetical scenario, as shown by the simulation results. With the presence of such capital increase, more households get out of poverty trap and achieve the non-poor zone at the end. In summary, the use of cash transfers show positive impacts over rural livelihood poverty and resilience, and it is more effective when there is an increased capital endowment. Nevertheless, the positive impacts from cash transfers are associated with the security of this funding: if government cancelled this payment abruptly, households may experience unnecessary shift in livelihood states and end up in a poorer condition.

This chapter represents an early effort to use an ABM to quantitatively assess resilience in a dynamic coupled human-environment system. The aim here is to further push the theoretical frontier in resilience, and especially on “development resilience” (Barrett and Constas, 2014). Resilience is a property of complex systems. However, its definition does not indicate how to implement the assessment. Therefore, the prototype in this chapter can be considered as an initial attempt and possible guide to assess resilience using model outcomes. This chapter evaluates the impacts of cash transfers on both poverty and resilience, which is a supplement to results from Chapter 4 regarding the effects of cash transfer programs on poverty severity. The subsequent studies in this chapter indicate the impact from government cash transfers goes beyond poverty issues and may affect resilience differently from poverty, due to the different reasons why households are in these two states and the different reactions households may have for cash transfers. Therefore, the evaluation of cash transfer applications should focus on both poverty and resilience aspects. Moreover, when combined with other interventions as suggested by poverty literatures (e.g., capital boost) (Barrett, 2008; Carter et al., 2007), cash transfer programs may have more significant impacts on rural livelihoods.

6.2 Challenges and future work

This thesis explores a few frontiers in the hope of deepening our understanding of the dynamics of rural livelihoods. The limitations for each study are discussed in detail in the previous chapters (from Chapter 3 to Chapter 5). Here, we provide a discussion on some general challenges and potential paths that we and other researchers can take for future work.

Capturing the dynamics of rural livelihoods: Empirical approaches, such as the household survey used in this thesis, provide an important starting point to understand complex human-environment systems. However, a sample taken at one moment in time of a continuous phenomenon may not be sufficient to trace how households use their resources to make a living over time, particularly when we consider their behavioral responses to external stimuli such as environmental changes and cash transfer programs. We can outline findings that reveal the dependence levels, household characteristics, and livelihood strategies by analyzing the static data from the household survey. We can also see the improvement in society in the estuary region during the past few decades, such as the higher average education level among younger and smaller households in comparison to the older and bigger households.

Household surveys are a powerful first step to carry on sequential studies (e.g., the agent-based modelling in this thesis) since it can offer “credible and defensible representations” (Robinson et al., 2007, p. 32) of the real world. However, a longitudinal survey will bring more information and give us a chance to make more accurate hypotheses regarding the changes and dynamics, which may eventually explain the growing heterogeneity that is found in dependence levels. Having established a successful relationship with local communities and research institutions, it is possible to conduct long-term collaboration at the riverine region, which brings a solid foundation for future research.

Representing the dynamics by agent-based modelling: Agent-based modelling has been proved to be a powerful approach to simulate the micro-level processes and the resulting aggregate level phenomenon. However, its advantage of being flexible when modelling the real world is also associated with uncertainty and errors that might be introduced in many processes (Evans, 2012). Our empirical data is not sufficient for us to establish validated decision making rules for the household agents that we are simulating in the model. The adoption of an ensemble approach that incorporates three decision making strategies is one approach to explore and better understand such uncertainties. However, we deliberately selected these three decision rules to represent stereotypes in order to capture a possible range of outcomes.

To represent human decision making more accurately, a next step could be to inform the ensemble members with weights during the model construction. For instance, in this study we run the three decision strategies separately that having the assumption as they are equally weighted (“one vote per ensemble” (Flato et al., 2013, p. 755)); in future study, with the information of the proportion of these three (or any other) decision strategies in a population, we can set up the weighted ensemble module in agent-based model according (Murphy et al., 2004). This way, we can more accurately represent the heterogeneous decision making mechanisms in a population and manage the uncertainty.

Simulating resilience as an emerging property: Resilience is one property that emerges from complex systems among many others (e.g., non-linear, time-lag, feedback loops) (Liu et al., 2007). In the various interpretations of resilience, adaptive capacity is often mentioned (Folke et al., 2002; Smit and Wandel, 2006; Walker and Holling, 2004; Brian Walker and Salt, 2012). Adaptations are strategies that human systems can use to enhance system resilience for dealing with climatic and other socio-economic changes. There have been observed across the world as scientists are trying to understand the mechanisms that form such adaptations (Brondizio and Moran, 2008; Cinner et al., 2011; Feng et al., 2010).

An agent-based model is capable of representing adaptations from two levels (Le et al., 2012a): the first level is that agents follow consistent/uniform decision making mechanisms and strategies, which can be seen in nearly every model; the second level is that agents actually change their decision making strategies, asides from artificial intelligence as decision making algorithm. Only a few models have touched this second level (Gotts and Polhill, 2009; Le et al., 2012a; Matthews, 2006; Ng et al., 2011). Once environmental changes are beyond the tipping point, or even the threat of it, a system may trigger drastic attempts at reorganizing decision making strategies and behaviors (Day, 2005). It is still not clear how agents modify the logic of their decision making, with or without climate change and cash transfer programs, and our model only represents the first level adaptation. However, this should be clarified in future study since it is fundamental for us to understanding the changes in human behaviors.

Describing rural livelihoods of Caboclos: The Amazon estuary has a long history of human-environment and global-local market interactions that characterize the river-sea domains in the state of Pará, Brazil (Brondízio, 2008). Local farmers, *Cabcolas*, have to construct a resilient system to cope with lancąntes and potential shocks from global market. They pursue a variety of livelihood activities including the production of agricultural and agroforestry products, non-farm activities, and fishing and shrimping.

We did not touch a few unique characters in the complex human-environmental interactions in this region: (1) Modelling fishing and shrimping activities, because it is a small margin of farmers who pursue fishing and shrimping as part of their production income and there is no data to parametrize such activity. (2) The seasonal changes of açaí yield and prices in the model due to the lack of data. (3) Exploring the impacts of *Bolsa Familia* on education and livelihoods in-depth. The importance of education is identified in this study, but the effects from this significant government cash transfer program and its influence on rural livelihoods need further investigation.

Transforming scientific findings to practises: It is always a challenge to inform policy-makers with scientific results, particularly true when it relates to human and environment (Bradshaw and Borchers, 2000; Jäger, 1998). This thesis, in fact, by focusing on government cash transfer programs, systematically evaluates impacts on rural livelihoods on poverty and resilience concerns, which is tightly associated with policy implications. In addition to its urgent practical value, the use of an ensemble approach and scenario designs promotes the easy and confident communication from our findings towards decision-makers. In the future, a more userfriendly interface of the model can be implemented as well as an interactive visualization module, which may help the transmission of information from academia to real practice.

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Appendix

Appendix A Table: ANOVA among decision strategies and scenarios

		Gini Index			Poverty Gap		
	Df	Sum Sq	F-value	Pr(>F)	Sum Sq	F-value	Pr(>F)
Decision Strategies	2	14.242	2250.6	***	52.8	5762.85	***
Experiment Scenarios	7	2.661	120.1	***	2.9	90.54	***
Decision Strategies: Experiment Scenarios	14	6.681	150.8	***	28.92	451.01	***
		Gini Index with CT			**Poverty Gap with CT**		
	Df	Sum Sq	F-value	Pr(>F)	Sum Sq	F-value	Pr(>F)
Decision Strategies	2	10.562	1876.53	***	2.214	979.2	***
Experiment Scenarios	7	5.979	303.5	***	10.459	1321.4	***
Decision Strategies: Experiment Scenarios	14	1.374	34.87	***	3.073	194.2	***

Note: null hypothesis: there is no difference of the value of index between two groups. P-value < 0.05 rejects null hypothesis which means two groups are different statistically.

Appendix B Table: The difference of means between scenario and baseline by HSD

	Gini		Poverty Gap		Gini with CT		Poverty Gap with CT	
Experiment Scenarios								
1: Baseline	0.551		0.219		0.397		0.020	
	Difference		Difference		Difference		Difference	
2: more varzea	-0.001		-0.008		-0.041	***	-0.001	
3: small capital	0.007		0.011		0.013	**	0.006	
4: big capital	0.001		-0.013		-0.002		-0.008	**
5: small family	-0.006		0.048	***	0.066	***	0.071	***
6: big family	0.033	***	0.067	***	-0.045	***	-0.005	
7: no ct	-0.066	***	-0.026	***	0.089	***	0.173	***
8: higher pension	-0.013	**	0.038	***	0.029	***	0.024	***
Decision Strategies								
	Difference		Difference		Difference		Difference	
SubsistenceFirst-MaxProfit	0.073	***	0.155	***	0.063	***	0.058	***
MaxLeisure-MaxProfit	0.166	***	0.321	***	-0.080	***	0.003	
MaxLeisure-SubsistenceFirst	0.094	***	0.166	***	-0.143	***	-0.055	***

Note: For instance, the HSD value in Gini index with CT between the small family (F-) and the baseline is 0.066, which shows that the mean of Gini index with CT in small family scenario is 0.066 more than the baseline mean 0.397.

Appendix C Table: Mean differences between different scenarios compared to baseline scenario for each decision strategy

	Gini		Poverty Gap		Gini with CT		Poverty Gap with CT	
Max Leisure								
1: Baseline	0.668		0.455		0.313		0.017	
	Difference value	p	Difference value	p	Difference value	p	Difference value	p
2: more várzea	-0.042	***	-0.015		-0.044	***	-0.002	
3: small capital	-0.013		-0.038	***	0.009		-0.001	
4: big capital	-0.026		-0.047	***	-0.021		-0.008	
5: small family	-0.085	***	-0.147	***	0.096	***	0.036	***
6: big family	0.121	***	0.226	***	-0.031	***	-0.003	
7: no ct	-0.207	***	-0.328	***	0.148	***	0.110	***
8: higher pension	-0.075	***	-0.124	***	0.029	***	0.008	
Max Profit								
1: Baseline	0.465		0.044		0.416		0.008	
	Difference value	p	Difference value	p	Difference value	p	Difference value	p
2: more varzea	-0.037	***	0.003		-0.029	***	0.005	
3: small capital	0.004		0.008		0.006		0.012	**
4: big capital	0.023	***	-0.003		0.016		-0.002	
5: small family	0.008		0.096	***	0.022	***	0.045	***
6: big family	-0.003		0.017	**	-0.045	***	0.004	
7: no ct	-0.018	**	0.074	***	0.030	***	0.109	***
8: higher pension	-0.011		0.056	***	0.001		0.018	***
Subsistence First								
1: Baseline	0.522		0.159		0.462		0.034	
	Difference value	p	Difference value	p	Difference value	p	Difference value	p
2: more varzea	-0.065	***	-0.012		-0.050	***	-0.007	
3: small capital	0.030	***	0.062	***	0.023	***	0.006	
4: big capital	0.006		0.011		-0.002		-0.013	
5: small family	0.059	***	0.195	***	0.080	***	0.132	***
6: big family	-0.018		-0.043	***	-0.059	***	-0.016	**
7: no ct	0.028	***	0.174	***	0.089	***	0.298	***
8: higher pension	0.047	***	0.179	***	0.057	***	0.046	***

Appendix D Table: Definition and frameworks of resilience studies in various disciplines

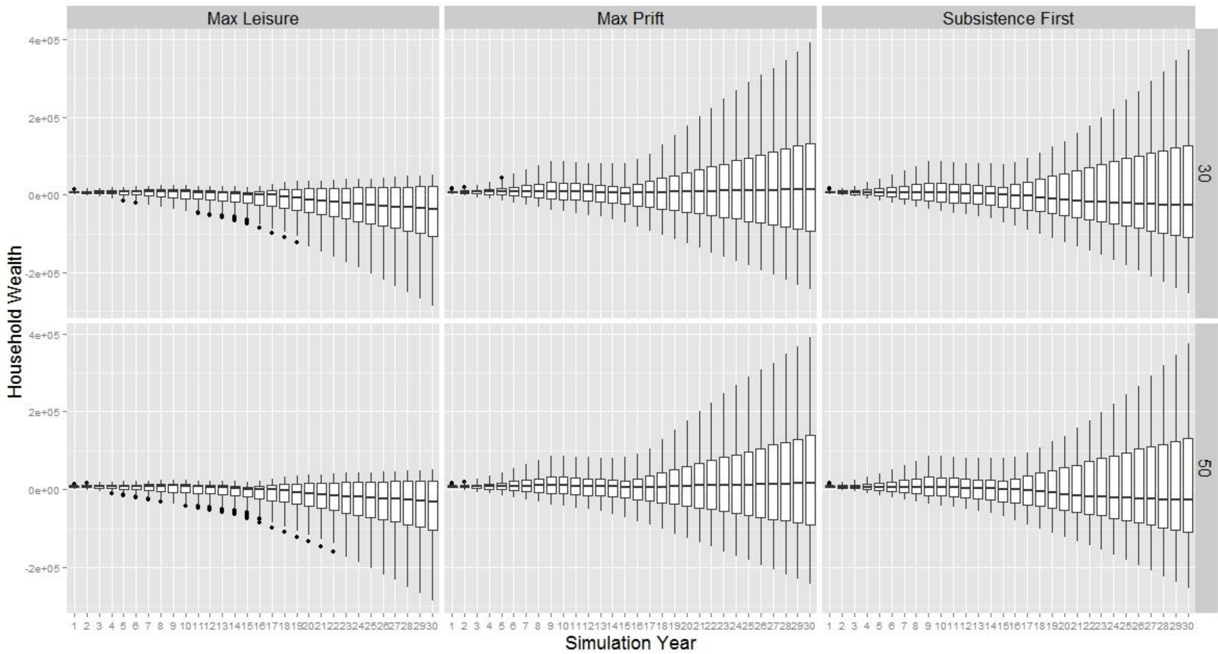
Resilience Field	Definition	Key References	Case studies	Of what to what	Framework / Metrics
Ecology	The capacity of a system recovering from the maximum perturbation without causing a shift to an alternative stable state	(Holling, 1973; Scheffer et al., 2001)	1) tropical forest and savanna (Hirota et al., 2011) 2) budding yeast system (Dai et al., 2012)	1) of keeping current ecosystem; 2) sustain population, to salt shock	1) **measurement**: Resilience of a state for a given annual precipitation level is the fraction of sites are in that state. a) Alternative states: forest, savanna, treeless; b) tipping point: bifurcation point; 2) **measurement**: loss of resilience(critical slowing down) before a tipping point a) tipping point, bifurcation (both internal factor—population density, and external factor—dilution factor)
Mechanical engineering	Capacity to absorb energy elastically (toughness is ability to absorb energy up to fracture)	Mechanical Properties of Metals[26]	A spring, to perform linear relation with the force	Of its elastic form, to external force	Metric: modulus of resilience, Ur = Area underneath the stress–strain (σ–ε) curve
Economics	The ability of an economy or a society to minimize welfare losses for a disaster of a given magnitude	(Hallegatte, 2014)	1) macro-resilience 2) micro-resilience	1) the ability to maintain aggregated consumption losses ($\Delta\tilde{C}$), to a given amount of capital losses (ΔK);	1) measurement, $R^{macro} = \frac{\Delta K}{\Delta\tilde{C}}$ 2) measurement,

[26] http://www.virginia.edu/bohr/mse209/chapter6.htm

				2) for a given level of aggregate consumption losses ($\Delta\tilde{C}$), the ability of an economy and society to minimize household welfare loses (ΔW)	$R^{micro} = \frac{\Delta\tilde{C}}{\Delta W}$
Cyber safety	When facing unexpected and malicious threats, a resilient system can maintain its state awareness and normal operation	(Linkov et al., 2013; Rieger et al., 2009)	a resilience matrix framework	Resilience of system's safety and recovery ability, to malicious attacks.	The matrix contains physical, information, cognitive, and social four rows which constitute the infrastructure, and four columns: plan and prepare, absorb, recover, and adapt, to represent four stages of the event management cycle.
Food security	The capacity of a socio-ecological system to maintain food security while facing hazards	(Lebot and Siméoni, 2015; Padgham et al., 2015; Schwarz et al., 2011; Walker et al., 2010)	1) Fishery communities in Solomon Islands 2) Urban/peri-urban agriculture (UPA) in Africa and Asia 3) Six villages in Vanuatu	1) Of community's ability to absorb and cope, To different categories of future threats; 2) of UPA's contribution to urban food and livelihood, to the rapid changing climate and environment 3) Of community's ability to absorb stresses, to external	1) A generic 360 integrated assessment map to structure the assessment, and based on the past events and response, via questionnaires, surveys 2) A series of integrated knowledge assessments across nine sites, exploring contexts of UPA, major stresses, key political and governance factors, etc. 3) Selected six variables from assets to as resilience indicators and five variables from constraints as

				general shocks.	vulnerability indicators, and used PCA to cluster the highly pressured communities.
Psychology	The process of adapting well in the face of stress and adversity[27].			an individual's capacity, to stress and adversity	Building resilience, but resilience is not a trait, it's a process involving behaviors, actions, and support.
Urban planning	The absorbing ability of cities for climatic risks	(Chelleri et al., 2015; Hunt and Watkiss, 2011; Muller, 2007)	Two cities' cost and adaptation estimation for enhancing resilience	Of urban settlements to absorb and adapt, to climate change	Qualitative and quantitative assessment of the climate impacts

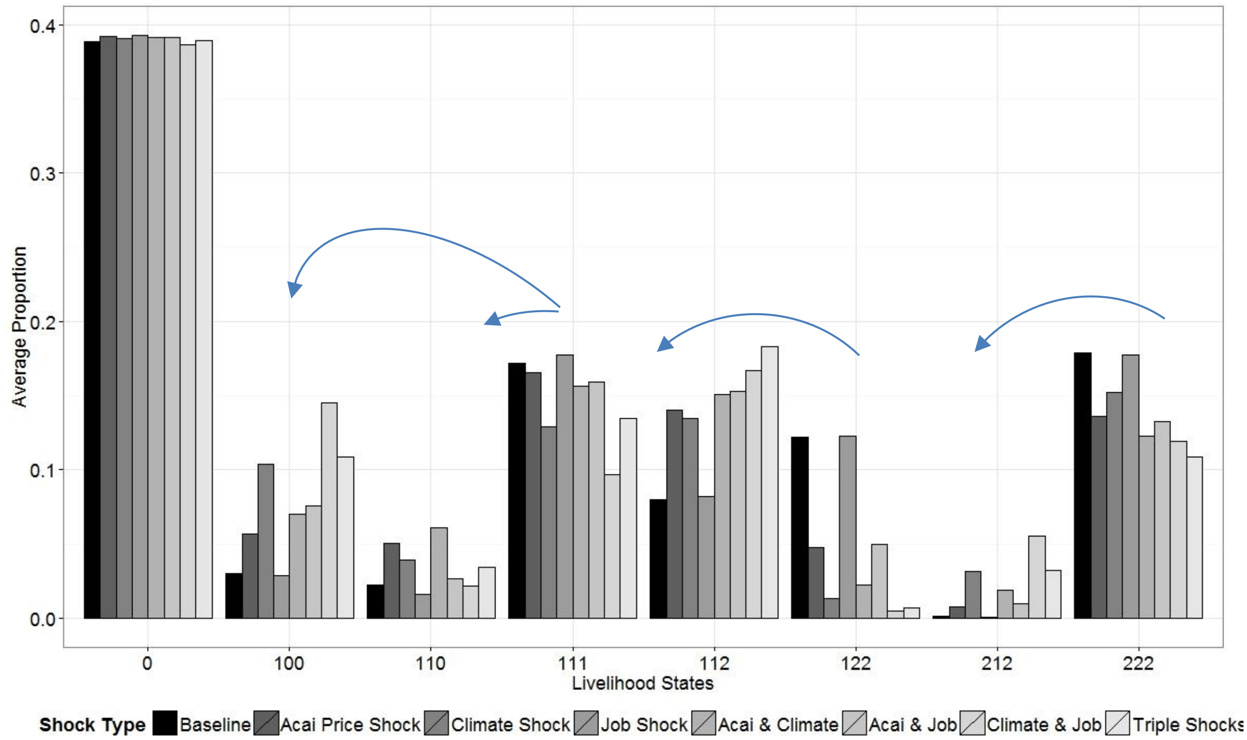
[27] http://www.apa.org/helpcenter/road-resilience.aspx



Appendix E Figure: Boxplots of two batches of simulation with 30 and 50 years, under scenario with triple shocks when there is no cash transfer program. ANOVA shows there is no significant difference in the capital and income between the two batches at each simulation tick.

Appendix F Table: Difference of proportion in shocks types and pension scenarios. Blank columns mean the results are not significant. The number indicates the margin compared to the baseline scenario.

No Pension Scenario								
difference in mean	**000**	**100**	**110**	**111**	**112**	**122**	**212**	**222**
Baseline	39.02%	2.19%	2.44%	16.48%	7.43%	12.25%	0.03%	19.33%
Acai Price Shock		0.032	0.030		0.061	-0.061		
Climate Shock		0.071	0.019		0.052	-0.052	0.029	
Job Shock								
Acai & Climate		0.043	0.043	-0.077	0.087	-0.087	0.056	-0.054
Acai & Job		0.042			0.071	-0.071		
Climate & Job		0.110			0.067	-0.067	0.019	-0.054
Triple Shocks		0.078			0.103	-0.103	0.036	-0.067
Static Pension Scenario								
difference in mean	**000**	**100**	**110**	**111**	**112**	**122**	**212**	**222**
Baseline	38.25%	2.46%	2.26%	18.41%	8.73%	12.14%	0.12%	17.22%
Acai Price Shock		0.029			0.058	-0.069		-0.050
Climate Shock		0.070			0.062	-0.103	0.032	-0.044
Job Shock								
Acai & Climate		0.110	0.071	-0.071	0.091	-0.115	0.050	-0.065
Acai & Job		0.048			0.069	-0.070		-0.052
Climate & Job		0.043			0.070	-0.100	0.019	-0.058
Triple Shocks		0.083			0.107	-0.115	0.031	-0.083
Dynamic Pension Scenario								
difference in mean	**000**	**100**	**110**	**111**	**112**	**122**	**212**	**222**
Baseline	39.42%	5.08%	1.90%	16.72%	7.83%	12.28%	0.16%	16.19%
Acai Price Shock			0.028		0.065	-0.079		
Climate Shock		0.081			0.052	-0.111	0.032	
Job Shock								
Acai & Climate		0.130			0.081	-0.119	0.057	-0.060
Acai & Job					0.080	-0.080		
Climate & Job		0.051	0.037		0.081	-0.104	0.015	-0.056
Triple Shocks		0.074			0.098	-0.119	0.023	-0.059



Appendix G Figure: Proportion of livelihood states under different shock types. We use blue arrows to represent the potential household movements from the better off livelihood states to the less-profit states.

Appendix H Table: Average value of household assets, decision making, and land types

average value							
	labour	total labour	subsistence requirement	household number	initial capital	initial per capita wealth	husband education
NP-2	0.96	1.66	2131	4.88	9182	2067	3.70
PT-0	1.03	1.72	2792	5.91	5885	1088	3.43
100	0.66	2.33	2606	5.01	7958	1671	3.56
110	0.78	2.50	2848	4.96	8873	1918	4.49
111	1.33	3.09	3717	6.25	8528	1613	3.63
112	0.97	2.58	2924	5.48	7894	1735	3.92
122	0.93	3.31	3302	6.78	8405	1477	3.37
	average female education	max leisure	max profit	subsistenc e first	varzea	upland	
NP-2	2.73	0.002	0.091	0.123	0.177	0.004	
PT-0	2.28	0.115	0.088	0.151	0.005	0.384	
100	3.54	0.010	0.011	0.009	0.026	0.004	
110	4.01	0.013	0.006	0.004	0.021	0.002	
111	4.05	0.150	0.014	0.007	0.046	0.126	
112	4.11	0.034	0.028	0.017	0.026	0.054	
122	3.92	0.007	0.059	0.056	0.008	0.114	

Note:

- Subsistence requirement, initial capital, and initial per capita capital are all in monetary unit.
- Maxi leisure, max profit, and subsistence first are in proportion; so are várzea and upland.

Appendix I Table: Factor loadings used to calculate livelihood states in basins of attractions and unstable state

Household Characteristics	Component		Component		Component	
	1 (26.94%)	2 (15.09%)	1 (21.81%)	2(16.70 %)	1 (22.10%)	2(13.33%)
	State 0 - 2		State 1-XX		State 1-XX (Triple Shocks)	
labour	-0.247	0.399	0.556	0.322	-0.506	0.141
Total Labour	-0.286	0.568	0.720	0.032	-0.632	0.165
Subsistence Requirement	-0.674	0.467	0.759	0.024	-0.757	0.156
Household Number	-0.565	0.347	0.769	0.014	-0.666	0.232
capital	0.727	0.160	-0.266	0.573	0.404	0.490
perCapita Wealth	0.853	-0.086	-0.712	0.406	0.692	0.136
pension	--	--	--	--	0.524	0.223
Husband Education	0.207	-0.385	-0.407	0.196	0.451	0.116
Average Female Education	0.019	0.670	0.246	-0.228	-0.383	-0.340
Max Leisure	-0.491	-0.317	0.080	0.631	-0.006	0.052
Max Profit	0.175	0.403	-0.047	-0.703	0.039	-0.584
Subsistence First	0.230	-0.136	-0.046	-0.003	-0.035	0.567
Upland	-0.818	-0.254	0.619	0.450	-0.558	0.514
Várzea	0.818	0.254	-0.619	-0.450	0.558	-0.514

Appendix J ODD Protocol of model description

The model used in this dissertation is described following ODD (Overview, Design concepts, and Details) protocol (Grimm and Railsback, 2012; Grimm et al., 2010).

1. Purpose

The purpose of this agent-based model is to simulate the behaviors of small farming households in the Amazon estuary region and evaluate their resilience to external shocks with the presence of several government cash transfer programs.

For the fourth chapter, *Understanding rural farming systems with agent-based modelling and decision making ensembles—a case study in the Brazilian Amazon estuary*, the model is implemented with three decision making mechanisms (Max Leisure, Max Profit, and Subsistence First) as individual ensembles to demonstrate the range of possible livelihood outcomes and to compare the influence of demographic and socio-economic factors. The specific research questions addressed in this chapter by the model are: (1) To what degree does the decision making strategies smallholder agents use affect their livelihood outcomes and impacts from cash transfers? (2) What demographic and socio-economic parameters significantly affect the outcomes of individual households or communities? (3) How does the influence of these factors change when different strategies are employed?

The decision making module is the core of agent-based modelling and it is often with great uncertainty that modellers “make decision” on which decision making strategy to use in one model. Comparison of different decision methods and their outcomes is conducted by a few studies (An, 2012; Cabrera et al., 2010). However, the range of outcomes is often limited by the choice of a single decision making method used in the model. This study integrates alternative decision making to avoid a major source of uncertainty, and thus represent the diverging patterns and possibilities of livelihood outcomes and cash transfer impacts.

For the fifth chapter, *Through the lens of development resilience: using agent-based modelling to explore rural livelihood resilience*, the model is used to quantify the resilience of rural livelihoods in the face of external pressure such as price oscillation and climatic events. Specifically, we adopt the definition and properties of "development resilience" as stated in Chapter five of this dissertation to frame the model output, in order to (1) identify the alternative states in the resilience landscape, (2) determine the negative influence from each shock, and (3) explore interventions to move households out of poverty trap or be more resilient. This is a pioneering effort to demonstrate the resilience dynamics by the simulation of an agent-based model, which extends the theoretical exploration and provides valuable policy implications.

2. Entities, state variables and scales

The two primary entities of this model are the household agent and the landscape. Each of them constitutes a list of core entities. One time step (tick) in the model is a single year.

Based on the decision making method, the *household agent* attempts to maximize its utility of capital (Max Profit), leisure time after subsistence is met (Max Leisure), and grow subsistence crops and maximize capital (Subsistence First). *Capital* is in fixed monetary unit since we don't consider inflation-adjustment in the model. The household agent uses capital to purchase seeds, manage soil, and cover the subsistence and other cost for family members. The household agent contains a list of *family members* (*person* agent) as their core entity. A person is described by his or her age, gender, and education. The *Labour* is derived from the age and gender of each member (Da Silva and Kageyama, 1983) and summarized into a total labour to the household agent. A male adult is considered as one labour unit, and teenagers and elders are bring a fraction of one unit, which depends on their age. A female labour unit is half of the male unit who contains same attributes. School-attending teenagers and pension-beneficiaries do not count as available labour for the household.

A person can age, die, and reproduce, resulting in a demographic change in the household agent. The number and demographic structure of family members in each household agent is populated at the initialization stage of the model and it follows a weighted distribution that can be adjusted based on scenario settings. The probability of death and reproduction for a person is based on the data of Abaetetuba derived from the Brazilian Institute of Geography and Statistics (Portuguese abbreviation: IBGE)[28]. However, there is no farm succession module in this model yet. The school attendance rate depends on the per capita capital in the household: if the per capita capital is beyond the poverty line, there is a slightly higher probability for children from this household to attend school compared to a household with a per capita capital below the poverty line. We use the percentage of school attendance from empirical studies as a proxy for the probability. The process of the demography module is shown below (Figure 0-1).

[28] http://www.ibge.gov.br/home/mapa_site/mapa_site.php#populacao

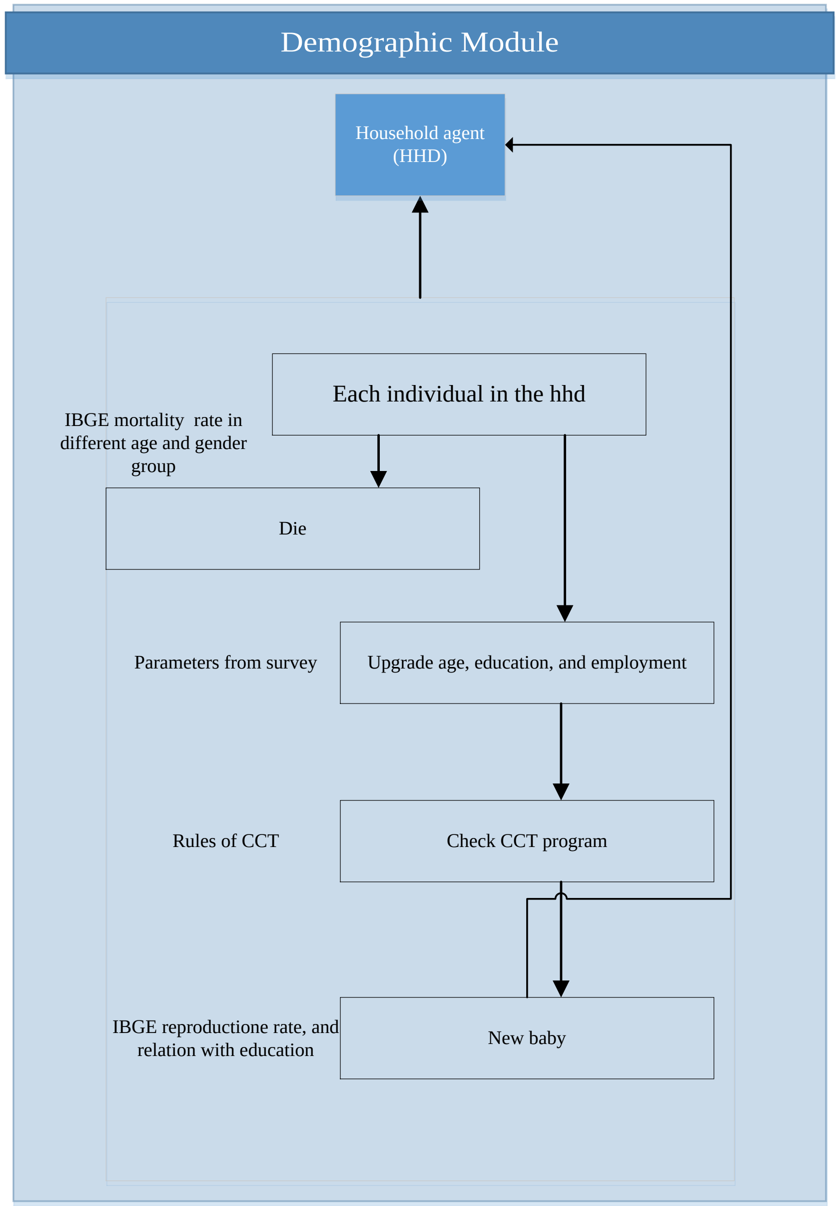


Figure 0-1 Model flow through the demography module

The age of a person is updated every year. The education is also updated every year if the kid attends school. Subsistence and other cost are calculated based on age and gender, and are updated every year. Capital is renewed at the end of each year: counting revenue from all activities and cash transfer program, and deducting the subsistence requirement.

The landscape is a 612 × 600 grid of 5 m ×5 m cells. It is a semi-theoretical landscape representing a binary land types: water and land. This landscape was recycled from a previous project of Paricuba, the region of which shares a high resemblance of Abaetetuba. The water region was masked off a Landsat TM/ETM image. Each household agent has a *property*, which is stored as a list of (x, y) coordinates on a 5 m-resolution raster grid. The household itself is stored as a (x, y) coordinates and does not occupy any grid cell. Each land *cell* is implemented as an agent in Repast Simphony. Based on the distance to water, land cells are classified as floodplain (varzea) or upland (terra firme). Cells are scheduled for land cover and soil fertility transition as agent and can be allocated to one of the four land uses: forest, intense acai, house gardens, and fallow. These land uses produce: timber[29], acai, and manioc[30]. The price of the three products refers to the market prices of goods.

Each land cell has the following attributes stored: land cover density (fuzzy variables), years since initial planting (age, as an integer), soil fertility (a fuzzy variable), and yield of each good (in kg) that is different for floodplain and upland (e.g., acai has a much higher yield on floodplain than upland when manioc is the opposite). Land cover transitions and resulting yields are derived from Brondizio (2004) and is scaled to a linear relation with the distance to water. The maintenance of land cells of the year is stored as a Boolean variable, which also affects the yield. The idea of this maintenance is a simplification of farming practices: whether a list of actions (e.g., weeding for manioc, or thinning for acai) has been performed or omitted.

The economy of the model is represented by market agent and employer agent. *Market agent* sets the prices for all commodities, which are conceptualized and operated as exogenous

[29] Because we didn't observe on-going deforestation in the Amazon delta, in this paper, we set the timber price extreme low to a point that farmers will never exact any goods from the forest or clear forest for timber. Therefore, the actual land use products are only acai and manioc.
[30] Manioc represents a collection of goods that can be extracted from house garden.

factors in our model. The price of each commodity is stored as an array for the length of simulation and is delivered to household agents at the beginning of every year. Having said that, the amount of goods that household agents produce does not affect the price of the commodity—household agents are simply price takers, which is a reasonable assumption since the overall acai outcome from Amazon delta plays no significant role in the world market. This design of market agent provides us freedom to stimulate the system with different price shocks for resilience testing.

The *employer agent* is located in nearby city of Belém and offers rural household agents off-farm job opportunities in the city. The agent sends a limited number of jobs, which is updated every year, to the household agents. Household agents are sorted (from highest to lowest) by the probability of employment which is calculated based on a function of average education of female members and the education of the husband. The probability function is empirically derived from a database that was collected in the year of 2012. Job opportunity is sent to household agents in the ascending order of probability which is then compared with a random number to determine whether or not this household can actually get the job. It is assumed that households, in order to get an off-farm job, have to compete with a larger community instead of the households within the model, and households with better education normally have a higher chance to get an off-farm job. If a household agent is capable of receiving a job offer, the most eligible family member (based on age, gender, and education) will be sent out to take this offer.

Policy in our model is represented by two types of cash transfer programs. The first program is pension, which offers a minimum wage to all the elder members. The other program is Bolsa Familia that is given to households with a per capita income lower than the gate value of the policy. Once receiving Bolsa Familia, children in the households will have a full attendance to school. Thresholds for pension (age and minimum wage) and Bolsa Familia (per capita income and amount) are stored as constant numbers in the model that can be adjusted by modellers.

3. Process overview and scheduling

The model operates on an annual base and is divided into major stages of cultivation and harvesting that are scheduled using Repast Simphony's priority based scheduler. A typical time step is listed (Table 0-1).

Table 0-1 Major stages and steps in each stage

Stage	Steps and scheduling
Setup	• land cell maintenance flags are reset • policy is renewed for the year • market prices, climate, and employment of the year is read from the file • each person's demography is updated (age, death, reproduction, education)
Broadcast	• employment offers are sent • market prices are broadcast
Planning	• households accept or reject the job offer • households allocate cultivation resources
Cultivation	• households perform cultivation • off-farm job labour moves to city
Biophysical	• land cover transitions • yields are calculated based on land use, soil fertility, and practices
Harvest	• households perform harvest • revenues are calculated
Retrospect	• all household attributes are updated and recorded for the next decisions

The setup stage sets the maintenance for land cover transition model (i.e., *isMaintained* flag set to be false). The policy and economy are also set at this stage. The model reads the external file to learn the amount of the Bolsa Familia and Pension program for this year, as well as the price for every commodity and number of jobs offered. Household agents update every person's demographic status: everyone age, some may reproduce or die, and kids attend school or help at home.

The setup stage is followed by the *Broadcast* stage, where market prices and job offers are broadcast to all household agents. Household agents are sorted based on education and then receive the job offer orderly with the assumption that employment is offered from big cities like Belém to these rural communities, and is more likely to be obtained by households with higher education.

In the *Planning* stage, households, no matter what decision making strategy they are using, traverse their resources and feasible actions. Employment is first evaluated and compared with average crop revenue, for households to decide to accept or reject the offer. After the employment decision is made, the household agent inventories for land use and management options. For each land cell, if the labour and capital are not constrains, household agents can choose one action from the following: (1) change the land use; (2) change the land use management: intensify, maintain, or abandon current crops. This is to give household agents an opportunity to make comprehensive decisions based on a full inventory or their resources and constraints, which also mimic the real decision making stage before the planting period.

The *Biophysical* stage is where land cover transitions occur. The transition is a mixed effect from natural processes and land use and management actions during the Cultivation stage. Yields are calculated as a result of these processes.

The decisions that are made during the Planning stage will all be executed during the *Cultivation* stage. Besides those already made decisions, households can decide whether or not to call back the member who is working off-site for the *Harvesting* stage. At the Cultivating stage, the cost of seeding and planting is taken away from the household capital. At the Harvesting stage, the revenue from selling crops can be collected. The feasibility of all planned actions during Planning stage is verified at this stage to avoid any error.

The last stage is the *Retrospect* stage in which household agents update all the properties and statistics for their future consideration. The system also writes the updated attributes into the database for this year.

4. Design Concepts

A few key concepts have been extensively discussed and raised awareness for the design of ABM (Grimm and Railsback, 2012; Polhill et al., 2008). Here we summarize the following concepts of our model, including emergence, adaptation, objectives, prediction, sensing, interaction, stochasticity, and collectives.

4.1 Emergence

Emergence is a standing out feature of agent-based model in contrast to many traditional dynamic models since no global equilibrium is needed. Simply speaking, emergence is the aggregated pattern from individual behaviors at a lower level. Many times this emergent pattern is surprising to modellers. Depending on what research questions this model is used to answer, the emergent patterns are different.

In Chapter Four, we used the model to investigate the impacts of cash transfers on household and community well-beings and we found a few emergent patterns from the results. We learnt that cash transfer significantly improves the well-being of households with the Max

Leisure decision making strategy, but is less influential for households with Max Profit and Subsistence First. Having bigger family labour has opposite impacts on Subsistence First households compared to the Max Profit and Max Leisure families. The emergent patterns exist not only in the decision making regimes, but also in the cash transfer scenarios that we designed: the impacts of cash transfer do not have a linear relationship with the amount of cash transfer that is assigned. Receiving higher cash transfer does not necessarily reduce the poverty or inequality of income.

We used the model to explore resilience concept and assess the factors and shocks on the resilience of household livelihoods in Chapter Five, which leads to a few emergent patterns as well. The first surprising finding is only eight out of 27 state combinations that we observed from the simulation results. This proves the theoretical concept of “basin of attraction”--entering a certain state of the livelihood system might drive households lock-in such state and households experience difficulty to walk out of it. The other emergence from model results is that raising household initial capital may not increase household resilience unless the raise is above a certain level. This result, nevertheless, gives an uncommon policy implication that in order to increase resilience the capital boost has to be significant otherwise it will not be effective.

4.2 Adaptation

Households do not change decision making strategy over the simulation. One household implements a single strategy in one model run.

4.3 Objectives

Three decision making strategies are implemented as three ensemble members. In the setting of this model, households have subsistence requirement of both acai and manioc based on the demographic structure of the family, while acai has higher market value and manioc is much more labour intensive. The Max Profit household agents seek to optimize the monetary profits based on their labour and capital resources and constraints. Therefore Max Profit household actors who live on várzea usually manage acai plots and not manioc. The Max Leisure households, instead of optimizing the profit, prefer having leisure time once they produce enough to meet their subsistence requirement. However, the Subsistence First households optimize neither monetary profits nor leisure time. Instead, they first conduct activities that fulfill their domestic needs of both acai and manioc. Once this demand is secured, they go after market value, which is acai planting and management.

4.4 Prediction

When household agents make crop decisions, there are two variables, crop price and yield, that are not certain and need prediction. Crop price is implemented as an external factor in the model and yield is a function of land cover transition and climate variable. Based on the research question in Chapter Four, the crop price is constant throughout the simulation, hence there is no prediction needed for household agents in the model and the price is broadcast to all agents at the beginning of each year. The climate variable in this chapter is also constant so that the yield is a function of land cover transition within a reasonable range.

However, when we investigate resilience for the acai price shock scenario in Chapter Five, household agents use the average price of the past three years as the price for this year when making cropping decisions. We also manipulate the climate variable to create a drastic dynamic for crop yield. In a similar way to predicting for crop price, agents also use the three year average as the yield prediction for this year. The three year window is chosen based on a field experiment that is done by Brondizio & Moran (2008).

4.5 Sensing

All agents have identical and perfect knowledge of their properties. Perfect knowledge means that they know the age, the land cover density, and soil fertility of each cell accurately. The broadcasting of crop price also reaches all agents at the same time. However, the sensing of non-farm job opportunities is in an order that depends on education level, which means that agents with higher education will have a better and earlier sense of the job opportunity.

Agents predict the price of this year based on the previous three years when making cropping decisions. However, they are not able to know the future price with certainty until later in the year during harvest season when they will know the value of their harvest based on this year's market price.

4.6 Interactions

Interactions between agents occur in three forms: message-passing between household agents, multi-site household communication, and the competition between household agents for available jobs.

The message-passing between household agents is prior to the Planning stage and during the execution stages. It is programmed as a public broadcast to all agents which simulates the information dissemination. Messages can also be sent from farming households to their connected off-site agents to recall for agricultural work; on the other direction, off-site agents will send half of their salary to the farming households to support subsistence or agricultural preparations. Between different household agents, they need to compete for the available off-farming jobs.

4.7 Stochasticity

The original MARIA uses a Poisson process to assign the non-farm job opportunities and a uniform distribution for wage. We changed this process and wage expectation to a probability function of household agents' education level that is derived from the empirical data. The probability calculated from the function is compared to a randomly generated number in the model, to determine whether this agent will get the job.

The stochasticity also happens during the model setup stage when a weighted distribution is used to populate households with different demographic structures, education for each member, and the initial capital. For instance, the baseline scenario for initial capital is that 25 % households in 1000-4000, 50 % will be having a capital within the range of 4000-7000, the rest will be assigning in 7000-10,000. The overall distribution is set up in a mixed form of regularity and randomness, which ensures a fixed number of households in a certain range but the exact value of capital is stochastically assigned. When we want to have a scenario with more households with a large capital, the weight on larger capital ranges can be set up higher.

During the simulation of one model run, the reproduction and death of a family member is also implemented by a probability compared to a randomly generated number. This stochasticity may change a household demographic structure significantly and is not scheduled at the beginning of the model but during the model run.

4.8 Collectives

A household in this model is treated as an explicit agent and a single decision making unit with its own property, capital and other resources. They do not form any social or kin groups. However, the off-site households and farming households are connected with economic and labour links, and the resources of the two households are maintained as one collective unit.

5. Initialization

The landscape is initialized as floodplain forest near the water and upland that is further away from the water cells. The demographic and capital resources of household agents are compliant with weighted distributions. The distribution of the baseline scenario aligns with empirical pattern we found in a household survey.

6. Input data

This model uses the following input data: the scenario file, the basic parameters, the decision making method, and the landscape (Table 0-2).

Table 0-2 Model input files and their functions

Input file	Explanation	Function
1. Scenario Input	defines the scenario (price, climate, job offers, etc…) and convert plain text file into the model	to set up scenarios
2. Basic Data	contains basic parameters and distribution weights used in model set up	to define the initial characteristics of the agents
3. Decision Making	defines the decision making method that agents use in this model run	to allocate the decision making strategy that agents use
4. Theoretical Landscape	represents the water cells, floodplain, and upland.	to initialize the environment that agents interact with

7. Submodels

In this section, we report the three decision making strategies that are implemented in this model, which are Max Profit, Max Leisure, and Subsistence First. They are all complied by a mixed-integer linear programming algorithm, the *lp_solve* library version 5.5.2.0. Every decision making strategy, although it uses the same algorithm, has a specific goal to optimize. However the general structure of decision variables and the coefficient are the same across different strategies. There are four decision actions that agents allocate their resources on, which are: expanding new land uses, maintenance of existing plots, acceptance of employment opportunities, and the recall of off-farming family member to the agricultural activities. Agents first send out the most eligible family member for the job offer (if there is one) and allocate the remaining resources on land uses.

The coefficients of the decision variables include crop prices, crop yields (expected yield for Planning stage and known yield for Harvesting stage), and costs, which are represented respectively by p, y, and c. Off-farm wages are represented by w. The agent's current resources (i.e., labour, capital, and land) are also the variables in the linear program definition. The available land for new land use expansion is old growth forest or fallow land that can be converted, and the plots for maintenance are existing land cells of acai or manioc.

7.1 Max Profit decision making

Agents adopting Max Profit strategy optimize the market value of different crops considering their resources and constraints. The revenue of each available land use action is to multiply the average expected profit (the price and average expected yield minus cost) by the number of action is taken (number of land cells), which can be represented by the following formula align with off-farm revenue:

$$\max \begin{Bmatrix} (p_{acai}y_{acai} - c_{n\_acai})n_{acai} + (p_{garden}y_{garden} - c_{n\_garden})n_{garden} + \\ (p_{acai}y_{acai} - c_{m\_acai})m_{acai} + (p_{garden}y_{garden} - c_{m\_garden})m_{garden} + \\ \sum_j \bar{r}_j w_j \end{Bmatrix}$$

subj. to

$$l_{n\_acai}n_{acai} + l_{n\_garden}n_{garden} + l_{m\_acai}m_{acai} + l_{m\_garden}m_{garden} + \sum_j \bar{r}_j l_j \leq Labour$$

$$c_{n\_acai}n_{acai} + c_{n\_garden}n_{garden} + c_{m\_acai}m_{acai} + c_{m\_garden}m_{garden} \leq Capital$$

$$n_{acai} + n_{garden} \leq AvailableLand$$

The employed family member can be recalled to the household and is represented by a Boolean variable $\bar{r}_j$. In the land use section, the number of new plots of acai and manioc gardens is represented by integers n_{acai} and n_{garden} respectively, and the number of existing acai and manioc gardens is represented by m_{acai} and m_{garden}. The labour is represented as *l*, and *c* is cost.

Above is the formula that agents use for planning the land uses. A similar linear program is used for the harvest stage, except there is no difference for labour requirement for new cells, maintained cells, and non-maintained cells. Resources are allocated towards the extraction of crop yields from existing land use cells. Employed family member can be recalled to help out harvest if their wage is not as substantial as the revenue from agricultural products. Other constraints are trivial and are omitted here for brevity (e.g., the upper bound of available land cells).

7.2 Max Leisure decision making

Agents using the Max Leisure strategy are implemented similarly as Max Profit, with different goals and constraints, shown as following:

$$\min\ l_{n\_acai}n_{n\_acai} + l_{n\_manioc}n_{n\_manioc} + l_{m\_acai}n_{n\_acai} + l_{m\_garden}n_{m\_garden} + l_j$$

subj. to

$$\begin{aligned}
&((p_{acai}y_{acai} - c_{n_acai})n_{acai} + (p_{garden}y_{garden} - c_{n_garden})n_{garden} + \\
&(p_{acai}y_{acai} - c_{m_acai})m_{acai} + (p_{garden}y_{garden} - c_{m_garden})m_{garden} + \\
&\textstyle\sum_j \bar{r}_j w_j + CashTrans) \geq MonetarySubsistence
\end{aligned}$$

$$c_{n\_acai}n_{acai} + c_{n\_garden}n_{garden} + c_{m\_acai}m_{acai} + c_{m\_garden}m_{garden} \leq Capital$$

$$n_{acai} + n_{garden} \leq AvailableLand$$

The narratives of this strategy is that agents allocate their resources on different land uses to make just enough for subsistence needs in monetary units. Their goal is to use as little labour as possible. This is still a utility maximization but with an extreme favored weight on leisure time. Notice that cash transfer income plays a significant role here in this decision making, since it counts as part of income to meet the subsistence requirement.

7.3 Subsistence First decision making

The agents who use the Subsistence First strategy follow this formula. They still try to optimize the profit from growing different crops, however, they are also subject to grow both acai and manioc enough to domestic consumption first. Note here the constraint is the quantity of acai and manioc, instead of a monetary unit like in Max Profit or Max Leisure.

$$\max \begin{array}{l} (p_{acai}y_{acai} - c_{n\_acai})n_{acai} + (p_{garden}y_{garden} - c_{n\_garden})n_{garden} + \\ (p_{acai}y_{acai} - c_{m\_acai})m_{acai} + (p_{garden}y_{garden} - c_{m\_garden})m_{garden} + \\ \sum_j \bar{r}_j w_j \end{array}$$

subj. to

$$(n_{acai} + m_{acai})y_{acai} \geq acaiSubsistence$$
$$(n_{garden} + m_{garden})y_{garden} \geq maniocSubsistence$$

$$c_{n\_acai}n_{acai} + c_{n\_garden}n_{garden} + c_{m\_acai}m_{acai} + c_{m\_garden}m_{garden} \leq Capital$$

$$n_{acai} + n_{garden} \leq AvailableLand$$

7.4 Production function

A production function expresses the systematic relation of the quantity of output with the quantity of input. The assumption in agriculture is that the crop yield responds to labour and capital use (e.g., fertilizer, herbicide, pesticide, irrigation). In our case, it is the relation between output of acai/manioc yield, labour use (l), and monetary cost (c) per crop on a per cell basis, as well as the maintenance of the land cell. The Cobb-Douglas function has been used as the production function in the ABM, a typical case of which is in MP-MAS that uses empirical Cobb-Douglas production function as the economic component (Berger and Schreinemachers, 2009; Schreinemachers and Berger, 2006a; Schreinemachers, 2005). Due to a lack of empirical data, we simplified the form of the production function in our model. The basic assumption of the production module in our model is that there is a fixed labour and capital cost for each crop in a per cell basis, which produces a fixed yield subject to the cell history and physical property. In addition, we also include the relation between crop yield and maintenance of a cell using a fixed amount of labour and capital input. The production function of crops in our model is specified as the following form:

$$Y_c = f(l, c, \bar{m}) * cv$$
$$\bar{m} = flag(l_m, c_m)$$

Where *l*, *c* are fixed labour and capital input for each cell, $\bar{m}$ is the Boolean variable to indicate if this cell is maintained, cv represents the climate variable that is used only in Chapter Five for the climate scenario. The yield function here is actually a constant value, to be specific the function can be written as:

$$Y_c = a * \bar{m} + b$$

a and b are constant, meaning if the cell is maintained, the yield will be a+b, if not, it will only be b. The management of the plots in reality includes a list of actions such as weeding, extracting, which is hard to quantify as a labour input. In the future, we can try to represent the relation between yield and this maintenance work in a more accurate mathematical form.

In the employment sector, the wage function depends on a few variables, the relation of which is derived from a database. We use a linear regression to estimate the relation between size of salary and these variables, the form of which is:

$$w = \beta_i \cdot v_i + d$$

Where y is the wage of a household, V_i is the ith variable, and d is the constant value. Data that are operated in this linear regression include only households that have employment, in this case, 277 households who have employment. Variables that we found significant for the wage amount are: husband education and husband age.