Early Action against drought induced food insecurity

An agent-based exploratory modelling study comparing different cash transfer policies to minimize household food insecurity in Kenya

J.F.M. Hoeijmakers

2021

TU Delft

510 AN INITIATIVE OF THE NETHERLANDS RED CROSS

Cover photo by Ahrend de Kruijf

EARLY ACTION AGAINST DROUGHT INDUCED FOOD INSECURITY

Master thesis submitted to Delft University of Technology in partial fulfilment of the requirements for the degree of

Master of Science
in **Engineering and Policy Analysis**

by

J.F.M. Hoeijmakers
Student number: 4169239

To be defended in public on July 5th 2021

Chairperson & First Supervisor:	Dr. T. Comes Multi-Actor Systems
Second Supervisor:	Dr. H.G. van der Voort Multi-Actor Systems
External Supervisor :	Dr. M. van den Homberg 510, Netherlands Red Cross
External Advisor :	M. Wens PhD researcher, Vrije Universiteit Amsterdam

TUDelft

*"Tactics is knowing what to do when there is something to do;
strategy is knowing what to do when there is nothing to do."*

– GM Savielly Tartakower

PREFACE

Before you lies my master thesis, the result of a couple of months of individual work. It marks the end of my time at the faculty of TPM and the TU Delft. I always expected that the final master thesis would be a challenge, but this thesis has proven to be the hardest project I have done so far. The current situation of the Corona pandemic has made an individual assignment even harder and more isolated then ever expected.

Luckily I had help from my supervisors throughout the entire process. First of all, I want to thank Tina Comes. When I came to you with my suggestion for a master thesis and the question if you wanted to be my supervisor, you immediately reacted positively. Your feedback throughout my thesis process was always critical and constructive. You made me reflect on my decisions and your experience guided me toward something that I can be proud of. Secondly, I would like to thank Haiko van der Voort. You delivered exactly what you promised when I contacted you for this thesis. A completely different perspective in meetings and on drafts. You made sure I would keep a broad view, as a real TPM student should.

In addition to my supervisors at TPM, there are two other people on my committee that I would like to thank. First of all Marthe Wens. I want to thank you for being there for all my smaller and bigger questions. Helping me in the development of my model and telling me that it is okay to be stuck or not feeling it once in a while. Lastly I want to thank Marc van den Homber. Your enthusiasm for this field is inspiring and you never had a lack for new ideas. From the beginning of this project you helped me find the right topic and provide me with all sorts of materials. The meetings with you and Marthe were the perfect way to stay on track and keep going.

There are many others that need to be acknowledged for my time in Delft. I want to thank Fuuk and Cjoe for helping me with my Mesa and Python struggles. Additionally, I want to thank my friends for keeping me sane during my master thesis. Teunis, thank you for draining all my energy and frustration in intense interval sessions. Ahrend, thank you for the distractions in the form of challenging games of chess. I want to thank everyone else for listening when I had something to complain about, or having a drink to help me get through it. Lastly, I want to thank my parents and my family, for their continuing support throughout my time in Delft and supporting me in every decision I would make.

Please enjoy reading this thesis.

Joep Hoeijmakers

EXECUTIVE SUMMARY

The United Nations has set a goal to eradicate hunger in the world by 2030. The World Food Programme (WFP) is the primary instrument for the UN to reach their goal and was even awarded the 2020 Nobel Peace Price for its efforts to combat hunger. However, even with all the efforts, this goals seems far away. The Food and Agriculture Organisation (FAO) 2020 estimates that still almost 690 million people in the world experience hunger. Nearly 750 million, close to one in ten people, experienced severe levels of food insecurity in 2019 and an estimated 2 billion people could not access safe, nutritious and sufficient food. Looking worldwide, these levels of food insecurity are not evenly distributed. In 2019, 19.1 percent of the African population, or more than 250 million people, were undernourished. This is more than twice the world average (8.9 percent) and it has a growing trend (FAO et al., 2020).

One of the substantial causes for food insecurity in an area is drought. Drought is a very insidious disaster. Unlike rapid onset disasters, like an earthquake or flood, it increases its grasp over an area over time. The longer the drought lasts, the more an area is destroyed leaving devastating effects that can last many years. The impacts of droughts are even bigger on areas that are predominantly dependent upon agriculture. One way to assist poor households facing chronic food insecurity and increase their resilience to shocks is through unconditional direct cash transfers. This approach differs from traditional aid, such as food aid, because it gives the power of decision-making back to the people who know best their needs. this study aims to explore different cash transfer policies as a humanitarian response to food insecurity caused by and the influence on household food security.

The main research question posed in this research was:

"How can an agent-based model be used to analyse the effect of different ex-ante cash transfer policies on the household food security in Kenya, as humanitarian anticipatory action to drought?"

The objective of this study is to gain insight into the complex structure of the food system when affected by a drought and, using a modelling approach, explore the effects of different cash transfer policies on the food insecurity of households under various scenarios. Agent-based modelling has been combined with exploratory modelling techniques and empirical data to achieve this objective.

The system that is observed in this study is based on previous drought models (e.g. (Vervoort et al., 2014), (IPCC, 2007)) including socio-economic and environmental drivers on the household level (Stephens et al., 2018). Figure 5.2 shows a visual representation of this system, including a household food system, food production and a market mechanism. It shows that these subsystems are highly interconnected. A shock (like a drought) in one of these systems will have a big impact on the rest of the system.

A household survey and choice experiments was conducted at 186 households in Isiolo by members of the Kenya Red Cross Society - International Centre For Humanitarian Affairs (KRCS-ICHA). The survey identified three main food sources of respondents; own livestock production, purchase on the market and own crop production. Many respondents have experienced severe food insecurity in the past and a seasonal rainfall deficit or excess of rainfall is the most prominent cause for food insecurity. Additionally, choice experiments were conducted to evaluate the preference of households regarding cash transfers. The results show that households prefer to have the cash transfer in one lump sum payment, rather than two payments. There has not been found any preference in the lead time of the transfer, but this could be due to to misunderstanding of the experiment. The regression analysis shows that a higher education level, income from labour or from 'other' sources significantly increases spending of the cash transfer on food. Households with only a primary education level, income from labour, private business or 'other' spent less on mitigative measures. Households with only secondary education spent more on household expenditures, while households with tertiary education would spend significantly less.

Three KPIs used to evaluate the performance of the system are; household food insecurity, crop stock at the local market and capital of households. The main policy levers are payment type and lead time. The policy interventions have been separated in two different policy strategies; (1) 'As Soon As Possible' (ASAP), characterised by long lead times and mainly one lump sum payments; and (2) 'Careful consideration', characterised by short lead times and two time payments.

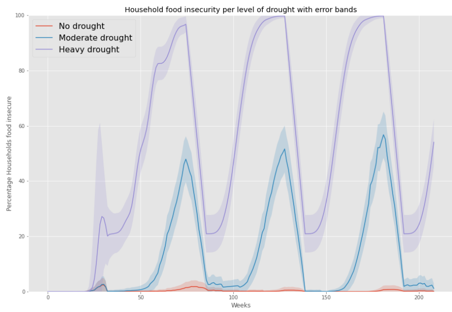


Figure 0.1: Food insecurity in different drought scenarios base model

The base model (Figure 0.1 shows that, without any drought, there are hardly any households that become food insecure. When drought occurs there is a peak in household food insecurity every year just before the harvest season. In the moderate drought scenario about 50% of households become food insecure each year, while this is close to 100% in the severe scenario. In a moderate drought scenario the average capital of working households drops when a drought occurs, while in a severe scenario the average capital increases. Without any drought, the local market will be balanced and will not run out of stock. When a drought happens, the market stock quickly runs out in both drought scenarios.

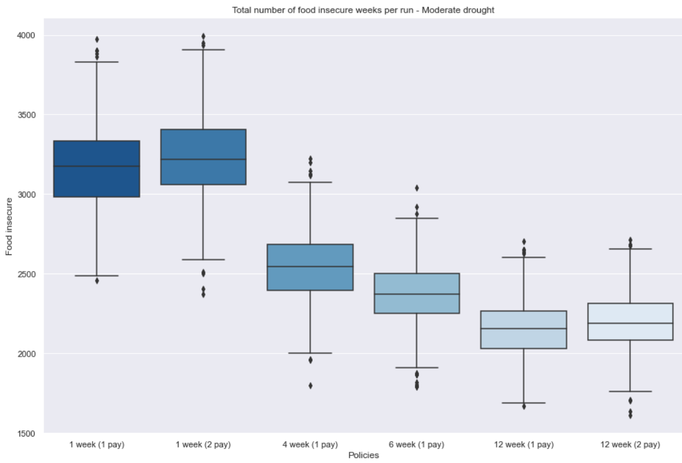


Figure 0.2: Effect Lead Time on Total weeks food insecurity - Moderate drought

The only policy leaver that has a significant impact on household food insecurity is the lead time. A longer lead time leads to less total food insecure weeks, as can be seen in 0.2. When comparing a 1 week lead time and 12 weeks lead time, the 12 week lead time causes a 45% decrease of total food insecure weeks. The policy levers do not seem to affect the average capital or market stock in a significant way.

Based on the results of this study, four recommendations are made for Netherlands Red Cross - 510 and any other humanitarian aid organisations interested in these results.

1. Firstly, the results show that cash transfers can be a valuable tool to use in combating food insecurity caused by drought. However, timing is important when considering cash transfers. Cash transfers have more impact if they are made well in advance of a drought disaster. If there is a will to implement cash transfers more often, a procedure should be constructed with well defined lead times and forecast probabilities. Longer lead times do however come with more uncertainty. It will be harder to convince other actors of acting when the forecast probability is still low.

2. Secondly, not all household types have the same needs in different drought scenarios. The results of this study show that in a severe drought scenario working households become completely food insecure and need food aid, while the other types still have some degree of self sufficiency. In a moderate drought scenario the working households are least affected and almost none are in need of cash, while the pastoral and semi-pastoral households become dependent on a cash transfer. This is due to the fact that these households have limited

income when their crops die out. These difference show that a cash transfer program should take into account the varying needs of the households types in different scenarios.

3. Thirdly, the future of food aid is not lost. Cash transfers may replace food aid as the dominant humanitarian response in the future, but will not completely replace it. The model simulations of a severe drought in this study have shown that cash transfers are not applicable in all situations. It is important to always perform an assessment of the local markets before considering providing cash transfers.

4. Last, it is important to recognise the multi-actor setting of cash transfers. Findings in this study and the F4S study can be used to convince other actors to invest time and resources in a cash transfer program. When doing this, the current cash transfer programs already in place by the Kenyan government should be taken into account. Additionally, it is important to understand that collaboration with local actors is key in creating a successful cash transfer program.

CONTENTS

1 INTRODUCTION 1
1.1 The global hunger crisis 1
1.2 The impact of drought 1
1.3 Humanitarian aid as a response to drought 2
1.4 Food insecurity as a complex problem 3
1.5 Research objective: Exploring cash transfer policies 3
1.6 Structure of this study 4
2 LITERATURE REVIEW 5
2.1 Review method 5
2.2 Key concepts of system 6
2.2.1 Food insecurity 6
2.2.2 Direct cash payments 6
2.3 Review of existing models 7
2.3.1 Food security models 7
2.3.2 Agent-based food security models 8
2.3.3 Take away current models 8
2.4 Knowledge gap 9
3 RESEARCH DESIGN 10
3.1 Main research question 10
3.2 Sub questions 10
3.3 Methodology 11
3.3.1 Sub-question 1: What factors influence the food insecurity of households in Kenya during a drought? 13
3.3.2 Sub-question 2: How can household food insecurity due to droughts in Kenya and the intervention of direct cash transfers be conceptualized and formalized in terms of policies, uncertainties and Key performance indicators? 14
3.3.3 Sub-question 3: How can the household food insecurity be implemented in an Agent-Based Model? 15
3.3.4 Sub-question 4: What is the effect of policy interventions on the household food security in the Isiolo region in Kenya? 15
3.3.5 Sub-question 5: How can the outcomes of this study be generalized to other drought crises? 16
4 FACTOR IDENTIFICATION 17
4.1 Case 17
4.2 Household survey 18
4.2.1 General information 19
4.2.2 Food insecurity 19
4.3 Choice experiments 20
4.3.1 Set-up of experiments 20
4.3.2 Data cleaning and analysis 21
4.3.3 Results of choice experiments 22

4.3.4 Regression analysis . . . 22
4.4 Conclusion . . . 24
5 MODEL CONCEPTUALISATION AND FORMALISATION 25
5.1 Actor Identification . . . 25
5.1.1 Humanitarian actors . . . 26
5.1.2 National government . . . 27
5.1.3 Local actors . . . 27
5.1.4 Visualisation . . . 28
5.1.5 Conclusion Actor analysis . . . 28
5.2 Conceptualisation . . . 28
5.2.1 Causal Loop Diagram . . . 29
5.2.2 Agent types, properties and interactions . . . 29
5.3 Using household survey and choice experiments for model formalisation . . . 31
5.4 Formalisation of systems . . . 31
5.4.1 Household formalisation . . . 31
5.4.2 Drought formalisation . . . 34
5.4.3 Food price formalisation . . . 34
5.5 XLRM Framework . . . 34
5.5.1 Key performance indicators . . . 34
5.5.2 Policy levers . . . 35
5.5.3 Uncertainties . . . 36
5.5.4 Visualisation of the XLRM Framework . . . 36
6 MODEL IMPLEMENTATION 37
6.1 Modelling environment . . . 37
6.2 Time Sequence . . . 38
6.3 parametrisation . . . 38
6.4 User interface . . . 39
6.5 Verification . . . 40
6.5.1 Extensive code walk-through . . . 40
6.5.2 Recording and tracking Agent behaviour . . . 40
6.5.3 Minimal model testing . . . 41
7 RESULTS 42
7.1 Base model behaviour . . . 42
7.1.1 Base model without drought . . . 42
7.1.2 Effect of drought on base model . . . 44
7.2 Experimentation . . . 47
7.2.1 Open exploration . . . 47
7.3 Effect policy interventions . . . 47
7.3.1 Payment type . . . 47
7.3.2 Lead time . . . 51
7.4 Conclusion . . . 53
8 ANALYSIS 54
8.1 Model validation . . . 54
8.1.1 Face validation through expert consultation . . . 54
8.1.2 Literature validation . . . 55
8.2 discussion policy levers . . . 56
8.2.1 Payment type . . . 56

8.2.2 Lead time 56
8.2.3 Interventions in severe drought 57
8.3 Analysing policy strategies 58
8.4 Real-world use and implementation 59
8.5 Conclusion 60
9 DISCUSSION 61
9.1 Limitation of the study 61
9.1.1 Critical assumptions 61
9.1.2 Model limitations 62
9.2 Reflection on the used approach 63
10 CONCLUSIONS AND RECOMMENDATIONS 65
10.1 Answering research sub-questions 65
10.2 Answering main research question 69
10.3 Societal contribution and recommendations for Red Cross . . . 70
10.4 scientific contribution 71
10.5 recommendations for future research 72
A HOUSEHOLD SURVEY ANALYSIS 84
A.1 Data cleaning 84
A.2 Plots 85
A.3 Choice experiment 87
A.3.1 Regression analysis 88
B ASSUMPTIONS 91
C PARAMETRISATION 92
D VERIFICATION 93
E RESULTS 94
E.1 Experimentation 95
E.2 Model results 95

LIST OF FIGURES

Figure 0.1 Food insecurity in different drought scenarios base model . . . vii
Figure 0.2 Effect Lead Time on Total weeks food insecurity - Moderate drought . . . viii
Figure 3.1 Research Flow Diagram . . . 12
Figure 3.2 Four pillars framework by (Dobbie and Balbi, 2017) . . . 14
Figure 3.3 Modeling approach by (Dobbie et al., 2018) . . . 15
Figure 4.1 Isiolo district in Kenya, map by (ISSAfrica, 2020) . . . 18
Figure 4.2 Causes for food insecurity . . . 19
Figure 4.3 How to prepare for drought . . . 20
Figure 5.1 Visual overview of actor relations . . . 28
Figure 5.2 Causal Loop Diagram of food insecurity system . . . 29
Figure 5.3 UML Diagram . . . 30
Figure 5.4 Decision process Households . . . 33
Figure 5.5 The XLRM framework . . . 36
Figure 6.1 Interface of the Agent-Based Model . . . 39
Figure 7.1 Food insecurity base model . . . 43
Figure 7.2 Average capital base model . . . 43
Figure 7.3 Market stock base model . . . 44
Figure 7.4 Food insecurity in different drought scenarios base model . . . 44
Figure 7.5 Food insecurity per agent type in different drought scenarios base model . . . 45
Figure 7.6 Average capital in different drought scenarios base model . . . 45
Figure 7.7 Average capital per agent type in different drought scenarios base model . . . 46
Figure 7.8 Market stock in different drought scenarios base model 46
Figure 7.9 Effect Payment type leaver on Total weeks food insecurity - Moderate drought scenario (Lower is better) . . . 48
Figure 7.10 Total weeks food insecurity - Base model and payment type levers - Moderate drought scenario (lead time 4 weeks) . . . 49
Figure 7.11 Total average capital - Base model, One payment, Two Payments . . . 49
Figure 7.12 Average Market stock - Base model, One payment, Two Payments (Higher is better) . . . 50
Figure 7.13 Effect Lead Time on Total weeks food insecurity - Moderate drought . . . 51
Figure 7.14 Effect Lead Time on Total weeks food insecurity - with base - Moderate drought . . . 52
Figure 7.15 Effect Lead Time on average capital - Base model, One payment, Two Payments . . . 52

Figure 7.16 Effect Lead Time on average Market stock - Base model, One payment, Two Payments 53
Figure 8.1 Effect two policy strategies on Total food insecurity weeks - Moderate drought scenario 58
Figure 8.2 Effect two policy strategies on Total food insecurity weeks compared to base model - Moderate drought scenario 59
Figure 10.1 Effect Lead Time on Total weeks food insecurity - Moderate drought 68
Figure A.1 Main food source 85
Figure A.2 Past years of food insecurity 85
Figure A.3 Main food source 85
Figure A.4 How cash aid has been spend 86
Figure A.5 Months with less food than needed in a 'normal year' . 86
Figure A.6 Months with less food than needed in extreme year . . 86
Figure A.7 Reliability of forecasts 87
Figure A.8 mlogit outcome for mixed logit model, accounting for correlation. 87
Figure A.9 mlogit outcome for basic mixed logit model. 88
Figure A.10 Choice distribution 88
Figure A.11 Regression analysis for Food Expenditures 89
Figure A.12 Regression analysis for Mitigative Expenditures 89
Figure A.13 Regression analysis for Household Expenditures. . . . 90
Figure D.1 Verification by code walk-through and agent tracking . 93
Figure E.1 Total weeks food insecurity with different payment types - Severe drought scenario 95
Figure E.2 Effect Lead Time on Total weeks food insecurity - Severe drought scenario 96

LIST OF TABLES

Table 2.1 Search terms used in review: adaptations on these strings have been used as well . . . 5
Table 4.1 mlogit outcome for mixed logit model, accounting for correlation . . . 22
Table 4.2 Regression analysis for Food Expenditures . . . 23
Table 4.3 Regression analysis for Mitigative Expenditures . . . 23
Table 4.4 Regression analysis for Household Expenditures . . . 23
Table 5.1 Actor identification . . . 26
Table C.1 Parameters for model . . . 92
Table E.1 Parameters for base model . . . 94
Table E.2 Parameters for experimentation . . . 95

1 INTRODUCTION

1.1 THE GLOBAL HUNGER CRISIS

In 2020 The Nobel Peace Price was awarded to the World Food Programme (WFP) "for its efforts to combat hunger, for its contribution to bettering conditions for peace in conflict-affected areas and for acting as a driving force in efforts to prevent the use of hunger as a weapon of war and conflict"(noa, 2020). As the world's largest humanitarian organisation, the WFP provided assistance to around 100 million people in 88 countries who suffered acute food insecurity and hunger in 2019. The Nobel committee emphasised in their explanation that this assistance to increase food security does not only prevent hunger, but it helps to improve the prospect for stability and peace (noa, 2020). The WFP is the primary instrument for the UN to reach their goal of eradicating hunger by 2030. However, even with all the efforts, this goals seems far away. The Food and Agriculture Organisation (FAO) 2020 estimates that still almost 690 million people in the world experience hunger. Nearly 750 million, close to one in ten people, experienced severe levels of food insecurity in 2019 and an estimated 2 billion people could not access safe, nutritious and sufficient food (FAO et al., 2020).

The prevalence of undernourishment (PoU), a measurement for food insecurity used by the FAO, shows in the FAO's latest report 2020 that Africa has the highest prevalence of undernourishment in the world. In 2019, 19.1 percent of the African population, or more than 250 million people, were undernourished. This is more than twice the world average (8.9 percent) and it has a growing trend (FAO et al., 2020). According to FAO et al., Africa is significantly off track to achieve the Zero Hunger target in 2030 and if the current rate persist, its PoU will rise from 19.1 to 25.7 percent. Prolonged drought in East Africa has led to a deep humanitarian crisis, with households facing substantial gaps in the consumption and access to food. Over 11 million people in nine East African countries are currently experiencing crisis or emergency levels of food insecurity (Godfrey and Tunhuma, 2020).

1.2 THE IMPACT OF DROUGHT

Drought is a very insidious disaster. Unlike rapid onset disasters, like an earthquake or flood, it increases its grasp over an area over time. The longer the drought lasts, the more an area is destroyed leaving devastating effects that can last many years (IFRC, 2021a). The livelihood of households in East Africa is still predominantly dependent upon agriculture, especially in rural areas. The impacts of droughts are large on these smallholder rain-fed agriculture systems, as they have a low capacity to adapt (Thornton and Herrero, 2001). This leads to a loss in food production due to diminished crop yields and death of livestock (Wens et al., 2020). A direct link can be observed between food production and famine (Ifejika Speranza et al., 2008) in East Africa. In Kenya, the devastating 2011 and 2019 famines could both be linked to reduced food production due to drought (OCHA, 2011; Anyadike, 2019).

Droughts can be defined as temporary deficits in water supply that often have a wide range of economic, social, and environmental impacts (Wens et al., 2019; IPCC, 2007; Wilwite, 2000). These impacts range from effects such as crop failures and widespread death of livestock, to higher food prices and inflation. However, food insecurity potentially has even more far reaching consequences, as it can add to political instability, trade issues, conflict and mass migration (Dermody et al., 2017). All these effects add to the multidimensional nature of food security (Connolly-Boutin and Smit, 2016) and make it a complex problem involving many different stakeholders. Climate change is expected to cause even more frequent and more severe droughts, having a significant effect on the livelihoods and food systems of communities (IPCC, 2007).

1.3 HUMANITARIAN AID AS A RESPONSE TO DROUGHT

There are several ways to deliver aid to areas that have been hit by drought. Traditionally, most responses to drought and food insecurity, including most responses of the Red Cross Crescent, prioritise the provision of food, safe water, basic health services and basic sanitation (IFRC, 2021a). Food aid is currently still the dominant humanitarian response to drought disaster (Barrett and Maxwell, 2005). There is extensive research on the effectiveness of emergency food aid and it has the potential to stimulate growth in developing countries (e.g. (Barrett et al., 2008; Harvey et al., 2010; Maxwell and Singer, 1979)). however there is also a risk that these food programs do not take into account a comprehensive plan for improving the livelihood of household in these areas (Maxwell and Singer, 1979) or even, either directly or indirectly, have negative consequences on the indigenous food systems (Jackson, 2020).

Another way to assist poor households facing chronic food insecurity and increase their resilience to shocks is through unconditional direct cash transfers. This approach differs from traditional aid, because in traditional aid humanitarian organisations choose where the money is spend on. Direct cash transfers gives the power of decision-making back to the people who know best their needs and can kick-start local markets and supply chains (Cross, 2017; UNDP, 2015). The Overseas Development Institute (ODI) and the Center for Global Development (CGD) 2015 state that cash transfers are among the most well-researched and rigorously-evaluated humanitarian tools. According to them, evidence shows that in most contexts direct cash as humanitarian aid is more efficient, more transparent and more accountable. Additionally, in the current 2020 global pandemic, cash transfers could be the only option for humanitarian aid.

Existing cash transfer programs for food insecurity are usually based on observed triggers and are crisis-driven, thus after an event has taken place (ex-post) (Guimarães Nobre et al., 2019). The result of this ex-post aid is that the assistance might not reach those in need on time or that too much damage is already done. Other options are to provide the cash during an ongoing crisis or before the crisis (ex-ante). Ex-ante cash transfers are based on forecasting systems and could work as a preemptive humanitarian aid tool. Getting money before a drought could help farmers better prepare and reduce damage (Wens et al., 2020). Ex-ante cash transfers could be the future of humanitarian response, but more research is needed on the effect of this measure.

1.4 FOOD INSECURITY AS A COMPLEX PROBLEM

It is apparent that food insecurity due to drought is a problem. This is especially the case in developing countries that are predominantly dependent upon agriculture and do not have many means to deal with a widespread drought. However, it is less apparent how to deal with this problem. The problem of food insecurity is not just complicated, but it is complex. Complex problems are characterised by the fact that they are highly adaptive, occur on many different dimensions and have many interconnected relations between actors (Dam et al., 2013). A drought does not only affect farmers and it does not only lead to a lack of food, there are many aspects to consider. Dam et al. therefore suggest that a 'systems thinking' approach that includes the interacting and interrelated elements is necessary. By viewing food insecurity as a complex adaptive system (Waldrop, 1992) it includes the interactions between levels and dynamic emergent patterns that arise from interactions between system components (Holland, 1996; Newman, 2003). This cannot be done by a single approach or description.

1.5 RESEARCH OBJECTIVE: EXPLORING CASH TRANSFER POLICIES

As will be elaborated in the following chapters, this study aims to explore different cash transfer policies as a humanitarian response to food insecurity caused by drought and the influence on household food security. The objective of this study is to gain insight into the complex structure of the food system when affected by a drought and, using a modelling approach, explore the effects of different cash transfer policies on the food insecurity of households under various scenarios. An Agent-Based Model is constructed and combined with exploratory modelling techniques, applied to a case study of the Isiolo district in Kenya. The goal is to find robust and useful policy interventions that can be used by the The International Federation of the Red Cross and Red Crescent Societies (IFRC).

1.6 STRUCTURE OF THIS STUDY

This first chapter of this study aims to introduce the subject, provide context and explain the societal relevance of the study. In Chapter 2, a literature review will be conducted which results in a scientific knowledge gap and main research question. Then, in Chapter 3 the research design and research methods will be explained and the subquestions formulated. After the problem is introduced, Chapter 4 aims to identify the factors involved in the system of household food security in Kenya by analysing the case of Isiolo county in Kenya and providing the results of a household survey. Next, Chapter 5 will transfer the factors and relations found in literature, survey results and choice experiments, into a conceptual model. Chapter 6 describes the implementation of the conceptual model into an Agent-Based Model. The results from the experimentation are presented in Chapter 7, after which they are interpreted and validated in Chapter 8. Chapter 9 provides a critical perspective on the outcomes of this study by stating its limitations. Finally, the conclusions of this research are presented in Chapter 10.

2 LITERATURE REVIEW

In this chapter, a literature review will be carried out. This will be done by looking at the current scientific literature and models on food security and direct cash payments. This will provide an overview of the current understanding of these concepts. Additionally, it will show where the current scientific literature does not yet suffice, making a knowledge gap apparent.

2.1 REVIEW METHOD

The literature review is divided in two main parts. The first part consists of literature on the key concepts in this study. The second part is aimed at existing food insecurity models, with a specific focus on Agent-Based Models. For this literature review, the following databases have been used: Web of science, Scopus and Google scholar. Additionally, "gray literature", documents that have not (yet) been published (Schöpfel, 2010), has mostly been gathered directly from the Red Cross or departments of the United Nations. No type of documentation has been excluded, but there is a focus on scientific published literature. 2.1 shows the search strings that have been used in this review. In addition to searching through databases, literature has been identified by means of 'snowballing' search (Jalali and Wohlin, 2012), in which key articles were used to identify other important authors or publications.

Table 2.1: Search terms used in review: adaptations on these strings have been used as well

Section	Search terms (TITLE-ABS-KEY)
Topic	("Food security" OR "Food accessibility") AND ("Drought" OR "Drought risk" OR "Climate change" OR "Shock")
Method	("Drought" OR "Drought risk" OR "Climate change") AND ("Agent-Based Model" OR "agent-based" OR "ABM" OR "Farm household model" OR "Household model" OR "agricultural model")
Policy	("direct cash transfer" OR "direct cash" OR "cash transfer") AND ("ex post" OR "ex ante" OR "early action" OR "EA")

2.2 KEY CONCEPTS OF SYSTEM

2.2.1 Food insecurity

Food security has been defined in different ways throughout history. The current definition was defined at the World Food Summit of 1996 and was slightly revised in a follow up meeting in 2001. This definition states: "Food security is a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2001). This definition is used by most global humanitarian organisations like the World Food Programme (WFP) and the Food and Agriculture Organisation (FAO) and it consists of four dimensions: availability, accessibility, utilisation and stability.

Within the field of food security research there is a push for a systems approach that connects these different dimensions. Ingram (2011) shows the complex relations between food systems and food security and highlights the lack of research that takes these interactions into account. A lot of the research on food security focuses on the availability of and access to food (Müller et al., 2020) and according to (Stephens et al., 2018) more work is needed to examine the links between food systems, agricultural systems and food security that include the produce markets and food demands.

2.2.2 Direct cash payments

For most of the poorest people, humanitarian aid is still an important instrument to achieve short-term goals of drought preparedness and recovery (Guimarães Nobre et al., 2019). There has been an increasing debate as to whether direct cash transfers should be given to people instead of the traditional aid (Harvey et al., 2014). Direct cash transfers are typically less expensive and give the power of decision-making back to the people who know best their needs and can kick start local markets and supply chains (Cross, 2017; UNDP, 2015). According to the Overseas Development Institute (ODI) and the Center for Global Development (CGD) 2015, evidence shows that in most contexts direct cash as humanitarian aid is more efficient, more transparent and more accountable.

Of all the different cash transfer programs, only a small group focus on transfers before the occurrence of an event (ex-ante) (Garcia and Moore, 2012). Most of the programs focus on aid after the event has taken place (ex-post) what could result in assistance not reaching those in need on time or that too much damage is already done. As this shift from ex-post to ex-ante aid is still a relatively new concept, not a lot of research has been done to examine the effects. Most research into cash transfers and food security just focuses on the benefits and results of this type of aid over the traditional type (Villanger, 2008; Balhara et al., 2017; Fenn et al., 2017; Schwab, 2020). The research that does take into account the difference in timing of the transfer mainly focuses on the economic aspects of these cash transfer policies

(Guimarães Nobre et al., 2019). Guimarães Nobre et al. evaluates the potential cost-effectiveness of ex-ante versus ex-post cash transfer responses for agricultural drought risk.

Looking at the research done in the area of ex-post versus ex-ante cash transfers, it can be noted that none directly take into account food security as a KPI, let alone food security at household level. Additionally, no research takes into account the decision-making on the household level. A different timing in cash transfers could lead to completely different decisions of the people that receive the aid, preparing them for an upcoming shock. Current research does not take into account how the difference in behaviour influences the food security of households.

2.3 REVIEW OF EXISTING MODELS

2.3.1 Food security models

In order to get an understanding of the complex socio-economic and environmental conditions that drive food systems and therefore food insecurity, a lot of work has gone into the development of models and scenarios (IPCC, 2007; Vervoort et al., 2014). However, research on food security modelling is often fragmented in literature and methodology, as it is often researched in disparate disciplines without much interconnection. Some reviews give insight into the different types of modelling that has been used to examine food-related issues (e.g. (van Tongeren, 2001; Millington et al., 2017; Huber et al., 2018)) with some addressing food security (van Wijk et al., 2014; Brown et al., 2017) and these have been used to create a clear overview of the current achievements and gaps in this field.

There is an increasing need to access the impacts of socio-economic and environmental drivers on the household level rather than the national or regional level (Stephens et al., 2018), as sufficient total global or regional food security does not necessarily ensure food security for individual households. Household models have been widely used in the agricultural community for ex-ante analysis and priority setting of technological interventions (Thornton and Herrero, 2001; Müller et al., 2017) and a lot of research takes crop and livestock model outputs to use for farm-level economic analysis. Rapid development takes place into different ways of modelling farm level decision-making (Stephens et al., 2018). Currently all sorts of food security models are being used with the major 'streams' being: dynamic simulation, mathematical programming (MP), and multi-agent modelling (van Wijk et al., 2014). However, Food security as KPI has still received little attention in models (van Wijk et al., 2014)

2.3.2 Agent-based food security models

Agent-Based Modelling (ABM) provides a useful tool to examine how interactions between households and the environment lead to the emergence of food security (Balbi and Giupponi, 2010). Different models have been used for different dimensions of food insecurity. Firstly, Agent-Based Models have been used to model production, focusing on interactions between land and farmer (Bharwani et al., 2005; Matthews et al., 2007; Ding et al., 2015; Wens et al., 2020). Additionally for the consumption side within and across households an ABM approach has been used, often focusing on smallholders in developing countries (Dobbie et al., 2018). Dobbie et al. developed a methodological approach for constructing ABM models to assess food security with an explicit focus on the four dimensions of food security.

Even though Agent-Based Models have been widely used to research food security, there are still clear gaps in this field of research. Firstly, in all reviewed models decision-making takes place on a seasonal or yearly basis, with matching time steps (van Wijk et al., 2014). This puts the focus on tactical and strategic decision making and eliminates the possibility of detailed climate risk analyses in which drought periods occur. Therefore explicit climate or market risk analyses have not been performed with these models (van Wijk et al., 2014; Stephens et al., 2018) and they often do not consider short-term variability from shocks (Müller et al., 2020). Secondly, little attention is given to non-agricultural activities (van Wijk et al., 2014) and farmers' income. Additionally they do not take preemptive measures such as food storage into account and they generally do not consider market changes (Müller et al., 2020). The result is that these models cannot fully describe climate related risk for food self-sufficiency and food security at household level (van Wijk et al., 2014). Lastly, these models are often research tools for assessing the consequences of system interventions and do not take into account the multi-actor nature of the problem (van Wijk et al., 2014). Because of this these models lack usefulness in the policy arena.

2.3.3 Take away current models

There have been many model studies in the area of food security and drought adaptation. This research aims to fill a gap that still exist within current literature. However, there are things that can be adopted from current model studies to incorporate in this research. Studies show the need for an assessment of socio-economic drivers at the household level. As mentioned, there are already many studies that take a detailed look at the farming of small household farms in times of drought. Additionally, there are models that present the food consumption and market interaction of households. These mechanisms can be used for constructing the Agent-Based Model in this study.

2.4 KNOWLEDGE GAP

By reviewing the current literature, it becomes apparent that to our knowledge (a) there is currently no useful Agent-Based Model that can analyse drought and takes into account different dimensions of household food security. (b) There is insufficient knowledge about the difference in behaviour of people in Kenya when provided with either ex-ante cash transfers as aid for drought. (c) There is no Agent-Based Model that takes into account these forms of cash transfers and the effect on household food security.

3 RESEARCH DESIGN

The knowledge gap identified in the literature review shows that there is currently insufficient knowledge regarding the effects of cash transfer policies as a humanitarian response to drought crises. This study aims to explore different cash transfer policies as a humanitarian response to food insecurity due to drought under different scenarios.

The design of the research will be discussed in this chapter by first addressing the main research question and the sub-questions. subsequently, the methodology will be discussed, accompanied by a visual research flow diagram. Finally, the methodologies per sub-question are explained.

3.1 MAIN RESEARCH QUESTION

This research focuses on one main research question that is derived by the academic knowledge gap. The main research question is formulated as follows:

"How can an Agent-Based Model be used to analyse the effect of different ex-ante cash transfer policies on the household food security in Kenya, as humanitarian anticipatory action to drought?"

3.2 SUB QUESTIONS

1. What factors influence the food insecurity of households in Kenya during a drought?
2. How can household food insecurity due to droughts in Kenya and the intervention of direct cash transfers be conceptualized and formalized in terms of policies, uncertainties and Key performance indicators?
3. How can the household food insecurity be implemented in an Agent-Based Model?
4. What is the effect of policy interventions on the household food security in Isiolo County in Kenya?
5. How can the outcomes of this study be generalized to other drought crises?

3.3 METHODOLOGY

In order to answer the main research question and the different subquestions, this study uses several research methods. The main research method is the development of an Agent-Based Model that is based on a case study in Kenya. Exploratory modelling techniques are used to find robust policy under different scenarios. The complete research design is visualised in 3.1, indicating the research phases and overall structure of the report. The figure shows the integration of data and the household survey in the main phase of the model study. This will be explained in more detail below. The research methods of the sub-questions will be described in more detail in the next sections.

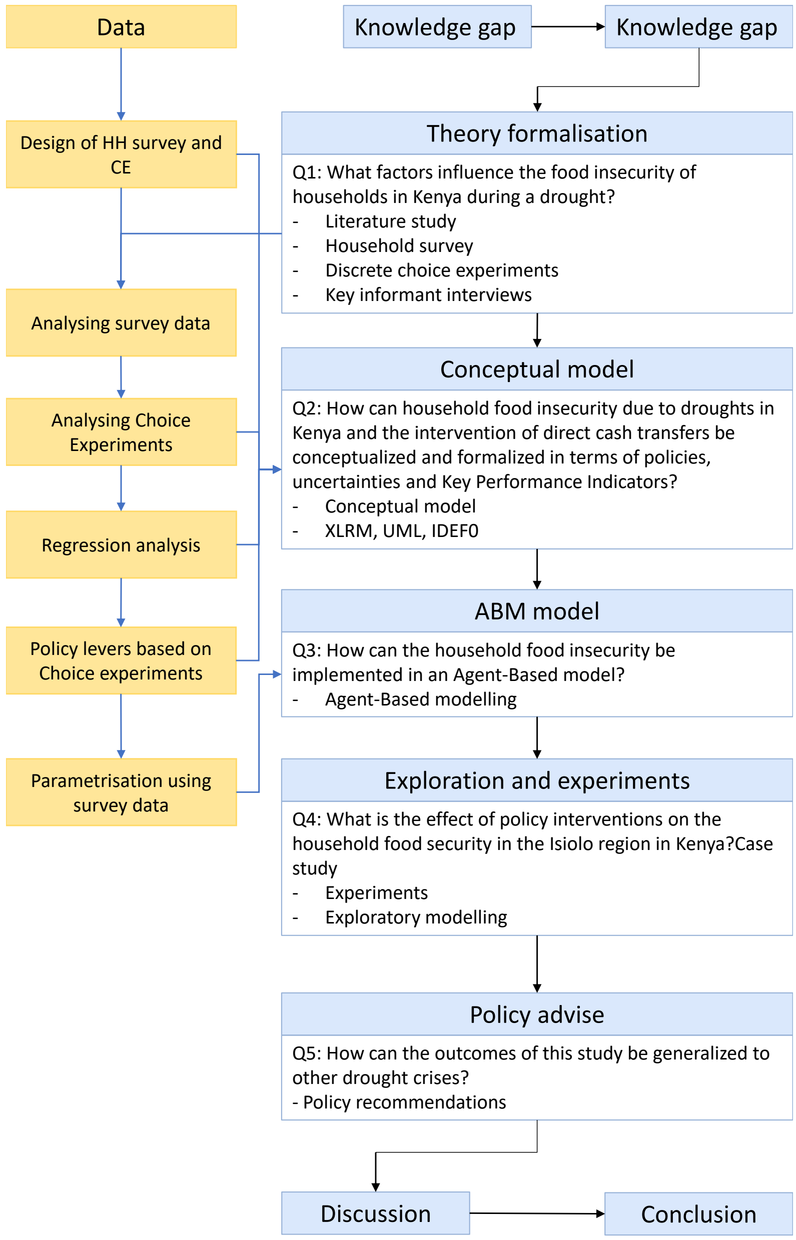


Figure 3.1: Research Flow Diagram

Integration of Household survey and choice experiments in the Model design

The household survey and choice experiments and the data that is gathered from these are used in multiple ways throughout this model study. The yellow flow in Figure 3.1 shows how the main model study and the data stream are connected. This flow diagram shows that the household survey and choice experiments are linked to the model study in two mayor ways. First, the survey and choice experiments are used in the conceptualisation phase of the model. This means that results from the survey, such as source of income, perspective on drought, source of food or how households deal with food insecurity have been used to create the conceptual framework of the model. Additionally, the design of the choice experiments has determined the design of the cash transfers and there fore policy levers in the model.

Second, the results from the household survey and choice experiments are used as input for the model. Model parameters are taken from the survey results and regression analysis. These input parameters include things as; the number of households, household size, income, crop production and available food. Additionally, the parameters for the cash transfers are based on the choice experiments.

3.3.1 Sub-question 1: What factors influence the food insecurity of households in Kenya during a drought?

The first sub-question aims to identify the factors within the food system and discover what factors influence the food insecurity of households during a drought. Answering the first sub-question will be done using multiple methods: a case study, conducting household surveys, analysing choice experiments and key informant interviews.

The case that will be used for this research concerns the Isiolo district in Kenya. According to the Kenyan National Drought and Management Authority, in 2017, 80% of the household in Isiolo were food insecure followed by a severe drought, which affected crop production, and consequently, the access to food, poor incomes and high food prices. Isiolo is a drought-prone county, which often rely on humanitarian organizations to provide food aid relief. This case study aligns with ongoing projects of the 510 Red Cross department.

The household survey has been conducted at 186 households within the Isiolo district by members of the Kenyan Red Cross. The survey is part of a larger project called Forecast-based Financing for food security (F4S). The F4S project is a joint project by Stichting VU - Institute for Environmental Studies (IVM-VU), Netherlands Red Cross - 510 (510), the UCSB Climate Hazards Center (CHC) and the Kenya Red Cross Society - International Centre For Humanitarian Affairs (KRCS-ICHA). Some specific questions have been added to the survey for this study. Due to the current COVID-19 crisis it is not possible for anyone to visit the case area in person and therefore all communication is done online. The household survey will provide empirical information on food insecurity of households in the district.

While conducting the household surveys, the respondents will also be asked to participate in several choice experiments. In these choice experiments the respondents are asked to choose between two scenarios. These scenarios have different values for a number of attributes. These experiments are constructed based on the theory of McFadden (1974) and rely on the hypothesis that the decision maker will choose an alternative that yields the highest utility in a given situation. The preference of alternatives is represented by a utility function and from the stated preference, the utility of attributes can be derived. The choice experiments are analysed using the mlogit package in R (Croissant, 2020b,a).

3.3.2 Sub-question 2: How can household food insecurity due to droughts in Kenya and the intervention of direct cash transfers be conceptualized and formalized in terms of policies, uncertainties and Key performance indicators?

A conceptual model will be made as a base for this research. This conceptual model will be based on current literature and conceptual models on food security, as well as the factors revealed by the first sub-question of this study. It is important that this conceptual model pays attention to the multidimensional nature of food security and therefore it will be based on the 'four pillars' framework that was created by FAO and later operationalised for modelling purposes by (Dobbie and Balbi, 2017). This framework (see figure 3.2) includes food availability, access, utilisation and stability.

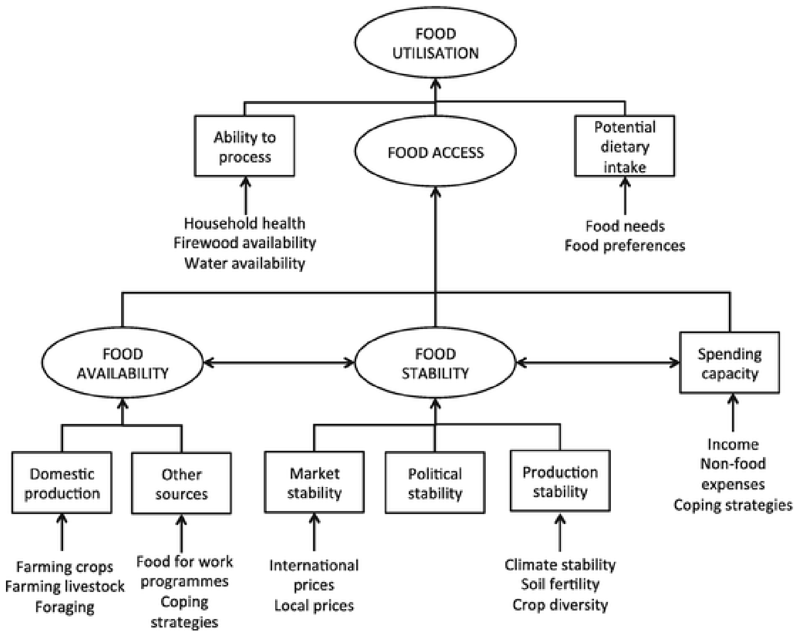


Figure 3.2: Four pillars framework by (Dobbie and Balbi, 2017)

Additionally the XLRM framework will be used to structure the information into policy levers(L), performance metrics (M), relationships (R), and external factors (X) (Nikolic et al., 2019). This framework helps in finalizing the conceptual model.

3.3.3 Sub-question 3: How can the household food insecurity be implemented in an Agent-Based Model?

Agent-Based Model

The outcome of the conceptualization phase will be formalized and implemented in an Agent-Based Model. The tool that will be used for this model is Mesa, a platform in Python for ABM analysis. Agent-Based Modelling (ABM) provides a useful tool to examine how interactions between households and the environment lead to the emergence of food security (Balbi and Giupponi, 2010). ABM is a bottom-up approach in which interactions at the local level lead to the emergence of patterns at the macro-level (Epstein and Axtell, 1996). It is very well suited to take the heterogeneous nature of households, individuals and the environment into account (Epstein, 1999) and analyse their decision-making behaviour. Lastly, Agent-Based Models are well equipped to integrate data from different sources and can work well in a data scarce context as they can deal with both qualitative and quantitative data (Janssen and Ostrom, 2006; Robinson et al., 2007).

For this research the methodological approach constructed by (Dobbie et al., 2018) will be used. This approach includes the four pillars framework and focuses on food security. An overview of this approach can be found in figure 3.3. As this research focuses on food security at the household level, households will be modelled as individual agents. These agents can have interactions with each other and their environment. Drought scenarios and cash transfer policies can be applied by changing the environment or changing the decision making rules of the agents.

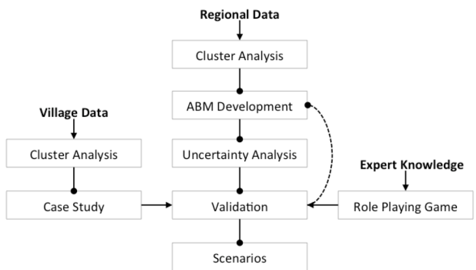


Figure 3.3: Modeling approach by (Dobbie et al., 2018)

3.3.4 Sub-question 4: What is the effect of policy interventions on the household food security in the Isiolo region in Kenya?

In order to answer this sub-question, the model will be used to explore different cash transfer policies under different scenarios.

Exploratory modelling

Exploratory Modelling and Analysis (EMA) is a modelling approach used when modelling under deep uncertainty. (Kwakkel et al., 2015) argues that systems are complex and their context is deeply uncertain, computer assisted reasoning is needed as human reasoning alone is not able to deal with this uncertainty. The ABM model provides insight into the structure and systemic behaviour, but given the deeply uncertain context this model is based upon (the possibility of sparse data), EMA can be used in order to deal with this uncertainty when composing policy advice.

3.3.5 Sub-question 5: How can the outcomes of this study be generalized to other drought crises?

This last sub question aims to summarize the findings of the case-study and will reflect on the identified policy interventions. The results will be used to see if this approach is suitable in other situations as well. Finally, this will result in recommendations for the Red Cross to inform them of cash transfer policy strategies.

4 FACTOR IDENTIFICATION

In the previous chapters the knowledge gap and focus of this study have been identified, as well as the approach and methodology that will be used to fill this knowledge gap and answer the research questions of this study. This chapter aims to identify the factors involved in the system of household food security in Kenya. In order to identify these factors, the household food security in the Isiolo county in Kenya will be analysed. This case provides a context for the implementation of cash transfer policies as humanitarian response to drought. A household survey and choice experiment for this case will be used as a base to conceptualise the complex system of household food security and gain insight into the decisions made by households when faced with impending drought. First, the case background will be discussed, followed by the results of the household surveys and choice experiments. Afterwards, a conceptual models are used to describe the system of household food security in the Isiolo county in Kenya. This answers the first sub-question of this study;

What factors influence the food insecurity of households in Kenya during a drought?

4.1 CASE

Isiolo county is located at the center of Kenya. With a population of 260.000, Isiolo is the second lowest populated county in Kenya (Kenya National Bureau of Statistics, 2019). Because the county is also the 7th largest (25,300 km2), it is one of the most sparsely populated areas of Kenya. Most of the county's land is flat and made of many superficial rock deposits, over 80 percent of the land cannot support crop farming. The climate can be described as hot and dry with an average annual temperature of 29 degrees Celsius. Annual rainfall ranges between 400 - 650 mm, however this falls mainly during two rainy seasons with almost no rain in most months. Additionally, the rainfall is not evenly divided over the county. The higher ground areas in the south-west receive between 500-670 mm, while the eastern and northern parts receive less than 300 mm (County Governmant of Isiolo, 2018).

Figure 4.1: Isiolo district in Kenya, map by (ISSAfrica, 2020)

The combination of the climate and land composition are the base for mainly agro-pastoral activities. Over 80 percent of the land is owned by the community under trust ship of the county government and is mainly used as grazing land by pastoralists. Livestock keeping and trading is the main driver of the county's economy and accounts for up to 70% of it, followed by small scale business (20%) and tourism (10%) (Isiolo County Government). According to Isiolo County Government, a high percentage of the population is not engaged in formal employment (85.5%) due to high illiteracy levels, lack of skill and simple unregulated nature of urban self-employment.

4.2 HOUSEHOLD SURVEY

To better understand the factors involved in household food security, a survey has been conducted at 186 households in Isiolo County by members of the Kenya Red Cross Society - International Centre For Humanitarian Affairs (KRCS-ICHA). The households have been selected through random sampling of the villages in the area in order to get a representative sample. The aim of this survey has been to gather local knowledge on food security, identify early actions that local households take to lessen the risk of food insecurity and see how this local knowledge can be implemented in a model. This section will cover results of the survey that are useful for this study starting with general information about the households, followed by local experience with food insecurity and ending with how locals deal with impending food insecurity. More details about the data analysis can be found in Appendix A. The data files, R code and original questionnaire can be found in the GitHub repository: https://github.com/JoepHoeijmakers/MasterThesis.

4.2.1 General information

The survey was conducted at 186 households with an average household size of 6.3. 151 of the respondents were female, 35 were male and the average age of the respondents was 32.6 years old. The main source of income for these households is livestock keeping, followed by a combination of livestock keeping and farming and lastly private business or casual labour. Almost all respondents indicated that their income was more than 300 KSh (2.27 Euro) per month, but a precise division cannot be made, as this was the highest amount that could be chosen in the questionnaire.

4.2.2 Food insecurity

This next section will cover the questions of the survey related to food insecurity. Additional plots can be found in Appendix A.

The three main food sources of respondents are own livestock production, purchase on the market and own crop production. This is in line with earlier observations about occupation and lifestyle. Many of the respondents are smallholder farms that mainly depend on their own production as a food source.

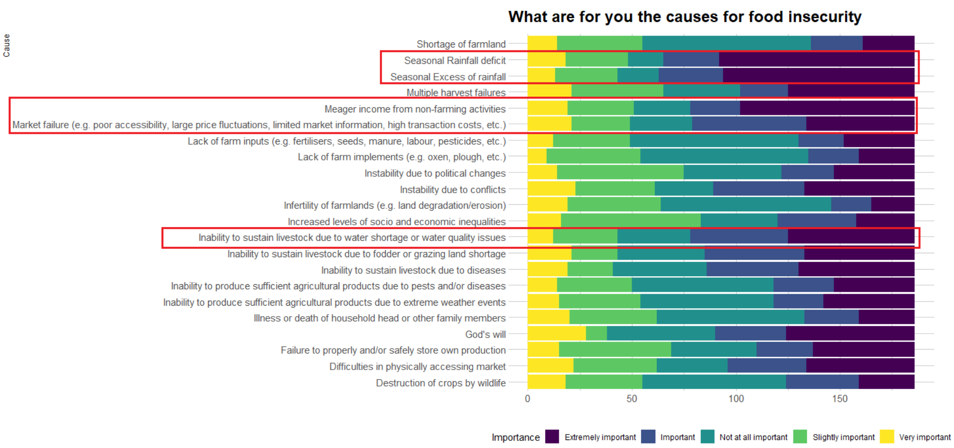


Figure 4.2: Causes for food insecurity

Figure 4.2 shows many causes for food insecurity, however a few stand out. A seasonal rainfall deficit or excess of rainfall, a drought or flood period, is the most prominent cause for food insecurity. Some other causes, as the inability to sustain livestock due to water shortage or water quality issues, are tied into these factors. Meager income from non-farming activities is mentioned as the third largest cause for food insecurity. This shows that there are no suitable alternatives to farming for the livelihood of the respondents, making them very dependent on external factors. Market failures is also high on the list of causes, possibly indicating that the market does not function properly in times of need.

Many respondents have experienced severe food insecurity in the past (Figure A.2) and there seems to be a growing trend. This trend could also be ascribed to the fact that recent events are still more ingrained into the memory of the respondents. The most difficult months for food security are June until September, which corresponds to the dry season in the county (County Governmant of Isiolo, 2018). People tend to find the forecasts about droughts very reliable and act upon these forecasts. The main responses to an upcoming drought are stocking up on food, increasing the sale of livestock and products and saving money, as can be seen in Figure 4.3.

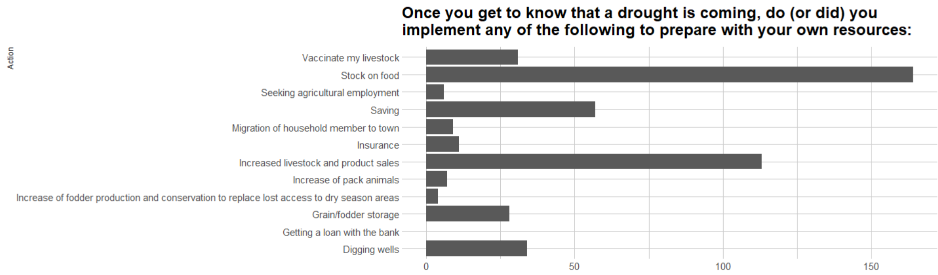


Figure 4.3: How to prepare for drought

4.3 CHOICE EXPERIMENTS

Subsequent to the questionnaire, the respondents have been asked to participate in a choice experiment. The goal of the choice experiments has been to evaluate what attributes of cash transfers households prefer in different scenarios.

4.3.1 Set-up of experiments

The experiment consisted of six rounds for each participant. The participants where given a different scenario per round and had to choose between two options of cash transfers, based on what their preferred option would be. Each round a choice card with the two scenario's was shown. These scenarios could vary in the hazard type (flood or drought), the severity (moderate or severe) and the time of the drought warning. The cash transfer options provided could vary in the type of payment (one lump sum or two consecutive amounts) and the lead time (long or short). The lead time indicates how far ahead of the drought the cash transfer would be received. Additionally, the respondents were asked how they would spend the money by dividing fake coins over different expenses. An example of a choice card is included in Appendix A.3 and all experiment card, including the explanation given to the participants, can be found in the GitHub repository.

4.3.2 Data cleaning and analysis

The data of the choice experiments has been extracted from the complete data file of the survey and only the drought scenario choice experiments have been used. The data cleaning has been conducted in Python in the file "Choice experiments Kenya.ipynb" and the analysis of the experiment has been conducted in R in the file "Kenya_CE.R", both can be found in the GitHub repository. For the data cleaning, the results have been divided into different dataframes for the different rounds and all non essential attributes (columns) were dropped. Additionally, all entries where no round number was indicated by the enumerator were dropped. Steps of the data cleaning process can be found in Appendix A.1.

While processing the data, a major fault has been found. The enumerators of the experiments had to indicate which round was being played, which card deck was chosen (Red or green), which option the participant chose (A or B) and what payment type and lead time corresponded to that choice. The red and green card decks were different sets of cards, each with the same six rounds. The indication of the payment type and lead time by the enumerator was a redundant step. The combination of the deck colour, round number and scenario choice always belong to a certain payment type and lead time. For instance, scenario A of round 1 in the red card deck consists of two payments with a long lead time (see A.3). However, it was found that enumerators would indicate a payment type or lead time that was not consistent with the card and choice they indicated. In the example card mentioned, they would indicate that scenario A was chosen, but that a one lump sum payment was chosen as well.

It could be that enumerators did not indicate the correct deck of cards, correct choice or made a mistake in writing down the payment type and lead time. A script was developed (see Python file) to check all entries and compare it to all combinations of valid options. The results gave 362 false entries and 359 correct entries. All false entries have been dropped for analysis, as it is impossible to determine the cause.

Random utility models have been used to analyse the choice experiments. These can be used to analyse the discrete choice of a decision maker, by looking at the utility of the choice attributes (Croissant, 2020a). McFadden won the Nobel Price in economics for his development of a theory to analyse discrete choice. The models work on the assumption that the decision maker can rank the posed alternatives by an order that provides the highest level of utility (Croissant, 2020a). A utility function is composed of two components: a systematic component and an unobserved component. The mixed logit model takes the heterogeneity of the population into account by assuming that the parameters of the utility function vary between individuals.

4.3.3 Results of choice experiments

Both a basic mixed model and a mixed model that accounts for correlation have been used to see if correlation effects have any influence on the results. Looking at the Log-Likelihood of both models, they both describe the data the same and their estimates of the coefficients are nearly identical. Table **??** shows the results of the mixed logit model. Detailed outcomes of the models can be found in Appendix A.3.

Table 4.1: mlogit outcome for mixed logit model, accounting for correlation

Coefficients	Estimate	std. Error	z-score	Pr(>|z|)	Significant
Lead time (LD)	0.067	0.141	0.48	0.6347	No
Payment Type (Type)	0.801	0.295	2.72	0.0066	Yes

Payment type

The results of the mixed logit model (Figure A.8) show that the payment type is significant and has a estimated value of 0.80. This means that there is a significantly higher change of a participant choosing an option, when the payment type of that option is one lump sum payment. Participants prefer to be payed in one sum, rather than two separate payments when receiving a cash transfer. It is unknown why participants have a preference for one payment.

Lead time

The lead time has not been found significant in the choice experiments and had only a small estimated value. This means that the lead time of the presented option did not influence the choice of the participant in any scenario. There are several possibilities that could explain this. Firstly, it could be that lead time really does not matter for people receiving cash transfers. Secondly, participants could have misunderstood the meaning and distinction of the dates in the scenarios. Participants indicated in the questionnaire that the choice experiments were often confusing and this could lead to distorted results. Thirdly, participants could have misunderstood or neglect the distinction between the moderate drought scenarios and the severe drought scenarios. This again has to do with the understanding of the experiment and this has been discussed in debriefings of the experiment.

4.3.4 Regression analysis

In addition to analysing the choice experiments, the spending in each round has been evaluated. A regression analysis has been carried out for each expenditure to examine what factors influence this spending. The following factors were included for analysis: Payment Type, household size, education level, source of income, income level, land owned. The results per type of expenditure are described below and table 4.2, 4.3 and 4.4 show the significant results per expenditure type. The (significant) income factors have been omitted as these were faulty in the questionnaire. Detailed results can be found in Appendix A.3.

Table 4.2: Regression analysis for Food Expenditures

Coefficients	Estimate	std. Error	t value	Pr(>|t|)
Education Tertiary	5.36233	1.67132	3.208	0.00140
Income labour	2.26839	0.73707	3.078	0.00217
Income other	2.28423	0.78666	2.904	0.00380

The regression analysis of food expenditures shows (Table 4.2) that a higher education level significantly increases spending of the cash transfer on food. Additionally, when households had income from labour or other sources, they also spent more on food expenditures. This could be explained to the fact that these households would not get any food from their own production.

Table 4.3: Regression analysis for Mitigative Expenditures

Coefficients	Estimate	std. Error	t value	Pr(>|t|)
HH_size	0.13195	0.03319	3.976	7.74e-05
EducationPrimary	-0.77334	0.22030	-3.510	0.000476
incomeLabour	-1.68947	0.55484	-3.045	0.002414
incomeOther	-1.37168	0.59217	-2.316	0.020825
incomePrivate business	-1.89097	0.42824	-4.416	1.17e-05
Land_owned	0.20025	0.03199	6.260	6.72e-10

The regression analysis of mitigative expenditures shows (Table 4.3) that there is a negative correlation between a lower education and spending the cash on mitigative expenditures. Additionally, households with income from labour, private business and 'other' spent less on mitigative measures. This is logical, as these households do not have crops that need mitigation. Households that owned land or had a larger household size would spend more on mitigative expenditures.

Table 4.4: Regression analysis for Household Expenditures

Coefficients	Estimate	std. Error	t value	Pr(>|t|)
HH_size	0.04499	0.01971	2.283	0.022726
EducationSecondary	0.46408	0.23617	1.965	0.049806
EducationTertiary	-2.21152	0.74702	-2.960	0.003175
incomeOther	1.19825	0.35161	3.408	0.000692
incomePrivate business	1.82058	0.25428	7.160	2.04e-12

The regression analysis of household expenditures shows (Table 4.4) that household size had a small positive correlation to household expenses. Additionally, households with only secondary education spent more on household expenditures, while households with tertiary education would spend significantly less. Also households with income from private business or 'other' had would spend more of the cash on household expenditures.

4.4 CONCLUSION

This chapter discusses the first research question and identifies factors involved in the system of household food security in Kenya. This is done by looking at a case study of Isiolo county, the second lowest populated county in Kenya. A household survey and choice experiments have been conducted at 186 households in Isiolo by members of the Kenya Red Cross Society - International Centre For Humanitarian Affairs (KRCS-ICHA). The survey identified three main food sources of respondents; own livestock production, purchase on the market and own crop production. Many respondents have experienced severe food insecurity in the past and a seasonal rainfall deficit or excess of rainfall is the most prominent cause for food insecurity. The choice experiments have been conducted to evaluate the preference of households regarding cash transfers. The results show that households prefer to have the cash transfer in one lump sum payment, rather than two payments. There has not been found any preference in the lead time of the transfer. The regression analysis shows that a higher education level, income from labour or from 'other' sources significantly increases spending of the cash transfer on food. Households with only a primary education level, income from labour, private business or 'other' spent less on mitigative measures. Households with only secondary education spent more on household expenditures, while households with tertiary education would spend significantly less.

5 MODEL CONCEPTUALISATION AND FORMALISATION

This chapter covers the conceptualization and formalization phase of this study. The goal is to transfer the factors and relations found in literature, survey results and choice experiments, into a conceptual model. The conceptual model describes the specific, complex system of drought crisis in the Isiolo district in Kenya. The chapter is divided into three distinct parts. First, the actors involved in the system of cash transfers in Kenya will be identified. Second, conceptualisation of the system, agents and interactions is described. Third, an explanation is given of how factors and mechanisms are formalised in order to implement them in the Agent-Based Model. Finally, the policy interventions and uncertainties are defined using the XLRM Framework. The sub-question addressed in this chapter is as follows:

How can household food insecurity due to droughts in Kenya and the intervention of direct cash transfers be conceptualized and formalized in terms of policies, uncertainties and Key performance indicators?

5.1 ACTOR IDENTIFICATION

There is a large variety of actors involved in a humanitarian operation. Actors are entities, persons or organisations that are able to exert influence on a decision Enserink et al. (2010). As policy problems are rarely solved by one actor alone, it is important to understand the interest and objectives of other actors. This section will identify and analyse the actors that are important for this model study from the perspective of the Red Cross. The actors in this study are divided between; humanitarian, national government and local actors. An overview of all actors can be found in table 5.1.

Table 5.1: Actor identification

Actor	Objective
Humanitarian actors	
510/Netherlands Red Cross	Help people in need during emergencies, conflicts and disasters
Red Cross Kenya	Help people in need during emergencies, conflicts and disasters
The Red Cross Climate Centre	Help the Red Cross and Red Crescent Movement and its partners reduce the impacts of climate change and extreme-weather events on vulnerable people
World Food Programme (WFP)	Delivering food assistance in emergencies
World Bank	Reducing poverty, increasing shared prosperity, and promoting sustainable development
National government	
Kenyan national government	Increase livelihood of citizens in all 47 counties
National Drought Management Authority	Establish mechanisms to limit the impact of drought
Local actors	
Households	Maximize personal livelihood, maximize food security
Local officers of the Red Cross Society	Help people in need during emergencies, conflicts and disasters
District agricultural officers	Coordinating agricultural projects in the district
Community development officers	Support programs aimed at reducing poverty and helping to improve the lives of people who live in deprived areas.

5.1.1 Humanitarian actors

The International Federation of Red Cross and Red Crescent Societies (IFRC)

The International Federation of Red Cross and Red Crescent Societies (IFRC) is a global humanitarian network that aims to help people dealing with disaster, conflict and health and social problems. The network consists of 192 National Red Cross and Red Crescent Societies that work together to respond natural and man-made disasters in non-conflict situations (IFRC, 2021b).

There are multiple Red Cross Societies involved in this study; 510/Netherlands Red Cross, Red Cross Kenya and The Red Cross Climate Centre. These societies have worked together in the "Forecast-based Financing for Food security (F4S)" project, of which this study is a part of. Their aim is to develop information that enables the triggering of early actions to reduce the risk of food insecurity in Ethiopia, Kenya, and Uganda. The report focusses on "challenges inherent to decision-making based on forecasting information, with a special focus on the implementation of ex-ante cash transfers"(Guimarães Nobre et al., 2021, p.5).

World Food Programme (WFP)

The World Food Programme (WFP) is the World's largest humanitarian organization. Their aim is to save lives in emergencies and use food assistance for people recovering from conflict, disasters and the impact of climate change (World Food Programme, 2021). Even though food assistance is the main tool of the WFP, they do see the need for early action based on early warning. The World Food Programme is currently developing their anticipatory action plan in some countries such as Ethiopia and Uganda and have identified cash transfer as a desired activity.

World Bank

The World Bank is one of the largest sources of funding and knowledge for developing countries in the world (World Bank, 2021). They are already involved in some cash transfer programs in Kenya such as the Hunger Safety Net. The world bank has signed a financing agreement to expand the program to include the Isiolo district.

5.1.2 National government

The Kenyan government aims to maximize the livelihood of its citizens and therefore minimize the food insecurity when droughts occur. However, the government is limited by budgeting and has many other interests to handle. Kenya has four national Cash Transfer programs under the National Safety Nets Programs, to provide social protection for its citizens. One of these programs is the aforementioned Hunger Safety net, implemented through the National Drought Management Authority and financed through the World bank. "The programme's main objective is to deliver regular and emergency cash transfers and influence the development of an integrated social protection mechanism both at the national and county levels" (HSNP, 2021).

5.1.3 Local actors

Local actors are important for successful development of cash transfer programs. Local key stakeholders such as local branches of the Red Cross Societies, district agricultural officers and community development officers have knowledge and experience with the situation of the community. They can provide feedback and help with gathering information and identifying the need of households, as was done during the F4S project. Additionally, it will most likely be up to local actors to practically implement a cash transfer program.

Households

Households are a key actor in this study, for the obvious reason that they are the beneficiaries of cash transfers. In turn they provide information to aid providers. Households are not always the same, and this study makes a distinction between three different types; Pastorals, semi-pastorals and working households. Each different type of household and even each individual household will have different needs and different means to combat food insecurity. When implementing a cash transfer program these different needs should be taken into account.

5.1.4 Visualisation

The Actors from Table 5.1 have been visually represented in Figure 5.1. It can be seen that the three types of actors overlap in some areas.

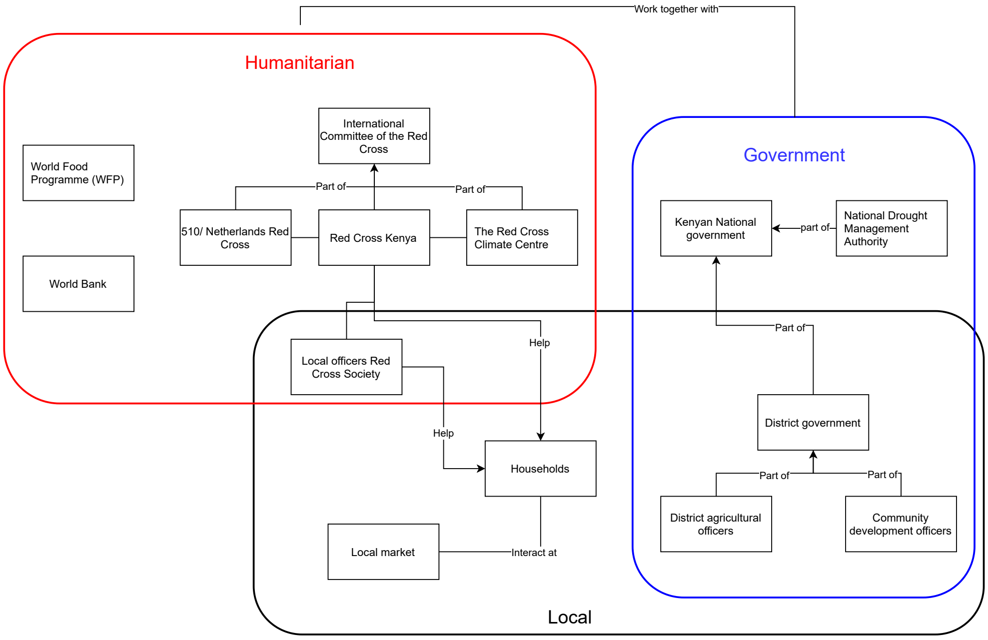


Figure 5.1: Visual overview of actor relations

5.1.5 Conclusion Actor analysis

The actor identification shows that there are many actors involved in the decision making around the design of cash transfers. The authority and mandate of these actors partially overlap in some cases and all have a common goal to reduce food insecurity. There are already institutions and programs in place that aim to reduce food insecurity caused by droughts, which should be taken into account when designing new cash transfers. Findings in this study can be shared with these actors, as a better understanding of cash transfers is mutually beneficial. The Red Cross should be aware of these other actors in order to successfully work together toward a common goal.

5.2 CONCEPTUALISATION

The method of systems thinking is used to better understand difficult and complex problems (Kirkwood, 1998). It is a tool for policy makers to deal with wicked policy problems and help them understand the system at hand. This can then be translated into policy action (Haynes et al., 2019).

It is important to understand how the system components and processes are conceptualised and formalised, as this inherently influences the model outcome. Nikolic et al. (2019) call this the concept of 'observer-dependence' and state that, when building a complex model, the model builder "cannot be fully separated from the system". The model is a specific simplification of reality. Understanding the assumptions made in the conceptualisation and formalisation gives insight in how the synthetic world of the model works. The system at hand will first be visualised with a Causal Loop Diagram. Then the agent types and their interactions will be mapped in a UML-Diagram.

5.2.1 Causal Loop Diagram

The factors identified in the previous sections, including the literature review, have been used to build a conceptual model of the system of food insecurity due to drought. Figure 5.2 shows a causal Loop Diagram (CLD) to provide insight into the complex socio-technical system and better understand the structures causing patterns of behaviour. The figure shows the different components and how they can affect each other in a positive or negative way. The CLD reveals how individual factors can change the entire system through their direct effect and indirect effects such as feedback loops and delays (Kirkwood, 1998).

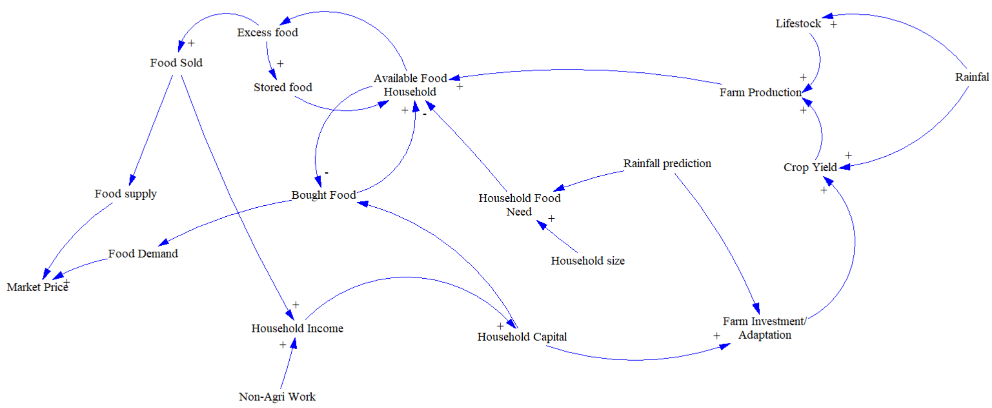


Figure 5.2: Causal Loop Diagram of food insecurity system

The diagram in Figure 5.2 is based on previous drought models (e.g. (Ververoort et al., 2014), (IPCC, 2007)) including socio-economic and environmental drivers on the household level (Stephens et al., 2018). The CLD includes a household food system, food production and a market mechanism. It shows that these subsystems are highly interconnected. A shock (like a drought) in one of these systems will have a big impact on the rest of the system.

5.2.2 Agent types, properties and interactions

In order to implement the agents and processes in the Agent-Based Model, the system is divided into several classes. The central aspect of the system described by figure 5.2 are the households.

The environment sets the ground rules for the model. This includes the initial set-up and external factors. All classes interact within and with the the environment. The household class is the central aspect of the model, with a subdivision into three household types; Pastoral, Semi-pastoral and working. All households have certain common characteristics such as size, food need, available food, capital and if they are food insecure or not. Additionally, all households can consume and buy food. Pastoral and semi-pastoral households have additional attributes for crop production, livestock and drought measures. Semi-pastoral and working households have an income from payed labour. Households interact with each other by trading food with the local market. The local market is a separate class within the model. Lastly the UML includes the cash transfer and its characteristics.

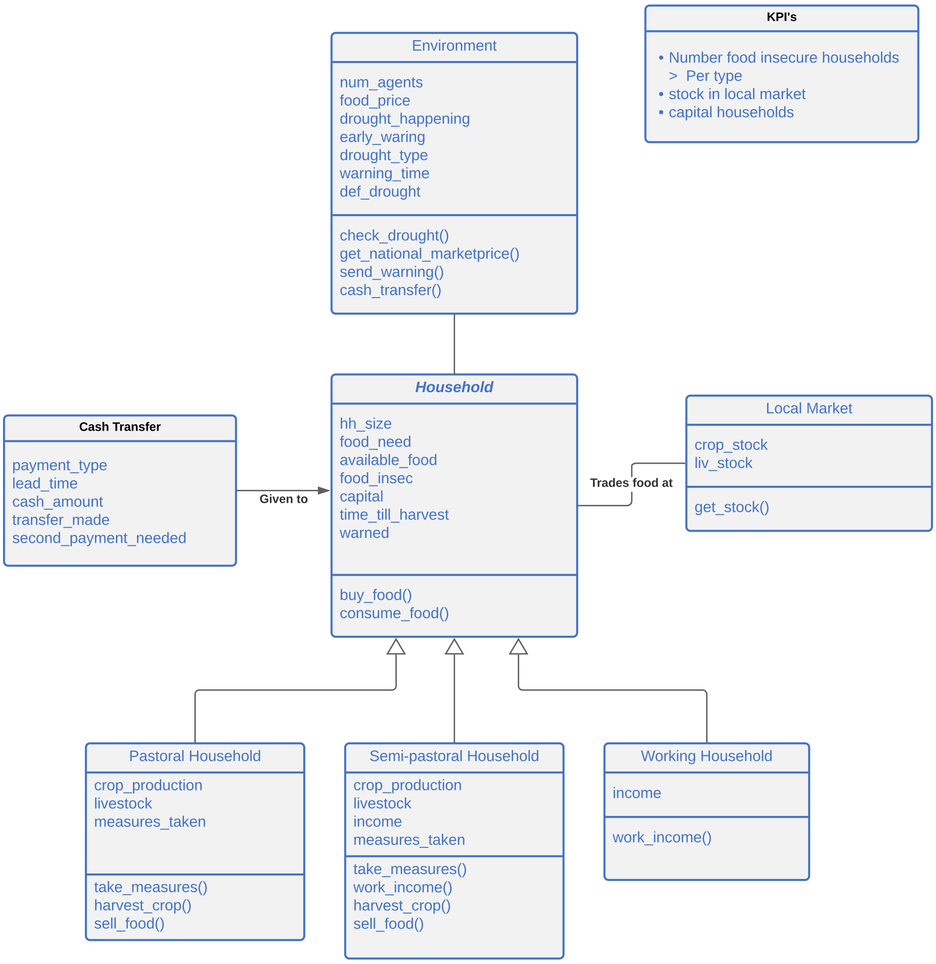


Figure 5.3: UML Diagram

5.3 USING HOUSEHOLD SURVEY AND CHOICE EXPERIMENTS FOR MODEL FORMALISATION

The household survey and choice experiments analysed in Chapter 4 are used in multiple ways throughout this model study. The survey and choice experiments have been used as a representation of a community. This means that the model largely follows the characteristics of the participants of the survey. The number of households, division between the types of households and sources of income are similar in the model and the survey. The policy levers in the model, the different ways of implementing cash transfers, are the same as the options given to the households in the choice experiments. Additionally, the survey has been used to parameterise the model input variables.

5.4 FORMALISATION OF SYSTEMS

After identifying the system and agents, as well as their behaviours, relationships and interactions, these concepts need to be formalised next. (Dam et al., 2013) states that formalisation is necessary because "even though the identified concepts may seem well-defined to the stakeholders, they may be far more context dependent or specific than the stakeholders realise and computers are ill-equipped to deal with ambiguity and context dependency"(p.82). The main concepts will be formalised in the next subsections.

5.4.1 Household formalisation

As mentioned in section 5.2.2 household agents have different attributes, relations and processes. This section explains how these are formalised, which assumptions were made and how the household agents make their decisions.

Household size
The household size is based on data from the household survey. The average household size was 6.2 people and the distribution of household size within the survey roughly followed a normal distribution. This distribution is used to randomly draw a household size for each agent in the model. The outcome is then transformed into a integer value.

Food need
As the available food of households is simplified to one food type (maize), the food need of households should be formalised accordingly. The household food needs are estimated as 160 kg per adult per year, based on the Kenya's per capita maize consumption (Abate et al., 2015) and taking into account no other food source. This number is used to determine the food need of a household, based on the household size and is calculated as an integer.

Income
The model does not include spending other than mitigating measures and food expenditures. This results in the fact that the income of workers and semi-pastorals cannot be based on the normal income distribution in Isiolo, but it has to be just the income that is allocated for food. According to (Muhammad et al., 2010) these types of households will spend about two-thirds of their income on food. Muhammad et al. does state that poor households spend more on food than richer households, but this is left out of the scope of the model. This data is used to determine the income of these households and is drawn for each household as a uniform integer value.

Crop production
Crop production of households in the model is based on a few factors. The first of these is the household survey, that provides insight in the community and in which households stated how much crops they produce. Next, the differentiation between pastorals and semi-pastorals is made based on Muhammad et al. (2010), where pastorals produce (in a normal situation) enough for their own household and additional harvest is sold. The assumption is made that pastorals provide two-thirds of the community's food supply and semi pastorals provide one-third. Lastly, the assumption is made that the pastorals and semi-pastorals are able to sustain the local community and therefore local market in a 'normal' (without drought) situation. Crop production is an integer variable for all households in the model, for working households this value is always zero.

Decision-making process

All agents within the model follow their own decision-making logic and base their actions on the outcome of this process. The decision-making process for households is shown in figure 5.4.

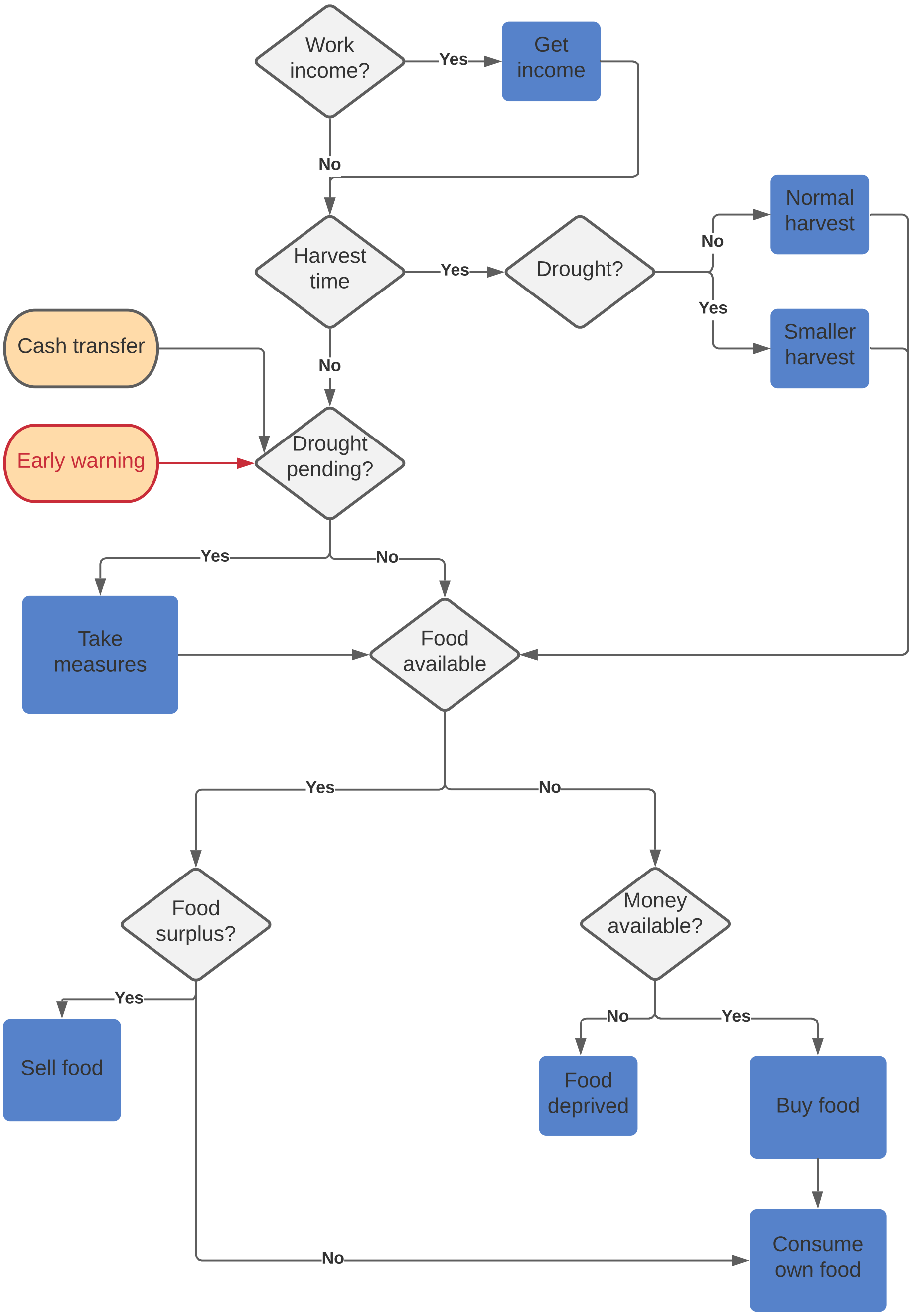


Figure 5.4: Decision process Households

During each step of the model, all households will go through the decision logic of Figure 5.4. Households will first check if they have work income, which applies to workers and semi-pastorals. Next they will check if it is time to harvest the crops. If so, the harvest will depend on the rainfall over the last three weeks and what type of drought is happening. If it is not yet time to harvest, households will check if they got a warning for a pending drought. If there is, they could be receiving a cash transfer and they could take measures to protect their crop against the drought. Next, all households will check if they have food available. If they do, they will check if they have a food surplus, this is defined as having more than a years supply of food.

The surplus will be sold on the market and available food will be consumed. If a household does not have food available, it will check if it is able to buy food on the market. The process of buying food takes into account the food price, market stock and type of drought that is happening. If households do not have food and cannot buy food, they will be food insecure.

5.4.2 Drought formalisation

As it is impractical to almost impossible to have an universal drought definition (Lloyd-Hughes, 2014), drought needs to have a usable formalisation within the model. Drought is defined within the model as three consecutive weeks of low to none precipitation. The data used in the model is 2016 - 2020 weekly historical precipitation data (in mm) of the Isiolo district that has been extracted from the open source Climate Hazards Center InfraRed Precipitation with Station data (CHIRPS) database (Funk et al., 2015).

5.4.3 Food price formalisation

The formalisation of the food price is derived from historical (2016-2020) data of the monthly wholesale food prices of maize in the Isiolo district. This data is acquired from The Humanitarian Data Exchange and is gathered by the World Food Programme (WFP - World Food Programme, 2021). The monthly food prices have been converted in a Python script into weekly food prices for maize in Kenyan shilling (KSh) per kg. The food price is further determined by the availability of food on the local market, which is set by supply and demand within the model.

5.5 XLRM FRAMEWORK

The XLRM framework (Lempert et al., 2003) is used to organize information relevant to decision making challenges under conditions of uncertainty. When using exploratory modeling, the system is conceptualized in a way that the uncertainties can be handled as external factors (Kwakkel, 2017) and are indicated with 'X' within the framework. The decision-makers cannot control these factors. The relationships of the system that have been conceptualised and formalised in the previous sections form the 'R' in the framework.

5.5.1 Key performance indicators

Three KPIs ('M') are used to evaluate the performance of the system; houshold food insecurity, crop stock at the local market and capital of households. The main objective of this study is to explore different cash transfer policies as a humanitarian response to drought induced food insecurity and the influence on household food security.

The main KPI used to evaluate the interventions in the system is the number of households that is food insecure, divided into the three household types. A household is food insecure when, at any given step in time, the available food is less than the food need and there is no option to buy food, either due to food shortage at the market or due to a lack of money. Households that are food insecure do not have to remain food insecure. When enough food becomes available in the next step, either by harvesting or buying food, the household will no longer be food insecure.

The second KPI is the stock of crops at the local market. The local market provides a good indication of how well the local community is able to provide for themselves. When the local market does not have any food in stock, this is an indication that there is not enough food within the whole community. Additionally, when there is no new stock coming into the market it means that households do not have any surplus crops after harvest. This means that they will probably get into trouble later in the year.

The third KPI is the capital of households. The capital of households indicates if households are able to buy food when they do not have any food available. As cash transfers directly influence households' capital, this shows what happens in different scenario's. It also indicates if the food insecurity is due to a lack of cash, or that there are other factors involved.

5.5.2 Policy levers

The Red Cross would like to understand more about how they can use cash transfers as a humanitarian aid for drought response. For this purpose policy levers ('L') are identified leading to two different policy strategies. The policy levers correspond to those used in the choice experiment

The first policy lever is the payment type. The type of payment of a cash transfer could vary between one lump sum or two consecutive amounts. The assumption is made that the two payments are split equally and the first payment is made at the given lead time. The second payment is made half of the lead time after the first payment.

The second policy lever is the lead time. Lead time indicates how far ahead of a predicted drought the households will receive the cash transfer. Longer lead times provide more security for households, while shorter lead times deliver aid just before the moment of drought.

The policy interventions have been separated in two different policy strategies. The first is the 'As Soon As Possible' (ASAP) strategy. This strategy is based on the idea that interventions can best be made as soon as forecast warnings show that a drought is coming. This strategy is characterised by long lead times and mainly one lump sum payments. Long lead times and one payments lead to a commitment to provide aid in an early stage and is thus less flexible. The second policy strategy is 'Careful consideration'. This strategy aims to postpone the intervention with cash transfer as long as possible. This strategy is characterised by short lead times and two time payments. Short lead times could give more certainty about the drought forecasts and with two time payments, the situation can still be assessed after the first payment. This strategy is more agile and change could still be made along the way.

5.5.3 Uncertainties

It is inherent to modelling a real-world situation that there will be uncertainties ('X'). These uncertainties cannot be controlled by decision makers and could influence the model outcomes. The main uncertainty for this model study is the drought itself. Different drought types could occur and it is (within the scope of this study) impossible to predict how a drought will manifest. There are also uncertainties in the price of food and the production of crops. Both of these factors are related to the drought.

5.5.4 Visualisation of the XLRM Framework

All elements of the framework are determined and are graphically shown in figure 5.5. The model system is represented by a box, as the inner workings are of less importance for the exploratory modelling.

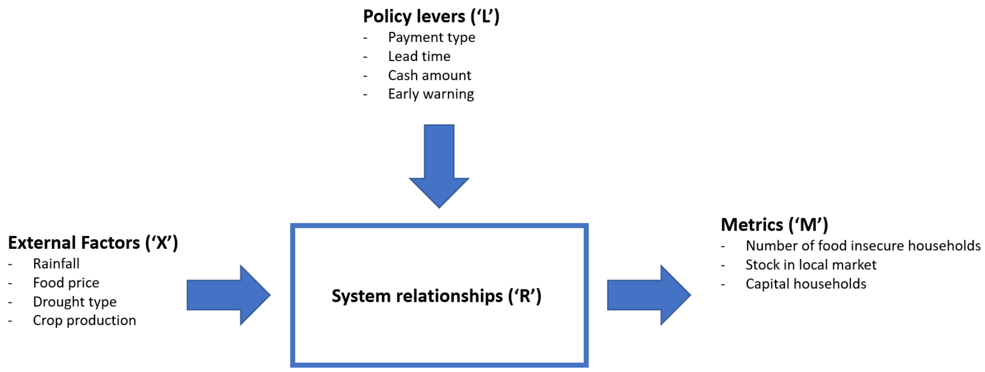


Figure 5.5: The XLRM framework

6 MODEL IMPLEMENTATION

In this chapter the implementation of the Agent-Based Model is described in order to answer the third sub-question of this study:

How can the household food insecurity be implemented in an Agent-Based Model?

First, the modelling environment is described to get a better understanding of the software infrastructure. Second, the time sequence of the Agent-Based Model is discussed. Third, the parametrisation of the variables is explained, after which the user interface is shown. The last section of the chapter will present the verification of the model.

6.1 MODELLING ENVIRONMENT

The modelling environment of the Agent-Based Model is created within a software infrastructure. The model provided in this study was built with Mesa, a Python-based open-source platform created for building, analyzing and visualizing Agent-Based Models. Mesa is component based, meaning its modeling, visualization and analysis components are separated with the intent to work together. This allows model creators to use existing components or build customisations.

Mesa is an alternative to the widely-used multi-agent programmable modeling environment NetLogo (Wilenski, 1999). NetLogo is used by many students and researchers worldwide because of its build in capabilities such as visualisation and 'drag-and-drop' build functionality of the user interface. NetLogo also requires less knowledge of programming language. However, the user interface and visualisation within the interface is of minor importance for this study.

As a Python-based platform, Mesa has all available Python packages at its disposal. This has the added benefit of using data analysis tools for input and output data, without having to convert into a different programming language. Additionally, Python has many data visualisation tools that can help in displaying the model results. The complete model code and model documentation is published on this Github:
https://github.com/JoepHoeijmakers/MasterThesis.

6.2 TIME SEQUENCE

The model runs in discrete time steps in which each time step represents one week. The decision of one week time steps is made as this better represents the situation and decision logic of households, compared to seasonal or monthly steps. Additionally, monthly or seasonal steps account less for fluctuations in food prices. By using weekly steps, aspects such as early warning messages and taking mitigating measures can be modelled. Daily steps would be too detailed for this modelling situation.

When being activated, agents execute their agent-step sequentially, not simultaneously. This means the agent will carry out the functions programmed in the agent-step one after another in the order that they are presented. The order of the agent step has been carefully chosen, as it can have a big impact on model behaviour. Agents will first check if they have work income, then they will harvest crop if available, next they will take measures if required, afterwards they will sell surplus food and lastly they will consume available food. Because agents interact with each other and agents depend on other agents' actions, the order in which agents are activated affects how agents interact. If this order would always be the same, it could lead to imbalanced results (Dam et al., 2013). For example, if one agent is always activated first, it could be that they have an advantage when trying to buy food at the market. Therefore the scheduler activating the agents activates the agents one at a time, in random order.

A complete model run contains 108 steps or 4 years in total. This run time should give a good indication of how the model performs in comparison to the real-world observations. Droughts can be a seasonal phenomenon, but the impact of drought can last for years to come. Consecutive years of drought could even have a larger impact than one severe drought. A 4 year time frame would provide an insight into these patterns.

6.3 PARAMETRISATION

Parametrisation is the process of finding the correct values for model variables. The values of the variables are important because the system could be sensitive to initial parameters (Dam et al., 2013). Different sources have been used to find correct values fore these variables.

First, the household survey and choice experiments conducted in Isiolo have been used for a major part of the parametrisation of variables. The cooperation with 510, the Netherlands Red Cross data team, provides a unique data set as input for the Agent-Based Model which is usually not acquired in the time frame of a master thesis.

Second, values for parametrisation have been gathered from literature regarding food insecurity and drought, as well as information provided by 510. This information could consist of discussions with experts, published papers, or internal documents. Third, data has been gathered from open data sources to get values for the historical food price of maize in Isiolo ((WFP - World Food Programme, 2021)) and the precipitation in the area (CHIRPS data (Funk et al., 2015)).

Last, for some variables it was not possible to find adequate data in the aforementioned sources. These parameters have been based on assumptions and a list of all model assumptions can be found in Appendix B. A list of all parameters and their sources can be found in Appendix C.

6.4 USER INTERFACE

A user interface has been created to visualise the model and make it interactive. The user interface is meant as an intuitive approach to gather insight in the behaviour of the model. It provides 'live' feedback about the model KPIs and can be adjusted for different settings. Figure 6.1 shows the interface of the model. The grid shows all agents with a different color per agent type and is mainly meant as a visual que for the initialisation of the model. On the left hand there are different sliders and a button for the model settings. Below the grid there are graphs that show the KPIs per time step.

Figure 6.1: Interface of the Agent-Based Model

6.5 VERIFICATION

Model verification is a check to verify that things are modeled correctly and perform as intended (Dam et al., 2013). Modeling a complex system based on real-world observations is prone to mistakes and errors, therefore there is a need to verify the model (Nikolic et al., 2019). Verification assures that no unintended model behaviour changes the results of the model.

Verification has been performed continuously during the model building process to constantly assure that all parts of the model worked as expected. The model building process has been iterative and new elements were only added after the current model worked as expected. Different verification steps have been conducted based on the methods defined by Dam et al. (2013). In total, four different methods were used for verification:

- Extensive code walk-through
- Recording and tracking Agent behaviour
- Minimal model testing

After performing all verification steps it can be concluded that the model works as expected and has no errors in the code. Explanation of these steps can be found in the next sub-sections.

6.5.1 Extensive code walk-through

The model code was checked during multiple stages of development. This meant checking if the model functions were correctly translated from the conceptual model and procedures and if the code itself was correct and had the correct outcome. The main method of verification in the code was the use of 'printf() debugging' (Spence, 2020). Printf() debugging is the process of adding print statements at key points in the code in order to get more or less carefully chosen status information as output of the model. This information can be observed to deduce what is going wrong in the code. Figure D.1 in Appendix D shows a snapshot of the model code with print statements for verification purposes. In addition to verification by print statements, the code has been checked by the modeller and externally by Johannes Knörr, Research associate Decision Sciences Systems, Department of Informatics Technische Universität München.

6.5.2 Recording and tracking Agent behaviour

To verify the model operation relevant output variables are be selected and monitored. In order to do this, plots have been designed and integrated in the model interface. Additionally, the print statements used in the code walk through have been used to track individual agents throughout the system. For instance, it has been recorded how much capital an individual agent has, how much food they have available and if they will buy food when they run out. Then it is monitored if they will become food insecure once they are unable to buy any more food. This same system is used to track if agents are buying from the local or regional market. In this verification step, agents would report their own status and action they would take in each step. There were no malfunctions found in the behaviour of agents and all agents functioned as expected.

6.5.3 Minimal model testing

Interaction testing in a minimal model is done by running the model with the minimum number of agents. In this case, the model has been run with 1, 2 and 10 agents. This is done to see of the recording and tracking behaviour from the previous section also works as intended when only a few agents are in the model. It shows if the basic agent interactions are functioning as laid out in the conceptualisation as well as seeing the interactions in their most basic form. The minimal model testing showed no problems in the behaviour of the agents. It did show that the local market had a hard time functioning, however this is due to the fact that there is no balance in the supply and demand of food.

7 RESULTS

The results from the experimentation are presented in this chapter. First, the base model behaviour is presented; first in a no-drought situation and later with the effect of different droughts on the base model. Secondly, the experimental design is explained. Finally, the results of different policy interventions are shown. Especially the effect of policies on the food security levels is highlighted.

The goal of this chapter is to present the results while at the same time limiting the interpretations of the results. The sub-question that will be answered in this chapter is:

What is the effect of policy interventions on the household food security in Isiolo County in Kenya?

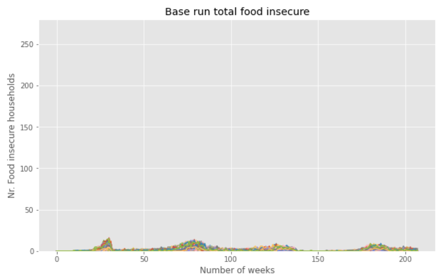
7.1 BASE MODEL BEHAVIOUR

In this first section the behaviour of the base model will be presented. This means that no policy interventions are made. The goal is to focus on the KPIs in scenarios without intervention, in order to get a reference for the experiments. The settings for this base model can be found in E.1. A batch runner has been used for all base model analyses in order to run 1000 iterations of the model. These iterations are made to account for probabilities in the model and to provide a more robust outcome.

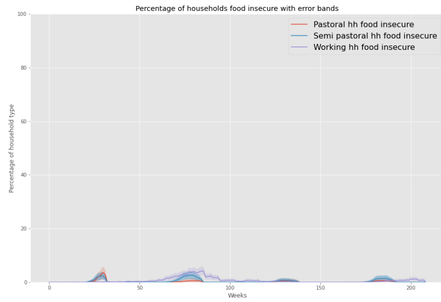
7.1.1 Base model without drought

This section will look at the behaviour of the base model in a situation without a drought. This situation is not the best reference for a 'normal situation' in Isiolo, as drought is a frequently occurring phenomenon. However, the results can be a good indication of model behaviour without any shocks.

Figure 7.1 shows the trajectory of the food insecurity over time when no drought occurs. Without drought, there are hardly any households that become food insecure. Figure 7.1a shows the total number of food insecure households, Figure 7.1b shows the percentage of food insecure households per household type. The graphs show that in a normal situation less than 15 of 280 households will ever become food insecure and the 'peaks' get smaller over time.



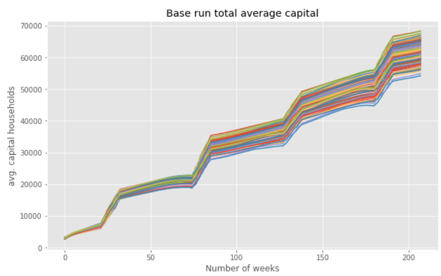
(a) Food insecurity trajectory base model



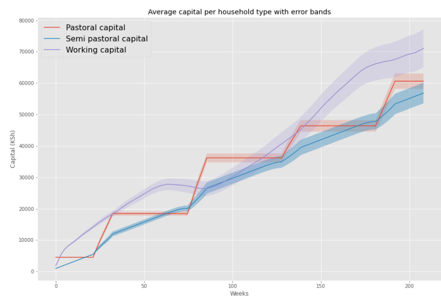
(b) Food insecurity per agent type base model

Figure 7.1: Food insecurity base model

Figure 7.2a shows the trajectory of the average capital over time when no drought occurs. Without any drought, the average capital of the community increases over time. Figure 7.2b shows the total average capital and Figure 7.2b shows the average capital per household type. Figure 7.2b shows that the working households have the highest capital at the end of the run, followed by pastorals and semi-pastorals. There is a clear oscillation for pastoral capital, due to seasonal harvest and crop sales. Semi-pastorals and working households have a more steady growth.



(a) Average capital trajectory base model



(b) Average capital per agent type base model

Figure 7.2: Average capital base model

The trajectory of the market crop stock is shown in Figure 7.3. The graph shows that, without any drought, the local market will not run out of stock. This is in line with the assumption made the conceptualisation phase. There is an oscillation based on seasonal harvest and crop sales. The stock at the end of each harvest is enough to sustain the local community until the next harvest.

Figure 7.3: Market stock base model

7.1.2 Effect of drought on base model

This section will look at the effect of drought on the base model. This analysis is done for both a moderate and severe drought. The section is divided into three parts; the effect of droughts on food insecurity, the effect on capital and the effect on the market.

Food insecurity

Figure 7.4 shows the effect of both drought types on the total food insecurity, as well as the no drought scenario. Both drought scenarios show three distinct peaks in the total food insecurity and the peaks are slightly higher each time. These peaks occur every year just before the harvest season. In the moderate drought scenario about 50% of households become food insecure each year. Following the harvest there is a period of around 25 weeks with little to no food insecurity. After this period the number of food insecure households rises again. The severe drought scenario presents much more food insecure households. The peaks reach to 100% of households being food insecure. Following the harvest season this number drops to 20%, but it quickly rises again.

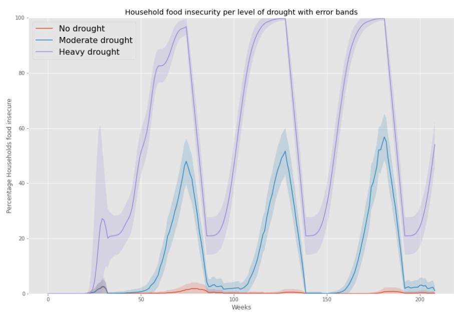
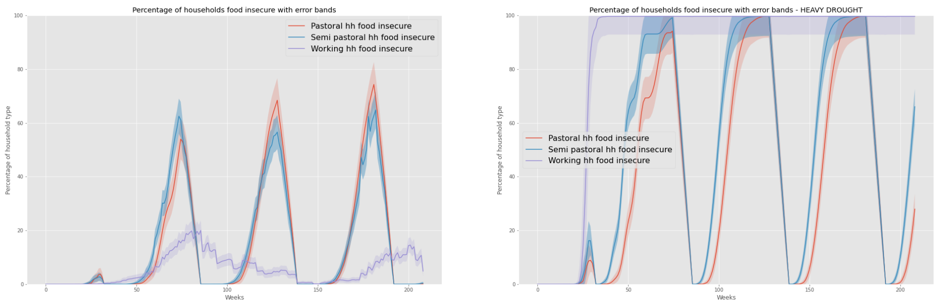


Figure 7.4: Food insecurity in different drought scenarios base model

In Figure 7.5 the household food insecurity is divided into the food insecurity per household type for the two drought scenarios. Figure 7.5a shows that in a moderate drought scenario pastoral and semi-pastoral households are more food insecure than working households. Only the poor working households become food insecure when the food price rises in the drought period. Richer working households are still able to get food at secondary markets. This indicates that households that are highly dependent on their own crops are more vulnerable to a moderate drought. In a severe drought (Figure 7.5b) working households are the first to become food insecure and they are not able to get out of this situation. This is due to the fact that, in a severe drought, it is not possible to get food at a secondary market. Pastorals and semi-pastorals become food secure just after harvest. However, this lasts only for a short time as the harvest is diminished.



(a) Moderate drought scenario

(b) Severe drought scenario

Figure 7.5: Food insecurity per agent type in different drought scenarios base model

Average capital

Figure 7.6 shows the effect of both drought types on the total average, as well as the no drought scenario. For the average capital graphs the trend over time is more important than the exact values. In a moderate drought scenario, the capital roughly remains the same over time. A severe drought causes the average capital to take a linear incline.

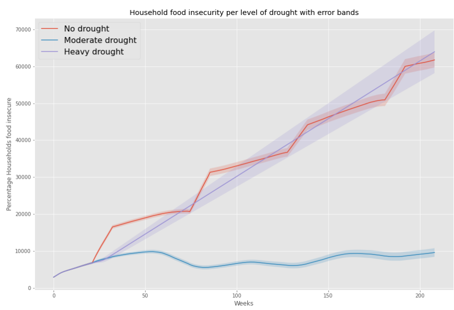


Figure 7.6: Average capital in different drought scenarios base model

(a) Moderate drought scenario **(b)** Severe drought scenario

Figure 7.7: Average capital per agent type in different drought scenarios base model

When looking at the average capital per household type (Figure 7.7) the trend lines of Figure 7.6 can be explained. In a moderate drought scenario 7.7a the average capital of working households drops due to high food prices when a drought occurs. The average capital of semi-pastorals fluctuates based on higher food prices and their availability of own grown crops. The average capital of pastorals goes down, as they have no way of generating income. When a severe drought hits, there is different behaviour in the average capital. In a severe drought scenario, there is no option to obtain food from a secondary market, when the local market cannot provide food. This means that working and semi-pastoral households still generate capital from work income, but they have no means of spending it once the local market runs out. The result is a linear increase of capital.

Local market stock

Figure 7.8 presents the effect of both drought types on the crop stock in the local market, as well as the no drought scenario. The figure shows that in both drought scenarios the market stock quickly runs out. No new stock is added to the market during the model runs. New market stock is only generated from the surplus of household production. No surplus in household production means no produce enter the local market.

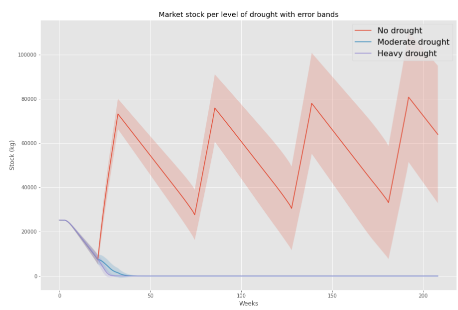


Figure 7.8: Market stock in different drought scenarios base model

7.2 EXPERIMENTATION

Experiments are performed to gain insight in the effect of the policy levers on the KPIs in comparison to the base model. Additionally, it is used to understand the effect of the different policy strategies on the base model. The base model cannot be viewed as a perfect reference to a 'normal' situation of drought in Isiolo, without the cash transfer. This is because in a normal situation of drought, there would be other humanitarian aid such as food aid when many households are starving. However, the base case does provide a benchmark to measure the effects of policy interventions.

7.2.1 Open exploration

The EMA Workbench has been used to analyse the effect of the policy interventions on the results. As pointed out in Chapter 3 the EMA Workbench has been developed by J.H. Kwakkel 2017 as an open source tool for open exploration. The workbench can account for uncertainty by performing each simulation run under a large sample size of scenarios, after which built-in analysis tools can be used to analyse the results. Table in Appendix E.1 shows the different simulation runs that have been performed and which policy parameters have been used. When choosing the design of experiments, there has been a careful consideration not to go for a full factorial design. This is in view of the prediction that cash transfers will have less impact in drought type 3, due to assumptions in the model. Each simulation run has been performed with a sample size of 1000.

7.3 EFFECT POLICY INTERVENTIONS

In this section the effects of the policy levers on the KPIs will be shown. First, the effect of the type of payment will be presented. Next comes the effect of the lead time and lastly there will be results of the two different policy strategies.

7.3.1 Payment type

The payment type determines if households will receive the cash transfer in one or two times. In order to see the influence of this policy leaver, simulations runs are chosen with a fixed lead time of 4 weeks. This section will first present the effect of payment type on the total food insecurity, then on the average capital and lastly on the market stock.

Food insecurity

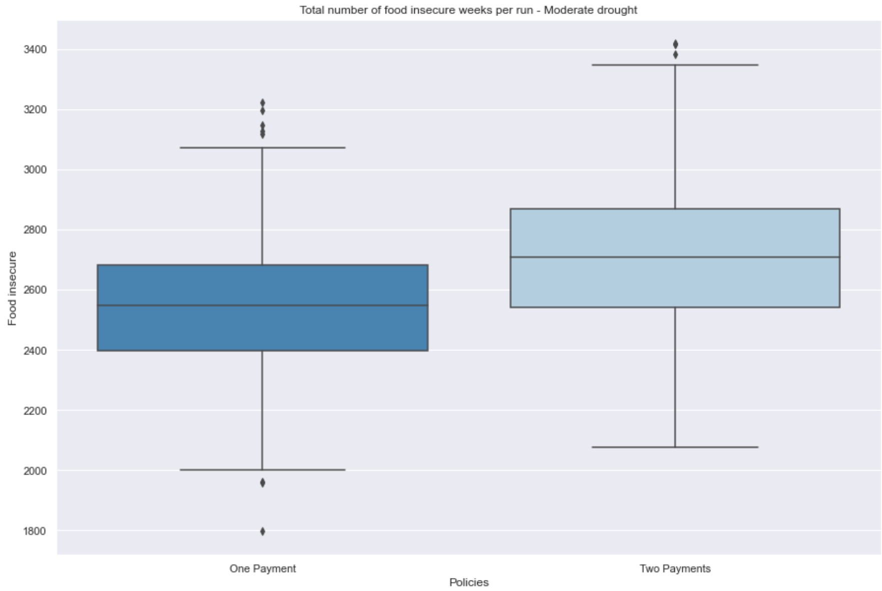


Figure 7.9: Effect Payment type leaver on Total weeks food insecurity - Moderate drought scenario (Lower is better)

Figure 7.9 shows the total number of food insecure weeks for households in a simulation run for each of the policy options. These simulation runs were done with a moderate drought scenario. The boxplots show that there is a slight increase in food insecure weeks when choosing for two payments compared to one payment. However, this increase is less than 6%. When comparing both policy options to the base model 7.10, it becomes apparent that both payment types lead to a huge reduction of food insecure weeks. Roughly 3175 food insecure weeks in a one payment situation and 3375 weeks in a two payment situation would be around 11.4 and 12.0 weeks of food insecurity per household respectively over a four year period. When looking at a severe drought scenario, the payment types have no influence on household food insecurity. The cash transfer does not seem to have any effect. More details can be found in Appendix E.2.

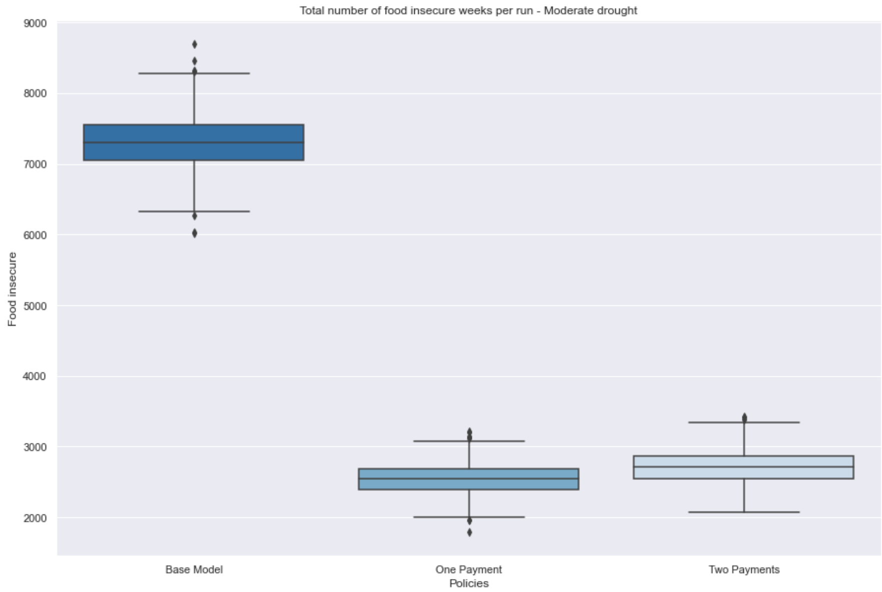
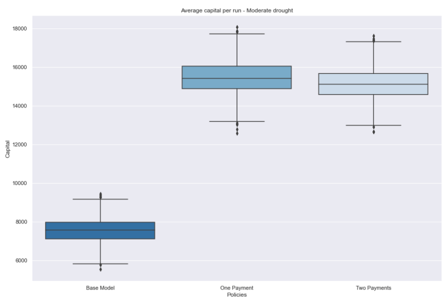


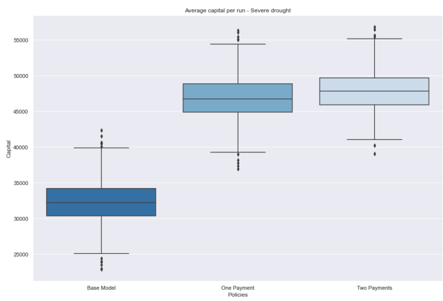
Figure 7.10: Total weeks food insecurity - Base model and payment type levers - Moderate drought scenario (lead time 4 weeks)

Average capital

Figure 7.11 shows the average capital of households in a simulation run for each of the policy options. Figure 7.11b shows the average capital in a moderate drought scenario and 7.11 for a severe drought scenario. In both scenarios the cash transfers lead to a higher average capital, with little difference between the type of payment. In the severe scenario the amount of capital is much higher than in the moderate scenario. This is in line with observations of the base model.



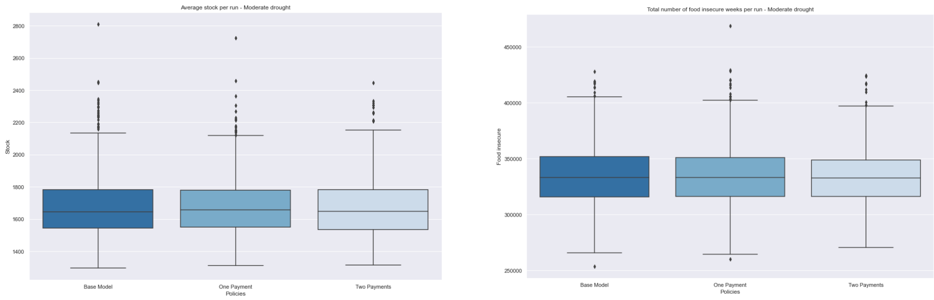
(a) Moderate drought scenario



(b) Severe drought scenario

Figure 7.11: Total average capital - Base model, One payment, Two Payments

Market stock



(a) Moderate drought scenario

(b) Severe drought scenario

Figure 7.12: Average Market stock - Base model, One payment, Two Payments (Higher is better)

Figure 7.12 shows the average market stock in a simulation run for each of the policy options. Figure 7.12a shows the average market stock in a moderate drought scenario and 7.12b for a severe drought scenario. In both scenarios there is no effect of the payment on the market stock, regardless of what payment type is used.

7.3.2 Lead time

The lead time determines how far ahead households will receive the cash transfer, when a drought is forecast. In order to see the influence of this policy leaver, simulations runs are chosen with both one and two payments, short and long lead times. This section will first present the effect of lead time on the total food insecurity, then on the average capital and lastly on the market stock.

Food insecurity

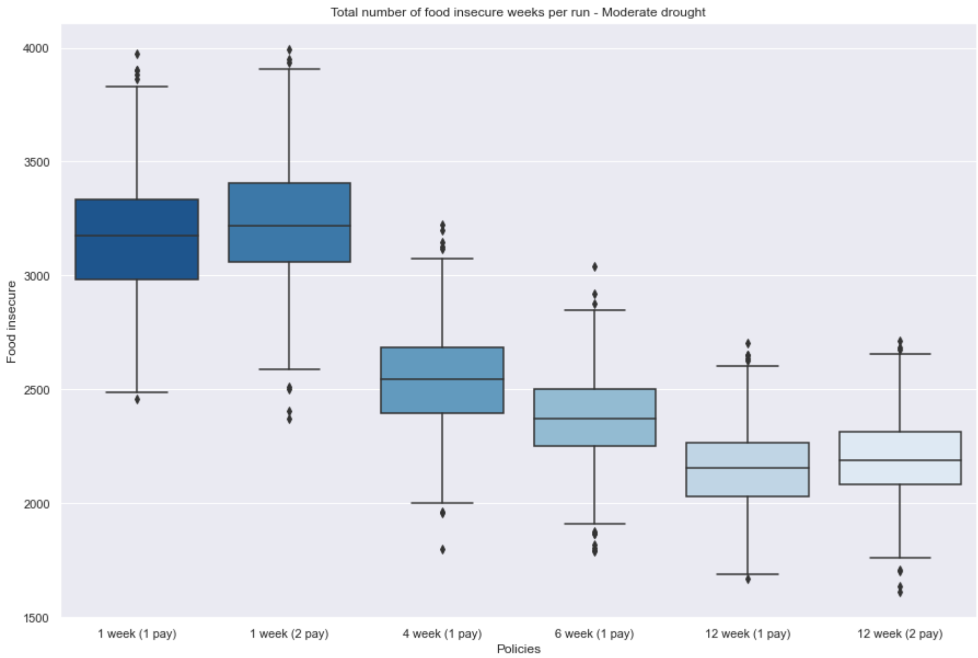


Figure 7.13: Effect Lead Time on Total weeks food insecurity - Moderate drought

Figure 7.13 shows the total number of food insecure weeks for households in a simulation run for each of the policy options. These simulation runs were done with a moderate drought scenario. The boxplot clearly shows that longer lead times lead to less total food insecure weeks. When comparing a 1 week lead time (1 payment) and 12 weeks lead time (1 payment), the 12 week lead time causes a 45% decrease of total food insecure weeks. When comparing different lead times to the base model 7.10, it becomes apparent that even a one week lead time generates a huge reduction in the number of food insecure weeks. The payment type in both 1 week and 12 weeks lead time (7.13) does not seem to have an effect other than previously observed. When looking at a severe drought scenario, the lead time has no influence on household food insecurity. Again, the cash transfer does not seem to have any effect at all. More details can be found in Appendix E.2.

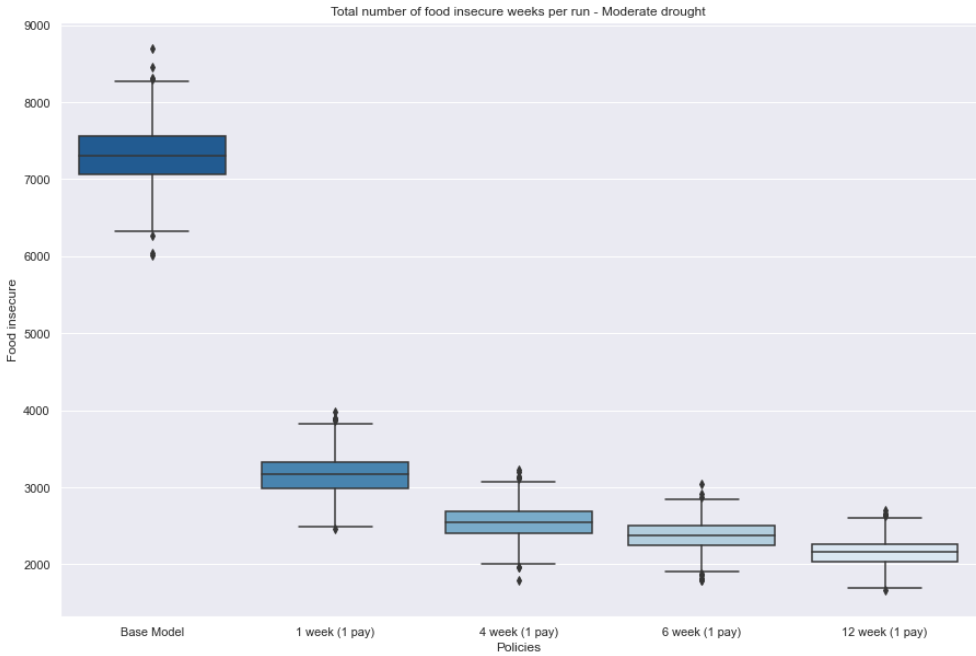
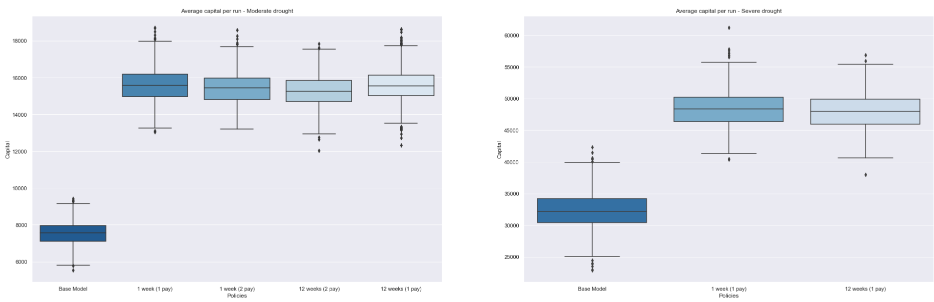


Figure 7.14: Effect Lead Time on Total weeks food insecurity - with base - Moderate drought

Average capital

Figure 7.15 shows the average capital of households in a simulation run for each of the policy options. Figure 7.15a shows the average capital in a moderate drought scenario and 7.15b for a severe drought scenario. In both scenarios the cash transfers lead to a higher average capital. However, there is little to no difference between the effect of the different lead times. In the severe scenario the amount of capital is much higher than in the moderate scenario, however lead time has no effect on this. This is in line with observations of the base model.

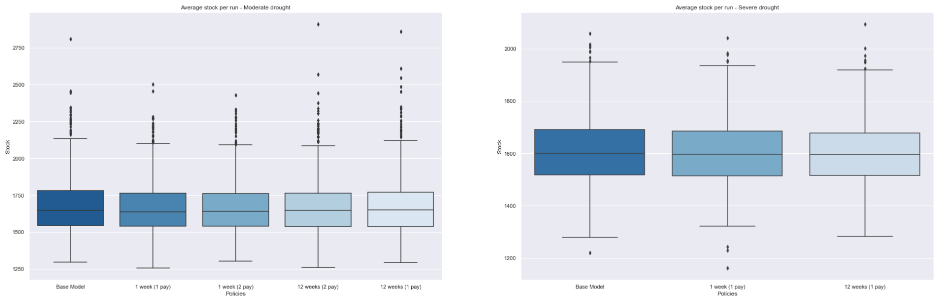


(a) Moderate drought scenario

(b) Severe drought scenario

Figure 7.15: Effect Lead Time on average capital - Base model, One payment, Two Payments

Market stock



(a) Moderate drought scenario

(b) Severe drought scenario

Figure 7.16: Effect Lead Time on average Market stock - Base model, One payment, Two Payments

Figure 7.16a shows the average market stock in a simulation run for each of the policy options. Figure 7.16b shows the average market stock in a moderate drought scenario and 7.16 for a severe drought scenario. In both scenarios there is no effect of the payment on the market stock, regardless of what lead time is used.

7.4 CONCLUSION

This chapter has presented the results of the base model and the effect of the policy levers. The base model shows that, without any drought, there are hardly any households that become food insecure. When drought occurs there is a peak in household food insecurity every year just before the harvest season. In the moderate drought scenario about 50% of households become food insecure each year, while this is close to 100% in the severe scenario. In a moderate drought scenario the average capital of working households drops when a drought occurs, while in a severe scenario the average capital increases. Without any drought, the local market will be balanced and will not run out of stock. When a drought happens, the market stock quickly runs out in both drought scenarios.

The only policy leaver that has a significant impact on household food insecurity is the lead time. A longer lead time leads to less total food insecure weeks. When comparing a 1 week lead time and 12 weeks lead time, the 12 week lead time causes a 45% decrease of total food insecure weeks. The policy levers do not seem to affect the average capital or market stock in a significant way.

8 ANALYSIS

After presenting the results in the previous chapter, in this chapter the results will be interpreted. First, the results of the model will be validated. Next, the results of the different policy levers will be interpreted and discussed. Afterwards, the policy strategies will be analysed. Finally, the real world implementation of these results will be examined.

The goal of this chapter is to interpret and discuss the results. The subquestion that will be answered is:

How can the outcomes of this study be generalized to other drought crises?

8.1 MODEL VALIDATION

Model validation is needed to check if the model behaviour is realistic compared to the real world. It also checks if the model is adequate for the goal set at the start of this study: exploring different cash transfer policies as a humanitarian response to drought induced food insecurity and the influence on household food security. Where the verification step was used to check that things are modeled correctly and perform as intended, validation is used to ensure that there is confidence in the model results (Sargent, 2010). A complete validation is out the scope of this research, as the goal is not to predict future events.

Validating a complex behavioral model is difficult due to a lack of empirical data and unique feedbacks (Claessens et al., 2012; Brown et al., 2017). Therefore it is especially useful that a household survey has been conducted and analysed as part of this study. Another validation challenge is provided by the high level of abstraction of the Agent-Based Model as implemented in this thesis. Dam et al. (2013) describe four types of validation of which two are implemented for this study. These types of validation are:

1. Face validation through expert consultation
2. Literature validation

8.1.1 Face validation through expert consultation

Expert consultation can provide a unique understanding of the real world situation. Experts can judge whether the observed behaviour and outcomes are in line with practical knowledge and experience. Modelling decisions and scoping choices have been discussed with experts in the humanitarian domain throughout this research. This started with the household survey and choice experiments used as input parameters for the model. Expert consultation for these came through a debriefing session on the 27th of January 2021 which was attended by members of 510, members of the Kenyan Red Cross and researchers from the VU Amsterdam. During this debrief the results of the survey and choice experiments have been discussed and compared to practical knowledge and experience. Additionally there was input on how; local knowledge on food security can be converted into a quantitative model input; the results of the choice experiment could be used to shape the design of future cash programs. This debrief was in the early stage of the model building process and the information gathered has been used while constructing the model.

The main expert consultation has been conducted in biweekly meetings with Dr. M. van den Homberg (510, Netherlands Red Cross) and M. Wens (PhD researcher, VU Amsterdam). These meetings have contributed to the continuous validation of the model and its input. One example of this is the validation that there is a trend in households becoming food insecure just before the new harvest.

8.1.2 Literature validation

A directly comparable study has not been found in the literature. The model studies presented in the literature review have different behaviour, time frame and intended outcome which makes exact quantification of factors impossible. However, Cirillo and Gallegati (2012) describe recommendations on how to establish the model to gain valid results, a method also used by Wens et al. (2020). These recommendations have been followed throughout this study. for example, (1) reanalysis climate data from CHIRPS (Funk et al., 2015) and food price data from the WFP (WFP - World Food Programme, 2021) have been used; (2) the model has been based on the existing framework by (Dobbie et al., 2018); and (3) a survey has been conducted (n = 186) in the region to gather empirical socioeconomic parameters to initialize the model.

Furthermore, the results of the base scenarios with drought can be compared to results shown in previous studies. The range of people in food insecurity simulated in both scenarios fitted the observed ranges over time. Ifejika Speranza et al. (2008) reported that during the (severe) 1999-2000 drought 91% of rural households experienced food insecurity. This is similar to the modeled peaks that arise during the simulation of the severe drought scenario. Additionally, The modeled outcomes for a moderate drought year (over 50% of households food insecure) correlate to the empirical findings of Gallup (2019). This data also shows that two years of consecutive moderate drought lead to an increased percentage of food insecure households.

8.2 DISCUSSION POLICY LEVERS

The policy interventions aim to reduce the amount of food insecure households and provide aid in times of drought. In this section, the policy levers are discussed with a focus on *how* they are implemented in the model.

8.2.1 Payment type

This policy lever indicates if households would get one or two cash payments. The idea is that one payment provides the household with a larger cash boost that they can use for preemptive measures. A two payment system is more focused on providing cash to spend on food. This is also shown by the outcome of the household survey, in which respondents indicated that they would spend their one sum payment on preemptive measures and household costs and save the rest for food.

In the model, the payment type system has been implemented in the most basic way. A one sum payment would be handed out to everyone when forecasts predict a drought is coming. This forecast was always perfect and is predicted given a certain lead time. For two payments the cash amount were split in two exact amounts that were given at the lead time and half lead time. There was no strategy in to whom the cash was given, the total amount of cash or the amount per payment. Additionally, there was no 'cost' of getting the payments to the households. In a real life situation, getting cash to households requires some kind of logistic operation. This means that more moments of payment could lead to more costs for households, which in turn could lead to more benefit in a one payment situation.

The type of payment only showed a small impact on the KPIs in this model. One payment policies had a slightly lower amount of food insecure weeks compared to two payments. This is because both payment types satisfy the cash need in order to prepare farmers for droughts. Additionally, the time between two payments is too small for households to run out of money between the payments. Adding more complexity in how the payments are performed or having strategical choices in the distribution of these payments could lead to a different outcome.

8.2.2 Lead time

The policy lever lead time indicates how far ahead of a predicted drought the households will receive the cash transfer. Longer lead times provide more security for households, while shorter lead times deliver aid just before the moment of drought.

In the model, the lead time is equivalent to the forecast capabilities. Meaning, a longer lead time will lead to forecasts made further ahead. This is because no probability has been taken into account for the forecasts. The model can look at a perfect prediction of the future and see if drought is coming. In a real world situation, forecasts are made with probabilities and the closer time gets to the actual event, the better a forecast will be. This will be further discussed when talking about the real world implications (8.4) and model limitations.

The lead time showed to have a significant impact on the KPIs in this model. This effect could mainly be observed in the total number of food insecure weeks of households. The longer the lead time, the fewer households would become food insecure. This can be explained by the fact that households run out of food and money just before the harvest season. Households are able to use their harvest for a long time throughout the year, but there comes a point at which they run out of food and need to cut into their cash reserves. This is confirmed by observations in both food insecurity and average capital. A longer lead time will prevent many households from running out of money before the new harvest can be used. Longer lead times are a way to 'flatten the curve' when it comes to the peaks in household food insecurity.

The longest lead time used in simulation runs is 12 weeks. It would be interesting to see if the progression of fewer food insecure households proceeds with even longer lead times. Additionally it would be interesting to see what happens if cash transfers were made when or after the drought has occurred. Both of these things are out of the scope of this study.

8.2.3 Interventions in severe drought

The model has also been used to evaluate policies in a severe drought scenario. This scenario had some additional assumptions in the model compared to the moderate drought scenario. The most untactful of these assumptions is the fact that, in a severe drought, households were not able to get food at a secondary market. This assumption was made to see the impact of a non-functional market system. Market failure was mentioned by households in the survey as one of the important causes of food insecurity.

By restricting the access of households to other markets apart from the local market, this drought scenario showed many extreme results. Almost all households became food insecure and stayed in that state during the entirety of the simulation run. The average capital of households with work income would only increase over time. No cash transfer policy had any influence on the household food insecurity. This seems obvious, as the choice was made and modelled to restrict access to food, but it shows a fundamental concept. When households have no access to food, the situation does not become a cash problem but a food problem. This implies that, when markets are unable to get food at the right place, cash transfers should not be considered as an option. Food aid remains the only option in these situations.

8.3 ANALYSING POLICY STRATEGIES

After analysing the effects of the policy levers on the KPIs in Chapter 7.3, this section will focus on the policy strategies that have been formulated in Chapter 5.5.2. The focus will be on the effect on household food insecurity, as this is the most important KPI and the analysis of the policy levers shows that this is most impacted by different policies. The strategies will be analysed by taking the mean of all simulation runs belonging to the strategy. This means that the ASAP strategy consists of 6 simulation runs, each performed with 1000 scenario iterations.

To recap the two different policy strategies; First there is the 'As Soon As Possible' (ASAP) strategy, characterised by long lead times and mainly one lump sum payments. This is based on the idea that interventions can best be made as soon as forecast warnings show that a drought is coming. The second policy strategy is 'Careful consideration', characterised by short lead times and two time payments. This strategy aims to postpone the intervention with cash transfer as long as possible.

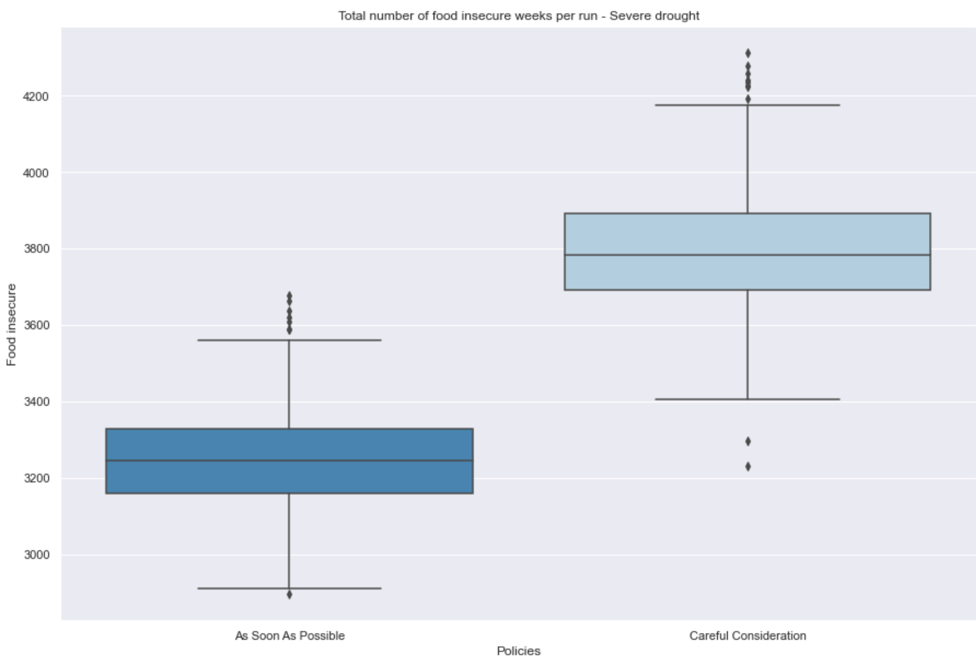


Figure 8.1: Effect two policy strategies on Total food insecurity weeks - Moderate drought scenario

Figure 8.1 shows the effect of the two policy strategies on the total number of food insecure weeks. It is clearly visible that the ASAP strategy results in less food insecure weeks. The careful consideration strategy leads to an increase of 15 % in food insecure weeks compared to the ASAP strategy. This percentage could be even higher if simulation runs with the severe drought scenario would be left out of consideration, as cash transfers have no effect in these simulation runs. The boxplot shows that early action leads to households saved from food insecurity.

When comparing both strategies to the base model (Figure 8.2) in a moderate drought scenario it becomes apparent that both strategies are a large improvement in terms of food insecure weeks. This is evident as any aid would always be better than no aid at all. Nonetheless, still it can be noted that the impact (reduction in total weeks of household food insecurity by 129%) of (both of) the cash transfers is immense. Comparing the two strategies to the base model puts into perspective the relative effectiveness between the two strategies, which seems less relevant in this case. However, it is important to note that the complete absence of intervention is not representative for a real world situation. Therefore the relative difference between the two strategies does matter.

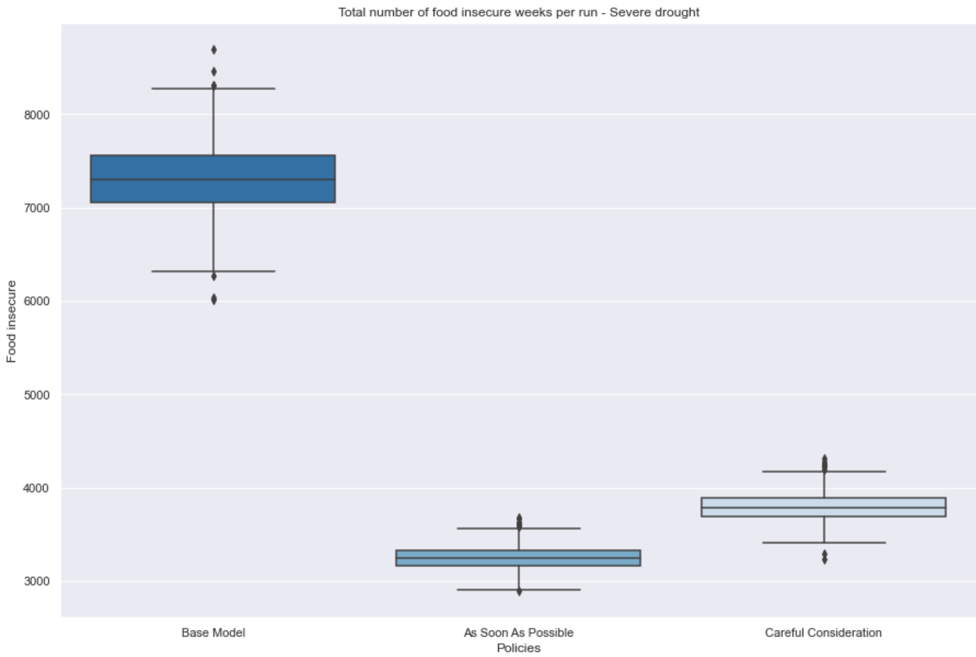


Figure 8.2: Effect two policy strategies on Total food insecurity weeks compared to base model - Moderate drought scenario

8.4 REAL-WORLD USE AND IMPLEMENTATION

After discussing the policy results in the previous sections, this section will focus on generalising the results and discuss how they could be implemented in real-world situations. As mentioned in the validation of the model, the model cannot be used to predict future events. It is possible to discuss how the results can be used in policy decisions.

To begin with, both empirical choice experiments and a behavioural model have been used in this study. Each of these provide their own insight in cash transfers, but they are both meant for finding the best policy. In the choice experiments, participants indicated a strong preference for one lump sum payments. The absence of significance in the lead time could be allocated to misunderstanding of the experiment. It seems that households will prefer more security when it comes to receiving aid. With two payments there is the risk of not receiving the second payment. The model shows no significant difference in terms of food insecurity between the payment types. If the flexibility of two payments is valued for humanitarian organisations, this could be a good option in terms of outcome. However, the preference of households should not be disregarded. This preference could stem from factors or desires outside the scope of this research, such as having extra money for education. This means it is important to assess the context of the community.

Secondly, the model shows that in a real-world situation the quality of forecasts is important. This is due to the fact that lead times are the key factor in providing aid. Longer lead times, as proven to be better in the model, can only be realised with good forecasts. Bad forecasts could lead to aid being given too late, causing more food insecure households. However, the opposite can happen as well. When policy is made that provides aid based on a long lead time, a bad forecast could lead to aid being provided unnecessary. Yet, some argue that aid given this way is a 'no regret' situation. Cash transfers made to households in poor regions will always improve the situation of a community, even when there is no drought. It could lead to improvements in agriculture, education, or overall livelihood that could be beneficial in future drought situations as well. Therefore, policies for cash transfers can best be made with a longer lead time in mind. When no early action has been taken and a community is suffering due to drought induced food insecurity, other aid alternatives could be more suited for the situation.

8.5 CONCLUSION

This chapter forms the final part of the modelling cycle and answers the final sub-question of this research. Where the previous chapters have been focused on the case study of the Isiolo district in Kenya does this chapter revolves around generalising the findings to other drought situations.

Based on the validation and analysis, three statements are made that form the answer to the fifth sub-question. Firstly, if one were to generalise the effects of cash transfer policies one should know that all forms of cash transfer have a meaning full impact on household food insecurity, when used in the correct context. Secondly, one should be aware of the fact that cash transfers are not the correct humanitarian aid tool in every situation . There should always first be a market assessment to check if providing cash will really prevent households from becoming food insecure. Thirdly, one should know the importance of timing when considering cash transfers. Cash transfers have more impact if they are made well in advance of a drought disaster. When no early action has been taken and a community is suffering due to drought induced food insecurity, other aid alternatives could be more suited for the situation.

9 DISCUSSION

The outcomes of the modelling study presented in the previous chapters are reflected upon in this chapter by evaluating the limitations of this study. The aim of this chapter is to provide a critical perspective on the outcomes of this study. First, the limitations of this study are discussed. This involves reflecting on the critical assumptions that were made and discussing what the model is able and not able to do. Afterwards, the chosen research approach will be evaluated. This is done by looking at the strengths and weaknesses of the survey, choice experiment and Agent-Based Model.

9.1 LIMITATION OF THE STUDY

This study has been conducted with the upmost care and effort, given the time at hand. However, it is natural that there are several limitations due to the chosen research approach and simplifications that have been made. Thus, before coming to a conclusion and considering the implications for policy makers, the main limitations of this study are discussed in this section. First, the critical assumptions of this study will be discussed. This includes the main limitations of the Agent-Based Model and household survey.

9.1.1 Critical assumptions

Assumptions made during conceptualization, formalization, and implementation of the model are highly influential for the outcomes of this study. This section will reflect on some of the critical assumptions and how they affect the model outcomes.

Drought

First of all, assumptions made regarding drought are critical when examining humanitarian aid policies for drought response. Drought is not a universally defined phenomenon and it comes in many shapes and sizes. For the purpose of this model study drought has been defined in two types; a moderate drought and a severe drought. This assumption does not account for dry spells, an on and off drought or any other form of drought. The assumption that only these two types of drought occur limits the complexity of the model study and its results. Additionally, the influence of drought on crop harvest is simplified for this study. Drought during the sowing or growing of crops has no influence on the harvest. Modeling drought in more complexity and the influence on household food security is left for future research.

Market system

Secondly, the assumption is made that the modelled community has a functional market system in a no drought and moderate drought scenario. Specifically this means that the pastoral and semi-pastoral households are able to sustain the local community and therefore local market in these scenarios. Evidently this means that the severe drought scenario does not have a functional market. This assumption is based on discussions with experts but has not been fully studied for this research.

9.1.2 Model limitations

Strategic behaviour of agents

Firstly, household agents in the model base their decisions on parameters in their decision logic. However, their actions cannot be described as being strategic. Agents have no strategic behaviour with the goal of not becoming food insecure. For example, household agents with crops will always take measures when given an early warning for drought and if they have the money. They do not consider how much of their capital is spend on these measures and if they will be able to buy food until the next harvest. It could happen that agents spend almost all their food on taking measures and become food insecure two steps later.

Additionally, agents have no strategy in buying food, based on the food price. Cash transfers are often given at in a stage where the food price has not increased yet, especially when there is a long lead time. Agents could use this transfer to buy and store food at a lower cost. Including these agent strategies could lead to interesting results and is left for future research.

Base model

Secondly, the base models used as reference scenarios are based on the assumption that no humanitarian aid will be provided. As mentioned before, this is not representative for a real world situation. In a real world situation, there would always be some form of aid when a drought disaster strikes. Therefore, comparing policy strategies to this base model does not provide a good overview of cash transfers in and on itself. The model developed for this study is more suitable for comparing the different kinds of cash transfers amongst each other. Using a base model that includes food aid would be useful to compare cash transfers to current situations. Additionally, a study could be done to compare cash transfers to other kinds of aid.

Cost effectiveness of cash transfer

The model and in broader sense this study does not take into account the cost effectiveness of cash transfers. As this study mainly aims to compare different cash transfer designs, the costs effectiveness is outside of the scope of this study. Especially the comparison between the costs of cash transfers and traditional food aid is not included in this study.

Forecast probability

Thirdly, the model does not take into account the probability of forecasts. Forecast are not always accurate and therefore early warnings are not always perfect. Forecasts are made with a certain probability and decision-makers are left making a choice based on the forecast and probability. This adds an extra layer of complexity to the choice of giving cash transfers to a community. Forecasts are less probable the further in the future you try to predict. Therefore, waiting with providing aid will lead to more certainty about the extend and severity of the drought disaster.

The model does not take into account the probability and always provides a forecast with a 100% certainty. Adding an extra layer of complexity, where cash transfers would sometimes be given and no drought would occur, would provide extra insight for decision makers. This is especially useful when looking at the cost effectiveness of cash transfers, but that is outside the scope of this study.

Nutritional needs of households

Lastly, the model does not take into account nutritional needs, but only incorporates one type of food. The simplification of the dietary needs of households is not representative for a real situation. Multiple types of food would provide more insight in choices of households and fluctuations in market prices. Not all crops are affected by drought in the same way and fluctuations in prices could lead to households adapting their diet. It could also be that, even if households get enough food in terms of calories, they could be undernourished because they don't have access to the nutrients they need. More nutrient food is often more expensive and during a crisis households could opt for cheaper options, leading to malnutrition.

Additionally, households in the model cannot starve if their food needs are not met, nor are new babies born that require food. Households can be food insecure for the entire simulation run. This limits the outcome of the model, as it denies the dynamics of a fluctuating population.

9.2 REFLECTION ON THE USED APPROACH

The approach taken in this research is unique for a master thesis. It combines empirical data from a household survey and choice experiment with an Agent-Based Model. One critique often given to Agent-Based Model studies is the lack of empirical data for parametrisation of assumptions McKenzie Alexander (2007). Especially in the field of humanitarian aid, it is not easy to gather empirical data and it often takes too much time for a master thesis. The opportunity to join the data collection in the Forecast-based Financing for Food Security (F4S) project through 510 has made this possible.

Even so, using an Agent-Based Model does have its drawbacks. It has been criticized for insufficient comparability and reproducability of results and the lack of transparency in those results Lysenko and D'Souza (2008). Additionally, there is critique for the lack of validation possibilities Zhang and Vorobeychik (2019). When reflecting on the use of Agent-Based Modelling in this study, it could be said that the agent based modelling was not used to its full potential. Agent-based modelling is most interesting to explore interactions of agents and how their decisions influence each other. The main interaction of agents in this study is through the market. More interactions, like peer effects on decision making, and strategic behaviour could have been used.

10 CONCLUSIONS AND RECOMMENDATIONS

This research started by illustrating the complexities in dealing with drought response, especially in areas predominantly dependent upon agriculture. The objective of this study was to gain insight into the complex structure of the food system when affected by a drought and, using a modelling approach, explore the effects of different cash transfer policies on the food insecurity of households under various scenarios. Agent-Based Modelling has been combined with exploratory modelling techniques to achieve this objective.

This chapter is the conclusion of this study by first revisiting the sub-research questions. Next, the answer to the main research question will be provided. subsequently, recommendations will be made for decision makers at 510 specifically and possibly other humanitarian aid organisations. Lastly, there will be suggestions for further research.

10.1 ANSWERING RESEARCH SUB-QUESTIONS

This section will revisit the sub-questions posed in Chapter 3.2. Each sub-question is answered in accordance to the findings in this study.

Sub-question 1: What factors influence the food insecurity of households in Kenya during a drought?

The first sub-question was answered by looking at a case study of Isiolo county, the second lowest populated county in Kenya. A household survey and choice experiments was conducted at 186 households in Isiolo by members of the Kenya Red Cross Society - International Centre For Humanitarian Affairs (KRCS-ICHA). The survey identified three main food sources of respondents; own livestock production, purchase on the market and own crop production. Many respondents have experienced severe food insecurity in the past and a seasonal rainfall deficit or excess of rainfall is the most prominent cause for food insecurity.

Choice experiments were conducted to evaluate the preference of households regarding cash transfers. The results show that households prefer to have the cash transfer in one lump sum payment, rather than two payments. There has not been found any preference in the lead time of the transfer, but this could be due to to misunderstanding of the experiment.

The regression analysis shows that a higher education level, income from labour or from 'other' sources significantly increases spending of the cash transfer on food. Households with only a primary education level, income from labour, private business or 'other' spent less on mitigative measures. Households with only secondary education spent more on household expenditures, while households with tertiary education would spend significantly less.

Sub-question 2: How can household food insecurity due to droughts in Kenya and the intervention of direct cash transfers be conceptualized and formalized in terms of policies, uncertainties and Key performance indicators?

The second sub-question was answered in the literature review and conceptualisation presented in Chapters 2 and 5. The aim of this sub-question was twofold. Firstly, it was to transfer the factors and relations found in literature, survey results and choice experiments, into a conceptual model. Secondly, it aimed to formalize policies, uncertainties and Key performance indicators for this study.

The identified factors were used to build a conceptual model of the system of food insecurity due to drought. A causal Loop Diagram (CLD) was created to provide insight into the complex socio-technical system and better understand the structures causing patterns of behaviour. The agent types and their interactions were mapped in a UML-Diagram. After identifying the system and agents, as well as their behaviours, relationships and interactions, these concepts were formalised. Next the decision making process of households was presented.

Next, the XLRM framework was used to organize information relevant to decision making challenges under conditions of uncertainty. This defined the KPIs and policy levers used in this research. Three KPIs used to evaluate the performance of the system are; household food insecurity, crop stock at the local market and capital of households. The main policy levers are payment type and lead time. The policy interventions have been separated in two different policy strategies; (1) 'As Soon As Possible' (ASAP), characterised by long lead times and mainly one lump sum payments; and (2) 'Careful consideration', characterised by short lead times and two time payments.

Sub-question 3: How can the household food insecurity be implemented in an Agent-Based Model?

The model provided in this study was built with Mesa, a Python-based open-source platform created for building, analyzing and visualizing Agent-Based Models. As a Python-based platform, Mesa has the added benefit of using data analysis tools for input and output data, without having to convert into a different programming language.

The model runs in discrete time steps in which each time step represents one week. When being activated, agents execute their agent-step sequentially, not simultaneously. This means the agent will carry out the functions programmed in the agent-step one after another in the order that they are presented. A complete model run contains 108 steps or 4 years in total.

Different sources have been used to for parametrisation of model variables. This included; the household survey and choice experiments conducted in Isiolo; literature regarding food insecurity and drought, as well as information provided by 510; and data gathered from open data sources to get values for the historical food price of maize in Isiolo ((WFP - World Food Programme, 2021)) and the precipitation in the area (CHIRPS data (Funk et al., 2015)). Assumptions filled the gaps in these sources. A user interface was created to visualise the model and make it interactive. The user interface is meant as an intuitive approach to gather insight in the behaviour of the model. Verification has been performed continuously during the model building process to constantly assure that all parts of the model worked as expected.

Sub-question 4: What is the effect of policy interventions on the household food security in Isiolo County in Kenya?

For this sub-question experiments were performed to gain insight in the effect of the policy levers on the KPIs in comparison to the base model. The EMA Workbench was used to analyse the effect of the policy interventions.

The base model shows that, without any drought, there are hardly any households that become food insecure. When drought occurs there is a peak in household food insecurity every year just before the harvest season. In the moderate drought scenario about 50% of households become food insecure each year, while this is close to 100% in the severe scenario. In a moderate drought scenario the average capital of working households drops when a drought occurs, while in a severe scenario the average capital increases. Without any drought, the local market will be balanced and will not run out of stock. When a drought happens, the market stock quickly runs out in both drought scenarios.

Food insecurity

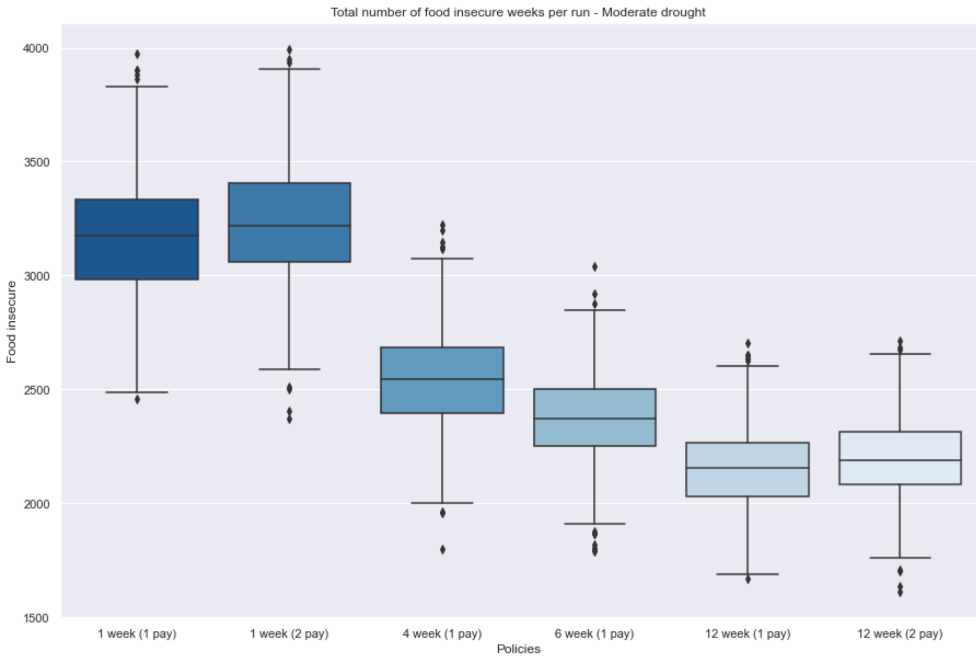


Figure 10.1: Effect Lead Time on Total weeks food insecurity - Moderate drought

The only policy leaver that has a significant impact on household food insecurity is the lead time. A longer lead time leads to less total food insecure weeks, as can be seen in 10.1. When comparing a 1 week lead time and 12 weeks lead time, the 12 week lead time causes a 45% decrease of total food insecure weeks. The policy levers do not seem to affect the average capital or market stock in a significant way.

Sub-question 5: How can the outcomes of this study be generalized to other drought crises?

Model validation was done to check if the model behaviour is realistic compared to the real world and if the model is adequate for the goal set at the start of this study. Modelling decisions and scoping choices have been discussed with experts in the humanitarian domain throughout this research to validate the model. Additionally, the results of the base scenarios with drought were compared to results shown in previous studies. This comparison showed that modeled outcomes for both drought scenarios correlate to empirical findings.

Based on the validation and analysis, three statements are made that form the answer to the fifth sub-question. Firstly, if one were to generalise the effects of cash transfer policies one should know that all forms of cash transfer have a meaning full impact on household food insecurity, when used in the correct context. Secondly, one should be aware of the fact that cash transfers are not the correct humanitarian aid tool in every situation . There should always first be a market assessment to check if providing cash will really prevent households from becoming food insecure. Thirdly, one should know the importance of timing when considering cash transfers. Cash transfers have more impact if they are made well in advance of a drought disaster. When no early action has been taken and a community is suffering due to drought induced food insecurity, other aid alternatives could be more suited for the situation.

10.2 ANSWERING MAIN RESEARCH QUESTION

Answering the sub-questions of this research, has provided a way to answer the main research question. The main research question posed at the start of this research was:

"How can an Agent-Based Model be used to analyse the effect of different ex-ante cash transfer policies on the household food security in Kenya, as humanitarian anticipatory action to drought?"

Analysis of food insecurity factors in Isiolo and consulting literature and experts in the humanitarian field led to the construction of an agent-based on household food insecurity due to drought. This study combines empirical data from a household survey and choice experiment with an Agent-Based Model. Exploratory modelling was used to generate results over a large sample size of scenarios and analyse the results.

The results of the model study show that the only policy leaver having a significant impact on household food insecurity is the lead time of the cash transfer. A 12 week lead time causes a 45% decrease of total food insecure weeks compared to a 1 week lead time. When looking at the two different policy strategies, the results show that all cash transfer strategies lead to a large improvement. Taking any action will lead to a reduction in total weeks of household food insecurity by 129%. When choosing the careful consideration strategy, it would lead to an increase of 15 % in food insecure weeks compared to the As Soon As Possible strategy.

This study has shown that the system of household food insecurity is highly dependent on agent behaviour and interactions between agents. As mentioned before, Agent-Based Models can best be used for situations where you have a bottom-up approach in which interactions at the local level lead to the emergence of patterns at the macro-level. The model in this study has shown that ABM works to model households and the environment and analyse their decision-making behaviour. The method has shown to be well suited for integrating data from different sources and dealing with both qualitative and quantitative data.

The Agent-Based Model in this study has been used to model the behaviour of agents at a household level with a time step of one week. This level of detail made it possible to include household choices and the interaction of households in the market. Additionally, the fluctuating (weekly) behaviour of rainfall created realistic drought scenarios and provided the possibility to model the cash transfers as real life situations. The fact that the model is based on empirical data from the Isiolo survey and choice experiments makes the parametrisation more valid. Even though the model does not take into account the strategic behaviour of households, it has shown to be a useful tool in comparing the different types of cash transfers for the Isiolo region. This tool could be used in more case studies, when provided with different data for parametrisation.

10.3 SOCIETAL CONTRIBUTION AND RECOMMENDATIONS FOR RED CROSS

In light of the global climate change, droughts are predicted to occur more frequently and more severe. This will inevitably lead to more people, especially in rural development areas such as Isiolo, to suffer from food insecurity. Traditional food aid is a reactive tool and does not deal with the full complexity of food insecurity, but mainly serves as a last resort against famine. This study shows that early action can indeed reduce the risk of food insecurity. This is in line with the current humanitarian movement of going from reactive aid to a more anticipatory response.

As mentioned in Chapter 5.1, there are many actors involved in the decision making, when it comes to providing humanitarian aid in a drought disaster situation. First of all, there are many different humanitarian organisations. Each of these ultimately has the same goal, providing aid to people in need. However, they differ in their means and perspective on how to provide this aid. Not all actors have experience with cash transfers, and some might still have doubts on how to design these programs. Findings in this study and the F4S study can be used to convince these actors to invest in a cash transfer program. Sharing information is key in creating broad support for the idea of cash transfers. Second, the analysis showed that the Kenyan government already has existing cash transfer programs in place. These programs should be taken into account when considering cash transfers as humanitarian aid when early warning signs predict a drought. To do this, the Red Cross should collaborate with national and regional government when implementing a program. Third, it is important to understand that collaboration with local actors is key in creating a successful cash transfer program. These local actors have important information about the community and are the ones best capable of accessing their needs.

Based on the results of this study, four recommendations are made for Netherlands Red Cross - 510 and any other humanitarian aid organisations interested in these results.

1. Firstly, the results show that cash transfers can be a valuable tool to use in combating food insecurity caused by drought. However, timing is important when considering cash transfers. Cash transfers have more impact if they are made well in advance of a drought disaster. If there is a will to implement cash transfers more often, a procedure should be constructed with well defined lead times and forecast probabilities. Longer lead times do however come with more uncertainty. It will be harder to convince other actors of acting when the forecast probability is still low.

2. Secondly, not all household types have the same needs in different drought scenarios. The results of this study show that in a severe drought scenario working households become completely food insecure and need food aid, while the other types still have some degree of self sufficiency. In a moderate drought scenario the working households are least affected and almost none are in need of cash, while the pastoral and semi-pastoral households become dependent on a cash transfer. This is due to the fact that these households have limited income when their crops die out. These difference show that a cash transfer program should take into account the varying needs of the households types in different scenarios.

3. Thirdly, the future of food aid is not lost. Cash transfers may replace food aid as the dominant humanitarian response in the future, but will not completely replace it. The model simulations of a severe drought in this study have shown that cash transfers are not applicable in all situations. It is important to always perform an assessment of the local markets before considering providing cash transfers.

4. Last, it is important to recognise the multi-actor setting of cash transfers. Findings in this study and the F4S study can be used to convince other actors to invest time and resources in a cash transfer program. When doing this, the current cash transfer programs already in place by the Kenyan government should be taken into account. Additionally, it is important to understand that collaboration with local actors is key in creating a successful cash transfer program.

10.4 SCIENTIFIC CONTRIBUTION

This thesis addresses the existing academic knowledge gap regarding a lack of literature and insight in; (a) the behaviour of people in Kenya when provided with either ex-ante cash transfers as aid for drought. (b) Agent-Based Models that can analyse drought and take into account different dimensions of household food security. (c) Agent-Based Models that takes into account cash transfers and the effect on household food security.

The first part of this scientific knowledge gap (a) has been addressed by conducting a household survey and choice experiments. The survey and choice experiments have been analysed and the results provide insight in the preferences of households concerning the design of ex-ante cash transfers and how households would spend this money.

The second (b) and third (c) part of this scientific knowledge gap have been addressed by developing an Agent-Based Model. This model has been based on; the household survey and choice experiments conducted in Isiolo, literature regarding food insecurity and drought, as well as information provided by 510, and data gathered from open data sources to get values for the historical food price of maize in Isiolo and the precipitation in the area (CHIRPS data). The model provides insight in household food insecurity, crop stock at the local market and the capital of households and it has the ability to model different cash transfer designs.

Apart from these knowledge gaps, this research is unique due to the fact that it combines empirical field data on households perspectives with an Agent-Based Model. The empirical data has been used in the design of the conceptual and computational model, as well as in the parametrisation phase. This is a big contribution to the current scientific knowledge, as many studies do not use empirical data and solely have to rely on assumptions to create the model.

10.5 RECOMMENDATIONS FOR FUTURE RESEARCH

Based on insights gained from the model, critical assumptions or model limitations, several recommendations for future research will be made.

The first recommendation stems from the model limitation in the behaviour of household agents. Agents have no strategic behaviour with the goal of not becoming food insecure. This strategic behaviour could be modeled in timing the buying or selling of food based on favourable market prices. Cash transfers are often given at in a stage where the food price has not increased yet. Especially when there is a long lead time this could have a significant impact.

Second, future work is suggested to find a optimisation between cash transfer lead times and forecast probability. This suggestion addresses both the model limitation of not implementing forecast probabilities and the importance of lead times noted in this study. It is understandable that organisations providing aid for drought disasters want their money well spend. It would be interesting to study if there is a optimal lead time given certain forecast probability, where both the chance of aid being provided unnecessary and additional food insecure households are taken into account.

Third, further research is advised to compare cash transfers to other kinds of aid. This would satisfy the limitation of this research of not including food aid as a policy option for the base scenario.

Lastly, A model study is advised to refine the interventions modelled in this research. This could be done by adding a variable amount of cash for the cash transfer, using a combination of cash and food aid or to refine the early warning given to households. Especially the combination of different forms of aid could provide meaningful insight for humanitarian aid organisations.

BIBLIOGRAPHY

The Nobel Peace Prize for 2020, October 2020. URL <https://www.nobelprize.org/prizes/peace/2020/press-release/>.

T Abate, S Mugo, H De Groote, and MW Regassa. Maize in Kenya: Chance for Getting Back to Former Glory. *DT Maize (CIMMYT)*, 4(3):1–3, 2015.

Obi Anyadike. Drought in Africa leaves 45 million in need across 14 countries, June 2019. URL https://www.thenewhumanitarian.org/analysis/2019/06/10/drought-africa-2019-45-million-in-need.

Stefano Balbi and Carlo Giupponi. Agent-Based Modelling of Socio-Ecosystems: A Methodology for the Analysis of Adaptation to Climate Change. *International Journal of Agent Technologies and Systems*, 2(4):17–38, October 2010. ISSN 1943-0744, 1943-0752. doi: 10.4018/jats.2010100103. URL http://services.igi-global.com/resolvedoi/resolve.aspx?doi=10.4018/jats.2010100103.

Kamna S. Balhara, David M. Silvestri, W. Tyler Winders, Anand Selvam, Sean M. Kivlehan, Torben K. Becker, Adam C. Levine, and the Global Emergency Medicine Literature Review Group (GEMLR). Impact of nutrition interventions on pediatric mortality and nutrition outcomes in humanitarian emergencies: A systematic review. *Tropical Medicine & International Health*, 22(12):1464–1492, December 2017. ISSN 13602276. doi: 10.1111/tmi.12986. URL http://doi.wiley.com/10.1111/tmi.12986.

Christopher B. Barrett and Daniel G. Maxwell. *Food aid after fifty years: recasting its role*. Priorities in development economics. Routledge, London ; New York, 2005. ISBN 978-0-415-70124-2 978-0-415-70125-9.

Christopher B. Barrett, Michael R. Carter, and Munenobu Ikegami. Poverty Traps and Social Protection. *SSRN Electronic Journal*, 2008. ISSN 1556-5068. doi: 10.2139/ssrn.1141881. URL http://www.ssrn.com/abstract=1141881.

Sukaina Bharwani, Mike Bithell, Thomas E Downing, Mark New, Richard Washington, and Gina Ziervogel. Multi-agent modelling of climate outlooks and food security on a community garden scheme in Limpopo, South Africa. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 360(1463):2183–2194, November 2005. ISSN 0962-8436, 1471-2970. doi: 10.1098/rstb.2005.1742. URL https://royalsocietypublishing.org/doi/10.1098/rstb.2005.1742.

Calum Brown, Peter Alexander, Sascha Holzhauer, and Mark D. A. Rounsevell. Behavioral models of climate change adaptation and mitigation in land-based sectors: Behavioral models in land-based sectors. *Wiley Interdisciplinary Reviews: Climate Change*, 8(2):e448, March 2017. ISSN 17577780. doi: 10.1002/wcc.448. URL http://doi.wiley.com/10.1002/wcc.448.

Pasquale Cirillo and Mauro Gallegati. The Empirical Validation of an Agent-based Model. *Eastern Economic Journal*, 38(4):525–547, September 2012. ISSN 0094-5056, 1939-4632. doi: 10.1057/eej.2011.34. URL http://link.springer.com/10.1057/eej.2011.34.

L. Claessens, J.M. Antle, J.J. Stoorvogel, R.O. Valdivia, P.K. Thornton, and M. Herrero. A method for evaluating climate change adaptation strategies for small-scale farmers using survey, experimental and modeled data. *Agricultural Systems*, 111:85–95, September 2012. ISSN 0308521X. doi: 10.1016/j.agsy.2012.05.003. URL https://linkinghub.elsevier.com/retrieve/pii/S0308521X12000753.

Liette Connolly-Boutin and Barry Smit. Climate change, food security, and livelihoods in sub-Saharan Africa. *Regional Environmental Change*, 16(2):385–399, February 2016. ISSN 1436-3798, 1436-378X. doi: 10.1007/s10113-015-0761-x. URL http://link.springer.com/10.1007/s10113-015-0761-x.

County Governmant of Isiolo. ISIOLO COUNTY INTEGRATED DEVELOPMENT PLAN, CIDP 2018-2022. Technical report, March 2018.

Yves Croissant. Estimation of Random Utility Models in *R* : The **mlogit** Package. *Journal of Statistical Software*, 95(11), 2020a. ISSN 1548-7660. doi: 10.18637/jss.v095.i11. URL http://www.jstatsoft.org/v95/i11/.

Yves Croissant. *mlogit: Multinomial Logit Models. R package version 1.1-0.* 2020b.

Kenya Red Cross. Drought Emergency Cash Transfer Response 2016–2017 Real Time Evaluation Report. 2017.

Koen H. van Dam, Igor Nikolic, and Zofia Lukszo, editors. *Agent-based modelling of socio-technical systems*. Number 9 in Agent-based social systems. Springer, Dordrecht ; New York, 2013. ISBN 978-94-007-4932-0. OCLC: ocn796762923.

Brian J. Dermody, Murugesu Sivapalan, Elke Stehfest, Detlef P. van Vuuren, Martin J. Wassen, Marc F. P. Bierkens, and Stefan C. Dekker. A framework for modelling the complexities of food andwater security under globalisation. preprint, Management of the Earth system: sustainability science, April 2017. URL https://esd.copernicus.org/preprints/esd-2017-38/esd-2017-38.pdf.

Deng Ding, David Bennett, and Silvia Secchi. Investigating Impacts of Alternative Crop Market Scenarios on Land Use Change with an Agent-Based Model. *Land*, 4(4):1110–1137, November 2015. ISSN 2073-445X. doi: 10.3390/land4041110. URL http://www.mdpi.com/2073-445X/4/4/1110.

Samantha Dobbie and Stefano Balbi. Design of an Empirical Agent-Based Model to Explore Rural Household Food Security Within a Developing Country Context. In Wander Jager, Rineke Verbrugge, Andreas Flache, Gert de Roo, Lex Hoogduin, and Charlotte Hemelrijk, editors, *Advances in Social Simulation 2015*, volume 528, pages 81–94. Springer International

Publishing, Cham, 2017. ISBN 978-3-319-47252-2 978-3-319-47253-9. doi: 10.1007/978-3-319-47253-9_7. URL http://link.springer.com/10.1007/978-3-319-47253-9_7. Series Title: Advances in Intelligent Systems and Computing.

Samantha Dobbie, Kate Schreckenberg, James G Dyke, Marije Schaafsma, and Stefano Balbi. Agent-Based Modelling to Assess Community Food Security and Sustainable Livelihoods. *Journal of Artificial Societies and Social Simulation*, 21(1):9, 2018. ISSN 1460-7425. doi: 10.18564/jasss.3639. URL http://jasss.soc.surrey.ac.uk/21/1/9.html.

Bert Enserink, Leon Hermans, and Jan Kwakkel. *Policy analysis of multi-actor systems*. Lemma, The Hague, 2010. ISBN 978-90-5931-538-9. OCLC: 901209596.

Joshua M Epstein. Agent-based computational models and generative social science. *Complexity*, 4(5):41–60, 1999. Publisher: Wiley Online Library.

Joshua M. Epstein and Robert L. Axtell. *Growing artificial societies: social science from the bottom up ; a product of the 2050 project, a collaborative effort of the Brookings Institution, the Santa Fe Institute, and the World Resources Institute*. Complex adaptive systems. Brookings Inst. Press [u.a.], Washington, DC, 1996. ISBN 978-0-262-05053-1 978-0-8157-2468-1 978-0-262-55026-0 978-0-262-55025-3 978-0-8157-2467-4. OCLC: 833038153.

FAO. *The state of food insecurity in the world 2001*. FAO, Rome, 2001. ISBN 978-92-5-104628-9. OCLC: 476029744.

FAO, IFAD, UNICEF, WPF, and WHO. *The State of Food Security and Nutrition in the World 2020: Transforming food systems for affordable healthy diets*. FAO, Rome, 2020. ISBN 978-92-5-132901-6. doi: 10.4060/ca9692en. URL http://www.fao.org/documents/card/en/c/ca9692en.

Bridget Fenn, Tim Colbourn, Carmel Dolan, Silke Pietzsch, Murtaza Sangrasi, and Jeremy Shoham. Impact evaluation of different cash-based intervention modalities on child and maternal nutritional status in Sindh Province, Pakistan, at 6 mo and at 1 y: A cluster randomised controlled trial. *PLOS Medicine*, 14(5):e1002305, May 2017. ISSN 1549-1676. doi: 10.1371/journal.pmed.1002305. URL https://dx.plos.org/10.1371/journal.pmed.1002305.

Chris Funk, Pete Peterson, Martin Landsfeld, Diego Pedreros, James Verdin, Shraddhanand Shukla, Gregory Husak, James Rowland, Laura Harrison, Andrew Hoell, and Joel Michaelsen. The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific Data*, 2(1):150066, December 2015. ISSN 2052-4463. doi: 10.1038/sdata.2015.66. URL http://www.nature.com/articles/sdata201566.

Gallup. Food insecurity: share of citizens without access to money to buy food in Kenya from 2010 to 2019, 2019. URL https://www.statista.com/statistics/1107617/food-insecurity-kenya/.

Marito Garcia and Charity M. T. Moore. *The Cash Dividend: The Rise of Cash Transfer Programs in Sub-Saharan Africa*. The World Bank, February 2012. ISBN 978-0-8213-8897-6 978-0-8213-8898-3. doi: 10.1596/978-0-8213-8897-6. URL http://elibrary.worldbank.org/doi/book/10.1596/978-0-8213-8897-6.

S. Godfrey and F.A. Tunhuma. The Climate Crisis: Climate Change Impacts, Trends and Vulnerabilities of Children in Sub Sahara Africa. Technical report, United Nations Children's Fund Eastern and Southern Africa Regional Office, Nairobi, September 2020.

Gabriela Guimarães Nobre, Frank Davenport, Konstantinos Bischiniotis, Ted Veldkamp, Brenden Jongman, Christopher C. Funk, Gregory Husak, Philip J. Ward, and Jeroen C.J.H. Aerts. Financing agricultural drought risk through ex-ante cash transfers. *Science of The Total Environment*, 653:523–535, February 2019. ISSN 00489697. doi: 10.1016/j.scitotenv.2018.10.406. URL https://linkinghub.elsevier.com/retrieve/pii/S0048969718343067.

Gabriela Guimarães Nobre, Marc van den Homberg, Halima Saado, and Frank Davenport. Forecast-based Financing for Food Security. Technical Report #1259359, The Disaster Risk Financing Challenge Fund, May 2021.

Celia A. Harvey, Zo Lalaina Rakotobe, Nalini S. Rao, Radhika Dave, Hery Razafimahatratra, Rivo Hasinandrianina Rabarijohn, Haingo Rajaofara, and James L. MacKinnon. Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 369(1639):20130089, April 2014. ISSN 0962-8436, 1471-2970. doi: 10.1098/rstb.2013.0089. URL https://royalsocietypublishing.org/doi/10.1098/rstb.2013.0089.

Paul Harvey, Karen Proudlock, Edward J Clay, Barry Riley, and Susanne Jaspars. *Food aid and food assistance in emergency and transitional contexts: A review of current thinking*. Humanitarian Policy Group, Overseas Development Institute, 2010.

Abby Haynes, Kate Garvey, Seanna Davidson, and Andrew Milat. What Can Policy-Makers Get Out of Systems Thinking? Policy Partners' Experiences of a Systems-Focused Research Collaboration in Preventive Health. *International Journal of Health Policy and Management*, 9(2):65–76, November 2019. ISSN 2322-5939. doi: 10.15171/ijhpm.2019.86. URL http://www.ijhpm.com/article_3687.html.

John H Holland. *Hidden order: How adaptation builds complexity*. Addison Wesley Longman Publishing Co., Inc., 1996.

HSNP. Hunger Safety Net Programme, 2021. URL https://www.hsnp.or.ke/index.php/as/objectives.

Robert Huber, Martha Bakker, Alfons Balmann, Thomas Berger, Mike Bithell, Calum Brown, Adrienne Grêt-Regamey, Hang Xiong, Quang Bao Le, Gabriele Mack, Patrick Meyfroidt, James Millington, Birgit Müller, J. Gareth

Polhill, Zhanli Sun, Roman Seidl, Christian Troost, and Robert Finger. Representation of decision-making in European agricultural agent-based models. *Agricultural Systems*, 167:143–160, November 2018. ISSN 0308521X. doi: 10.1016/j.agsy.2018.09.007. URL https://linkinghub.elsevier.com/retrieve/pii/S0308521X17309228.

Chinwe Ifejika Speranza, Boniface Kiteme, and Urs Wiesmann. Droughts and famines: The underlying factors and the causal links among agro-pastoral households in semi-arid Makueni district, Kenya. *Global Environmental Change*, 18(1):220–233, February 2008. ISSN 09593780. doi: 10.1016/j.gloenvcha.2007.05.001. URL https://linkinghub.elsevier.com/retrieve/pii/S0959378007000362.

IFRC. Climatological hazards: droughts, 2021a. URL https://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/definition-of-hazard/drought/#:~:text=In%20general%2C%20the%20Red%20Cross,to%20preserve%20and%20restore%20livelihoods.

IFRC. The International Federation of Red Cross and Red Crescent Societies (IFRC), 2021b. URL https://www.ifrc.org/en/who-we-are/the-movement/ifrc/.

John Ingram. A food systems approach to researching food security and its interactions with global environmental change. *Food Security*, 3(4):417–431, December 2011. ISSN 1876-4517, 1876-4525. doi: 10.1007/s12571-011-0149-9. URL http://link.springer.com/10.1007/s12571-011-0149-9.

IPCC. *Climate change 2007: contribution of ... to the fourth assessment report of the Intergovernmental Panel on Climate Change. 4: Synthesis report: [a report of the Intergovernmental Panel on Climate Change]*. IPCC, Geneva, 2007. ISBN 978-92-9169-122-7. OCLC: 934551357.

Isiolo County Government. About Us – County Government of Isiolo. URL https://isiolo.go.ke/about-us-2/.

ISSAfrica. Violent extremists find fertile ground in Kenya's Isiolo County, October 2020. URL https://issafrica.org/iss-today/violent-extremists-find-fertile-ground-in-kenyas-isiolo-county.

Guy Jackson. The influence of emergency food aid on the causal disaster vulnerability of Indigenous food systems. *Agriculture and Human Values*, 37(3):761–777, September 2020. ISSN 0889-048X, 1572-8366. doi: 10.1007/s10460-019-10006-7. URL http://link.springer.com/10.1007/s10460-019-10006-7.

Samireh Jalali and Claes Wohlin. Systematic literature studies: database searches vs. backward snowballing. In *Proceedings of the ACM-IEEE international symposium on Empirical software engineering and measurement - ESEM '12*, page 29, Lund, Sweden, 2012. ACM Press. ISBN 978-1-4503-1056-7. doi: 10.1145/2372251.2372257. URL http://dl.acm.org/citation.cfm?doid=2372251.2372257.

Marco A Janssen and Elinor Ostrom. Empirically based, agent-based models. *Ecology and society*, 11(2), 2006. Publisher: JSTOR.

Kenya National Bureau of Statistics, editor. *2019 Kenya population and housing census*. Kenya National Bureau of Statistics, Nairobi, 2019. ISBN 978-9966-102-09-6 978-9966-102-11-9.

Craig W Kirkwood. System dynamics methods. *College of Business Arizona State University USA*, 1998.

Jan H. Kwakkel. The Exploratory Modeling Workbench: An open source toolkit for exploratory modeling, scenario discovery, and (multi-objective) robust decision making. *Environmental Modelling & Software*, 96:239–250, October 2017. ISSN 13648152. doi: 10.1016/j.envsoft.2017.06.054. URL https://linkinghub.elsevier.com/retrieve/pii/S1364815217301251.

Jan H. Kwakkel, Marjolijn Haasnoot, and Warren E. Walker. Developing dynamic adaptive policy pathways: a computer-assisted approach for developing adaptive strategies for a deeply uncertain world. *Climatic Change*, 132(3):373–386, October 2015. ISSN 0165-0009, 1573-1480. doi: 10.1007/s10584-014-1210-4. URL http://link.springer.com/10.1007/s10584-014-1210-4.

Robert J. Lempert, Steven W. Popper, and Steven C. Bankes. *Shaping the next one hundred years: new methods for quantitative, long-term policy analysis*. RAND, Santa Monica, CA, 2003. ISBN 978-0-8330-3275-1.

Benjamin Lloyd-Hughes. The impracticality of a universal drought definition. *Theoretical and Applied Climatology*, 117(3-4):607–611, August 2014. ISSN 0177-798X, 1434-4483. doi: 10.1007/s00704-013-1025-7. URL http://link.springer.com/10.1007/s00704-013-1025-7.

Mikola Lysenko and Roshan M. D'Souza. A Framework for Megascale Agent Based Model Simulations on Graphics Processing Units. *Journal of Artificial Societies and Social Simulation*, 11(4):10, 2008. ISSN 1460-7425. URL http://jasss.soc.surrey.ac.uk/11/4/10.html.

Robin B. Matthews, Nigel G. Gilbert, Alan Roach, J. Gary Polhill, and Nick M. Gotts. Agent-based land-use models: a review of applications. *Landscape Ecology*, 22(10):1447–1459, November 2007. ISSN 0921-2973, 1572-9761. doi: 10.1007/s10980-007-9135-1. URL http://link.springer.com/10.1007/s10980-007-9135-1.

S.J. Maxwell and H.W. Singer. Food aid to developing countries: A survey. *World Development*, 7(3):225–246, March 1979. ISSN 0305750X. doi: 10.1016/0305-750X(79)90054-8. URL https://linkinghub.elsevier.com/retrieve/pii/0305750X79900548.

Daniel McFadden. The measurement of urban travel demand. *Journal of Public Economics*, 3(4):303–328, November 1974. ISSN 00472727. doi: 10.1016/0047-2727(74)90003-6. URL https://linkinghub.elsevier.com/retrieve/pii/0047272774900036.

J. McKenzie Alexander. *The Structural Evolution of Morality*. Cambridge University Press, Cambridge, 2007. ISBN 978-0-511-55099-7 978-0-521-87032-0 978-0-521-15269-3. doi: 10.1017/CBO9780511550997. URL https://www.cambridge.org/core/product/identifier/9780511550997/type/book.

James Millington, Hang Xiong, Steve Peterson, and Jeremy Woods. Integrating Modelling Approaches for Understanding Telecoupling: Global Food Trade and Local Land Use. *Land*, 6(3):56, August 2017. ISSN 2073-445X. doi: 10.3390/land6030056. URL http://www.mdpi.com/2073-445X/6/3/56.

Lutta Muhammad, Domisiano Mwabu, Richard Mulwa, WM Mwangi, AS Langyintuo, and Roberto La Rovere. Characterization of maize producing households in Machakos and Makueni Districts in Kenya. 2010. Publisher: KARI.

Birgit Müller, Falk Hoffmann, Thomas Heckelei, Christoph Müller, Thomas W. Hertel, J. Gareth Polhill, Mark van Wijk, Thom Achterbosch, Peter Alexander, Calum Brown, David Kreuer, Frank Ewert, Jiaqi Ge, James D.A. Millington, Ralf Seppelt, Peter H. Verburg, and Heidi Webber. Modelling food security: Bridging the gap between the micro and the macro scale. *Global Environmental Change*, 63:102085, July 2020. ISSN 09593780. doi: 10.1016/j.gloenvcha.2020.102085. URL https://linkinghub.elsevier.com/retrieve/pii/S0959378019307277.

Christoph Müller, Joshua Elliott, James Chryssanthacopoulos, Almut Arneth, Juraj Balkovic, Philippe Ciais, Delphine Deryng, Christian Folberth, Michael Glotter, Steven Hoek, Toshichika Iizumi, Roberto C. Izaurralde, Curtis Jones, Nikolay Khabarov, Peter Lawrence, Wenfeng Liu, Stefan Olin, Thomas A. M. Pugh, Deepak K. Ray, Ashwan Reddy, Cynthia Rosenzweig, Alex C. Ruane, Gen Sakurai, Erwin Schmid, Rastislav Skalsky, Carol X. Song, Xuhui Wang, Allard de Wit, and Hong Yang. Global gridded crop model evaluation: benchmarking, skills, deficiencies and implications. *Geoscientific Model Development*, 10(4):1403–1422, April 2017. ISSN 1991-9603. doi: 10.5194/gmd-10-1403-2017. URL https://gmd.copernicus.org/articles/10/1403/2017/.

M. E. J. Newman. The Structure and Function of Complex Networks. *SIAM Review*, 45(2):167–256, January 2003. ISSN 0036-1445, 1095-7200. doi: 10.1137/S003614450342480. URL http://epubs.siam.org/doi/10.1137/S003614450342480.

I Nikolic, Z. Lukszo, E.J.L. Chappin, M.E. Warnier, J.H. Kwakkel, P.W.G. Bots, and F.M. Brazier. Guide for Good Modelling Practice for policy support. Technical report, Delft University of Technology, 2019. URL http://resolver.tudelft.nl/uuid:cbe7a9cb-6585-4dd5-a34b-0d3507d4f188.

OCHA. Horn of Africa Drought Crisis Situation Report No. 5. Technical report, July 2011. URL https://reliefweb.int/sites/reliefweb.int/files/resources/Full_report_170.pdf.

ODI and CGD. Doing cash differently: How cash transfers can transform humanitarian aid. Technical report, Overseas Development Institute, September 2015. URL https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/9828.pdf.

Derek T. Robinson, Daniel G. Brown, Dawn C. Parker, Pepijn Schreinemachers, Marco A. Janssen, Marco Huigen, Heidi Wittmer, Nick Gotts, Panomsak Promburom, Elena Irwin, Thomas Berger, Franz Gatzweiler, and Cécile Barnaud. Comparison of empirical methods for building agent-based models in land use science. *Journal of Land Use Science*, 2(1):31–55, April 2007. ISSN 1747-423X, 1747-4248. doi: 10.1080/17474230701201349. URL http://www.tandfonline.com/doi/abs/10.1080/17474230701201349.

Robert G. Sargent. Verification and validation of simulation models. In *Proceedings of the 2010 Winter Simulation Conference*, pages 166–183, 2010. doi: 10.1109/WSC.2010.5679166.

Benjamin Schwab. In the Form of Bread? A Randomized Comparison of Cash and Food Transfers in Yemen. *American Journal of Agricultural Economics*, 102(1):91–113, January 2020. ISSN 0002-9092, 1467-8276. doi: 10.1093/ajae/aaz048. URL https://onlinelibrary.wiley.com/doi/abs/10.1093/ajae/aaz048.

Joachim Schöpfel. Towards a Prague definition of grey literature. In *Twelfth International Conference on Grey Literature: Transparency in Grey Literature. Grey Tech Approaches to High Tech Issues. Prague, 6-7 December 2010*, pages 11–26, 2010.

Ted Spence. The art of printf() debugging, January 2020. URL https://tedspence.com/the-art-of-printf-debugging-7d5274d6af44.

Emma C. Stephens, Andrew D. Jones, and David Parsons. Agricultural systems research and global food security in the 21st century: An overview and roadmap for future opportunities. *Agricultural Systems*, 163: 1–6, June 2018. ISSN 0308521X. doi: 10.1016/j.agsy.2017.01.011. URL https://linkinghub.elsevier.com/retrieve/pii/S0308521X16305182.

P.K Thornton and M Herrero. Integrated crop–livestock simulation models for scenario analysis and impact assessment. *Agricultural Systems*, 70(2-3):581–602, November 2001. ISSN 0308521X. doi: 10.1016/S0308-521X(01)00060-9. URL https://linkinghub.elsevier.com/retrieve/pii/S0308521X01000609.

UNDP. The impact of cash transfers on local economies. *Policy Focus*, 11: 1–28, 2015.

F van Tongeren. Global models applied to agricultural and trade policies: a review and assessment. *Agricultural Economics*, 26(2):149–172, November 2001. ISSN 01695150. doi: 10.1016/S0169-5150(00)00109-2. URL http://linkinghub.elsevier.com/retrieve/pii/S0169515000001092.

M.T. van Wijk, M.C. Rufino, D. Enahoro, D. Parsons, S. Silvestri, R.O. Valdivia, and M. Herrero. Farm household models to analyse food security in a changing climate: A review. *Global Food Security*, 3(2):77–84, July 2014. ISSN 22119124. doi: 10.1016/j.gfs.2014.05.001. URL https://linkinghub.elsevier.com/retrieve/pii/S2211912414000133.

Joost M. Vervoort, Philip K. Thornton, Patti Kristjanson, Wiebke Förch, Polly J. Ericksen, Kasper Kok, John S.I. Ingram, Mario Herrero, Amanda Palazzo, Ariella E.S. Helfgott, Angela Wilkinson, Petr Havlík, Daniel Mason-D'Croz, and Chris Jost. Challenges to scenario-guided adaptive action on food security under climate change. *Global Environmental Change*, 28:383–394, September 2014. ISSN 09593780. doi: 10.1016/j.gloenvcha.2014.03.001. URL https://linkinghub.elsevier.com/retrieve/pii/S0959378014000387.

Espen Villanger. Cash Transfers Contributing to Social Protection: A Review of Evaluation Findings. *Forum for Development Studies*, 35(2):221–256, December 2008. ISSN 0803-9410, 1891-1765. doi: 10.1080/08039410.2008.9666410. URL http://www.tandfonline.com/doi/abs/10.1080/08039410.2008.9666410.

M. Mitchell Waldrop. *Complexity: the emerging science at the edge of order and chaos*. Simon & Schuster, New York, 1992. ISBN 978-0-671-76789-1.

Marthe Wens, J. Michael Johnson, Cecilia Zagaria, and Ted I. E. Veldkamp. Integrating human behavior dynamics into drought risk assessment—A sociohydrologic, agent-based approach. *Wiley Interdisciplinary Reviews: Water*, page e1345, April 2019. ISSN 2049-1948, 2049-1948. doi: 10.1002/wat2.1345. URL https://onlinelibrary.wiley.com/doi/abs/10.1002/wat2.1345.

Marthe Wens, Ted I. E. Veldkamp, Moses Mwangi, J. Michael Johnson, Ralph Lasage, Toon Haer, and Jeroen C. J. H. Aerts. Simulating Small-Scale Agricultural Adaptation Decisions in Response to Drought Risk: An Empirical Agent-Based Model for Semi-Arid Kenya. *Frontiers in Water*, 2:15, July 2020. ISSN 2624-9375. doi: 10.3389/frwa.2020.00015. URL https://www.frontiersin.org/article/10.3389/frwa.2020.00015/full.

WFP - World Food Programme. Kenya - Food Prices, May 2021. URL https://data.humdata.org/dataset/wfp-food-prices-for-kenya.

Uri Wilenski. NetLogo (and NetLogo User Manual), 1999. URL http://ccl.northwestern.edu/netlogo/.

Donald A Wilwite. Drought as a natural hazard: concepts and definitions. *Published in Drought: A Global Assessment*, Vol. I:3–18, 2000.

World Bank. Who we are, 2021. URL https://www.worldbank.org/en/who-we-are.

World Food Programme. Mission, 2021. URL https://www.wfp.org/overview.

Haifeng Zhang and Yevgeniy Vorobeychik. Empirically grounded agent-based models of innovation diffusion: a critical review. *Artificial Intelligence Review*, 52(1):707–741, June 2019. ISSN 0269-2821, 1573-7462. doi: 10.1007/s10462-017-9577-z. URL http://link.springer.com/10.1007/s10462-017-9577-z.

A HOUSEHOLD SURVEY ANALYSIS

A.1 DATA CLEANING

The process of cleaning up the household data will be explained in this section. Most of this process was done in Python, some of it later in R. The Jupiter Notebook and R code can be found in the GitHub repository. These operations were done to clean up the data:

- The total data set contained 186 rows (one row for each respondent) and 610 columns. This dataframe was first converted into a long format, with each round of the choice experiment on a new line.
- All records where the entered value for the round did not match the corresponding round were removed. This choice has been made, as it is unclear what went wrong in these instances.
- All records where the entered type of payment did not correspond to the type of payment on the scenario card were removed. In these cases many things could have gone wrong i.a.; the wrong round or block color was entered, the payment type was misread from the card, the wrong cards were used or the wrong scenario was entered. As it is impossible to determine, all false records were removed.
- The expenditures in the choice experiment where in many cases not carried out correctly, the values did not add up to 10. For all these entries the values are taken into account as weights, taking the proportions instead of the total sum.
- Columns/questions not in the scope of this study were removed.
- Values have been converted for the choice experiments. String values for 'Education', 'Source_income' have been grouped and dummy variables were created.
- Columns were added for the choice model.

A.2 PLOTS

This section shows additional plots of the household survey.

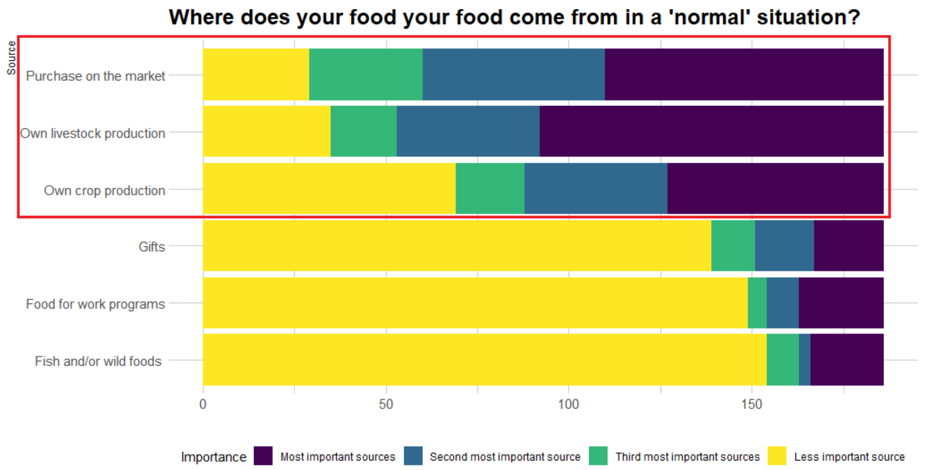


Figure A.1: Main food source

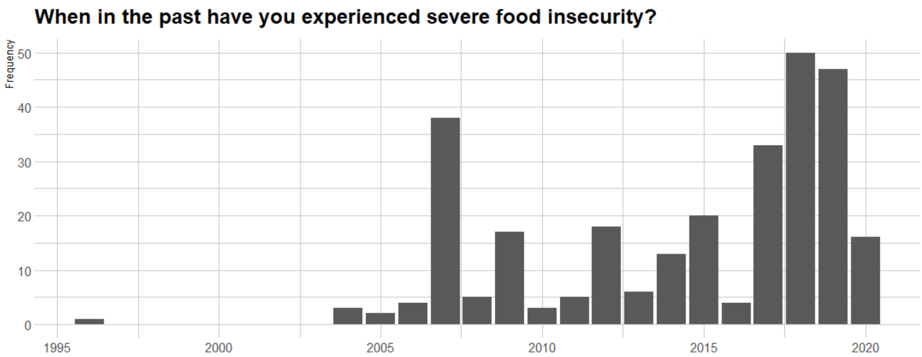


Figure A.2: Past years of food insecurity

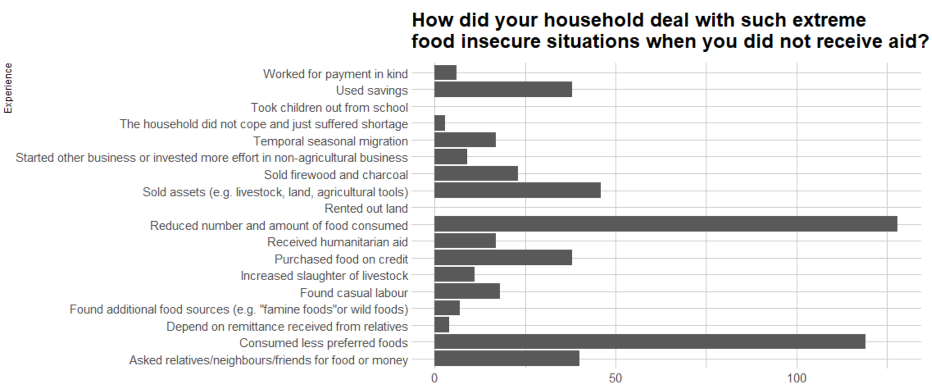


Figure A.3: Main food source

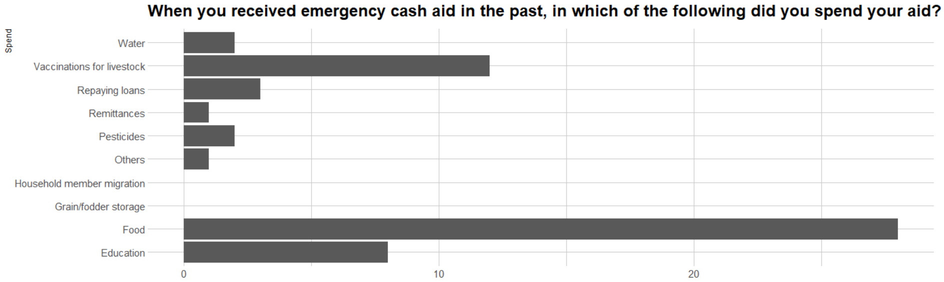


Figure A.4: How cash aid has been spend

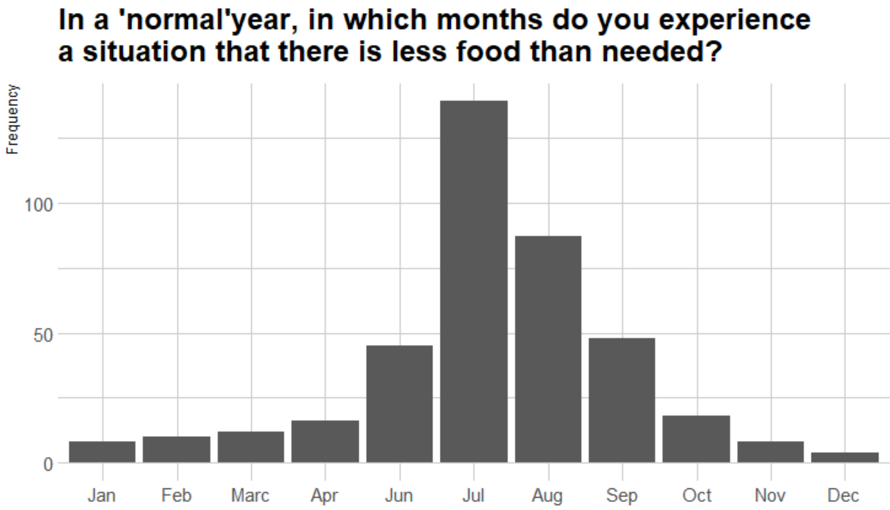


Figure A.5: Months with less food than needed in a 'normal year'

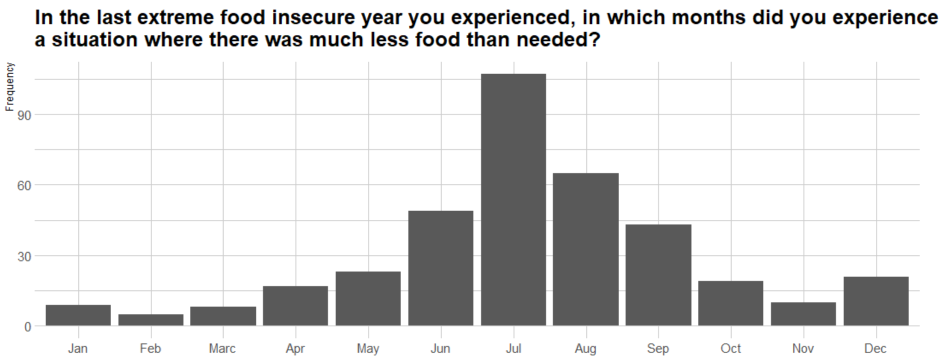


Figure A.6: Months with less food than needed in extreme year

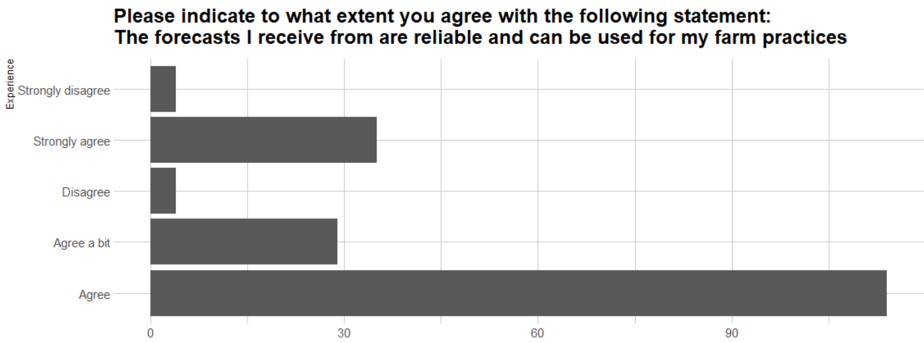


Figure A.7: Reliability of forecasts

A.3 CHOICE EXPERIMENT

This section shows the 'raw' data on the outcomes of the choice experiments. First it shows the outcomes of the mixed logit model, that accounts for correlation. This is the model used in this study. Additionally, the outcomes for the basic mixed logit model are shown. This model has not been used, as the model that accounts for correlation was a better fit. However, the results only vary slightly. The main results and explanation can be found in Chapter 4.3.3.

```
Call:
mlogit(formula = choice ~ LD + Type | 0, data = mlogitdata, rpar = c(LD = "n",
    Type = "n"), R = 1000, correlation = TRUE, panel = TRUE,
    Halton = NA)

Frequencies of alternatives:choice
scenario A scenario B
   0.76045    0.23955

bfgs method
17 iterations, 0h:0m:31s
g'(-H)^-1g = 3.56E-08
gradient close to zero

Coefficients :
               Estimate Std. Error z-value Pr(>|z|)
LD             0.067157    0.141344  0.4751 0.634694
Type           0.800844    0.294856  2.7161 0.006607 **
chol.LD:LD     0.029348    0.631370  0.0465 0.962925
chol.LD:Type   0.762541    4.874649  0.1564 0.875694
chol.Type:Type 1.624900    2.299996  0.7065 0.479890

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Log-Likelihood: -239.51

random coefficients
     Min.     1st Qu.     Median       Mean    3rd Qu. Max.
LD   -Inf  0.04736172 0.06715694 0.06715694 0.08695216  Inf
Type -Inf -0.40981707 0.80084400 0.80084400 2.01150506  Inf
```

Figure A.8: mlogit outcome for mixed logit model, accounting for correlation.

```
Call:
mlogit(formula = Choice ~ LD + Type | 0, data = mlogitdata, rpar = c(LD = "n",
    Type = "n"), R = 1000, panel = TRUE, Halton = NA)

Frequencies of alternatives:choice
scenario A scenario B
   0.76045    0.23955

bfgs method
10 iterations, 0h:0m:23s
g'(-H)^-1g = 9.05E-08
gradient close to zero

Coefficients :
          Estimate Std. Error z-value Pr(>|z|)
LD       0.0676058  0.1417570  0.4769 0.633424
Type     0.7980298  0.2941785  2.7127 0.006673 **
sd.LD    0.0049467  3.8349819  0.0013 0.998971
sd.Type 1.7775278  0.7420417  2.3955 0.016600 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Log-Likelihood: -239.57

random coefficients
     Min.     1st Qu.     Median       Mean    3rd Qu. Max.
LD   -Inf  0.06426928 0.06760575 0.06760575 0.07094222  Inf
Type -Inf -0.40089449 0.79802982 0.79802982 1.99695413  Inf
```

Figure A.9: mlogit outcome for basic mixed logit model.

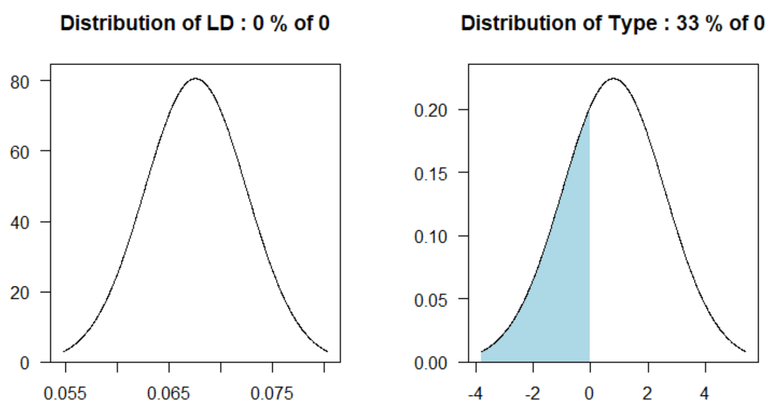


Figure A.10: Choice distribution

A.3.1 Regression analysis

This section shows the 'raw' data on the outcomes of the regression analysis. First, the regression analysis of the food expenditures are shown. Second, the mitigative expenditure regression analysis is given and third the analysis of the household expenses. These results show both the significant and non-significant factors. The main results and explanation can be found in Chapter 4.3.4.

```
Call:
lm(formula = regdata$Food_expenditures ~ regdata$Type + regdata$HH_size +
    regdata$Education + regdata$Source_income + regdata$Income +
    regdata$Land_owned)

Residuals:
    Min      1Q  Median      3Q     Max
-6.2010 -3.2212 -0.6882  2.3817  7.4100

Coefficients:
                                               Estimate Std. Error t value Pr(>|t|)
(Intercept)                                     3.14920    0.80405   3.917 9.85e-05 ***
regdata$Type                                   -0.13407    0.26909  -0.498  0.61848
regdata$HH_size                                 0.01060    0.04409   0.240  0.81010
regdata$EducationPrimary                       -0.02912    0.29266  -0.099  0.92078
regdata$EducationSecondary                     -0.20918    0.52839  -0.396  0.69231
regdata$EducationTertiary                       5.36233    1.67132   3.208  0.00140 **
regdata$Source_incomeAgriculture Livestock keeping -0.48152    0.49204  -0.979  0.32811
regdata$Source_incomeLabour                     2.26839    0.73707   3.078  0.00217 **
regdata$Source_incomeOther                      2.28423    0.78666   2.904  0.00380 **
regdata$Source_incomePrivate business           1.11148    0.56890   1.954  0.05113 .
regdata$Income200 - 300 KSh                     0.07055    0.68244   0.103  0.91769
regdata$Income50 - 100 KSh                     -1.78650    0.98598  -1.812  0.07043 .
regdata$IncomeLess than 50 KSh                  0.57318    1.06207   0.540  0.58959
regdata$IncomeMore than 300 KSh                 0.73834    0.61163   1.207  0.22778
regdata$Land_owned                             -0.02840    0.04250  -0.668  0.50418
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 3.458 on 703 degrees of freedom
Multiple R-squared:  0.09786,	Adjusted R-squared:  0.07989
F-statistic: 5.447 on 14 and 703 DF,  p-value: 5.477e-10
```

Figure A.11: Regression analysis for Food Expenditures

```
Call:
lm(formula = regdata$Mitigative_expenditures ~ regdata$Type +
    regdata$HH_size + regdata$Education + regdata$Source_income +
    regdata$Income + regdata$Land_owned)

Residuals:
    Min      1Q  Median      3Q     Max
-5.4716 -1.9841 -0.3102  1.6448  8.1593

Coefficients:
                                               Estimate Std. Error t value Pr(>|t|)
(Intercept)                                     0.59193    0.60526   0.978 0.328424
regdata$Type                                    0.12050    0.20256   0.595 0.552100
regdata$HH_size                                 0.13195    0.03319   3.976 7.74e-05 ***
regdata$EducationPrimary                       -0.77334    0.22030  -3.510 0.000476 ***
regdata$EducationSecondary                      0.14464    0.39775   0.364 0.716232
regdata$EducationTertiary                       0.15072    1.25810   0.120 0.904678
regdata$Source_incomeAgriculture Livestock keeping  0.10897    0.37039   0.294 0.768699
regdata$Source_incomeLabour                    -1.68947    0.55484  -3.045 0.002414 **
regdata$Source_incomeOther                     -1.37168    0.59217  -2.316 0.020825 *
regdata$Source_incomePrivate business          -1.89097    0.42824  -4.416 1.17e-05 ***
regdata$Income200 - 300 KSh                     2.95848    0.51371   5.759 1.26e-08 ***
regdata$Income50 - 100 KSh                      2.61038    0.74221   3.517 0.000464 ***
regdata$IncomeLess than 50 KSh                 -0.55480    0.79949  -0.694 0.487950
regdata$IncomeMore than 300 KSh                 1.26484    0.46041   2.747 0.006165 **
regdata$Land_owned                              0.20025    0.03199   6.260 6.72e-10 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.603 on 703 degrees of freedom
Multiple R-squared:  0.2421,	Adjusted R-squared:  0.227
F-statistic: 16.04 on 14 and 703 DF,  p-value: < 2.2e-16
```

Figure A.12: Regression analysis for Mitigative Expenditures

```
Call:
lm(formula = regdata$Household_expenditures ~ regdata$Type +
    regdata$HH_size + regdata$Education + regdata$Source_income +
    regdata$Income + regdata$Land_owned)

Residuals:
    Min      1Q  Median      3Q     Max
-3.3641 -0.8697 -0.3801  0.9083  7.9148

Coefficients:
                                                   Estimate Std. Error t value Pr(>|t|)
(Intercept)                                         0.31851    0.35938   0.886 0.375777
regdata$Type                                       -0.19612    0.12027  -1.631 0.103411
regdata$HH_size                                     0.04499    0.01971   2.283 0.022726 *
regdata$EducationPrimary                           -0.24330    0.13081  -1.860 0.063308 .
regdata$EducationSecondary                          0.46408    0.23617   1.965 0.049806 *
regdata$EducationTertiary                          -2.21152    0.74702  -2.960 0.003175 **
regdata$Source_incomeAgriculture Livestock keeping  0.13897    0.21993   0.632 0.527656
regdata$Source_incomeLabour                        -0.42055    0.32945  -1.277 0.202183
regdata$Source_incomeOther                          1.19825    0.35161   3.408 0.000692 ***
regdata$Source_incomePrivate business               1.82058    0.25428   7.160 2.04e-12 ***
regdata$Income200 - 300 KSh                         1.28832    0.30503   4.224 2.72e-05 ***
regdata$Income50 - 100 KSh                          0.01092    0.44070   0.025 0.980235
regdata$IncomeLess than 50 KSh                      0.84677    0.47471   1.784 0.074895 .
regdata$IncomeMore than 300 KSh                     0.20560    0.27338   0.752 0.452260
regdata$Land_owned                                  0.02547    0.01900   1.341 0.180367
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.546 on 703 degrees of freedom
Multiple R-squared:  0.2149,    Adjusted R-squared:  0.1993
F-statistic: 13.75 on 14 and 703 DF,  p-value: < 2.2e-16
```

Figure A.13: Regression analysis for Household Expenditures.

B ASSUMPTIONS

A List of assumptions made throughout the modelling.

1. Households will buy food when they need it. When they buy food, they will buy exactly the amount they need.
2. Pastorals and semi-pastorals are able to sustain the local community and therefore local market in a 'normal' (without drought) situation.
3. One harvest per year.
4. Only one type of food is available.
5. Poor households spend same on food as rich households.
6. No food at secondary market in severe drought.
7. Households will always take measures if they are warned and they have the cash available.
8. Households do not starve by being food insecure for a long time. this is outside of the scope of the research.

C PARAMETRISATION

Table C.1: Parameters for model

Type	Variable	Value/Range
Model	num_agents	280
	early_waring	True
	warning_time	4
	cost_measures	3
	drought_type	1
	warned	False
	def_drought	8
Agent	agent_type	1 - 3
	hh_size	np.random.normal(6,1)
	food_need	3*hh_size
Pasto	available_food	530-600
	capital	4500 - 4600
	crop_production	1320-1610
	income	0
	time_till_harvest	22-32
Semi	available_food	430 - 530
	capital	500-1000
	crop_production	1030 - 1260
	income	125 - 300
	time_till_harvest	22-32
Work	available_food	70 - 140
	capital	600 - 800
	crop_production	0
	income	900 - 1500
	time_till_harvest	-
Market	init_crop_stock	21840
Policy	payment_type	0
	lead_time	4
	cash_amount	8000

D VERIFICATION

Both during and after the construction of the model, various tests have been executed to verify the model. The complete verification process is made up of four steps. First, an extensive code walk-through is conducted to check for code errors. Second, agent behaviour is tracked and recorded to see check model behaviour. Third, a minimal model is tested and in the last step the model is tested for extreme values. Below is a screenshot that shows the code for the extensive code walk-through.

```python
def buy_food(self):

    if self.model.drought_type == 3:

        #heavy drought
        if self.model.market.crop_stock > self.food_need:
            # if food available on market buy food
            self.capital -= (self.food_need * (self.model.food_price * 1.5)) #buy food for retail price (*1.5) and consume immediately
            self.food_insec = False
            print('Agent type ' + str(self.agent_type) + ' has bought' + ' and drought is ' + str(self.model.drought_type))
            self.model.market.crop_stock -= self.food_need

        else:
            #when no food available in local market, there is no food in severe drought
            self.food_insec = True
            print('im food insec')

    else:
        # For light and medium drought
        if self.model.market.crop_stock >= self.food_need:
            # if food available on market buy food
            self.capital -= (self.food_need * (self.model.food_price * 1.5)) #buy food  and consume immediately
            self.food_insec = False
            print('Agent type ' + str(self.agent_type) + ' bug1' + ' and drought is ' + str(self.model.drought_type))
            self.model.market.crop_stock -= self.food_need

        elif self.capital >= (self.food_need * (self.model.food_price * 1.5) * 1.4):
            # when no food available in local market, Food needs to be collected at regional market with cost penalty.
            # Check if there is capital to pay for the cost penalty

            self.capital -= (self.food_need * (self.model.food_price * 1.5) * 1.4)
            print('Agent type ' + str(self.agent_type) + ' bug' + ' and drought is ' + str(self.model.drought_type))
            self.food_insec = False


        else:
            #when no capital to pay for food with the cost penalty
            self.food_insec = True




def harvest_crop(self):

    if self.time_till_harvest == 0:
        # one time harvest per year

        if self.model.drought_happening == True:

            #When there is a drought, the harvest will be affected

            if self.model.drought_type == 1: #easie drought
                if self.measures_taken == True:
                    self.available_food += self.crop_production # when time to harvest, the crops become available as food
                    self.time_till_harvest = 52

                else:
                    self.available_food += (self.crop_production * 0.9)
                    self.time_till_harvest = 52
```

Figure D.1: Verification by code walk-through and agent tracking

E RESULTS

Table E.1 shows the model parameters as used for the base model run.

Table E.1: Parameters for base model

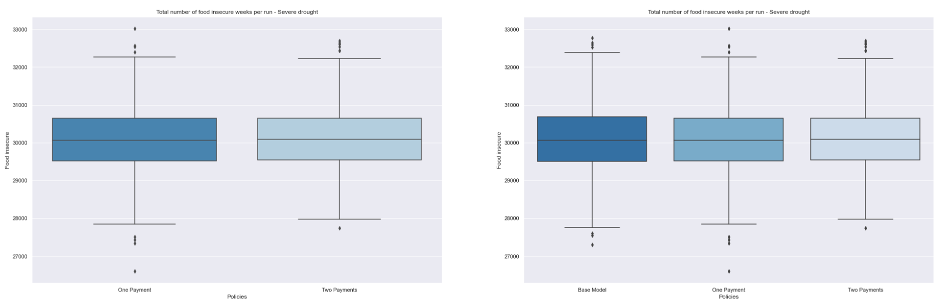
Type	Variable	Setting	Meaning
Model	num_agents	280	Number of agents
	early_waring	True	Will there be warning
	warning_time	4	Time warning before drought
	cost_measures	3	Cost of measures
	drought_type	1	Type of drought occuring
	warned	False	Agents warned at start
	def_drought	8	Definition of drought
Market	init_crop_stock	21840	Initial stock in market
Policy	payment_type	0	No cash transfer
	lead_time	4	Lead time cash transfer
	cash_amount	8000	Cash amount

E.1 EXPERIMENTATION

Table E.2: Parameters for experimentation

Policy label	Code	Drought type	Payment type	Lead time
	p0	1	0	0
Reference	p02	2	0	0
	p03	3	0	0
	p2c2	2	1	6
	p2d2	2	1	12
As soon as Possible	p2c22	2	2	6
	p2d22	2	2	12
	p2c3	3	1	6
	p2d3	3	1	12
	p2a2	2	1	1
	p2b2	2	1	4
	p2a22	2	2	1
Careful Consideration	p2b22	2	2	4
	p1b3	3	2	4
	p2a3	3	1	1
	p2b3	3	1	4

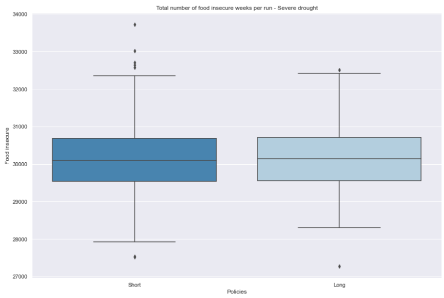
E.2 MODEL RESULTS



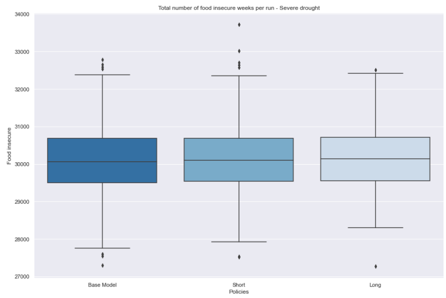
(a) Policy comparison payment type

(b) Payment type

Figure E.1: Total weeks food insecurity with different payment types - Severe drought scenario



(a) Policy comparison payment type



(b) Payment type

Figure E.2: Effect Lead Time on Total weeks food insecurity - Severe drought scenario