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(Title) Agent-Based Simulation Modeling For Analysis And Support Of Rural Producer Organizations In Agriculture

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Agent-Based Simulation Modeling

For Analysis And Support

Of Rural Producer Organizations

In Agriculture

Contents

Summary

Development of smallholder agriculture is widely recognized as an important pathway to poverty reduction in rural areas, particularly in Sub-Saharan Africa. Many researchers propose collective action of smallholder farmers by means of rural producer organizations (RPO) as a promising opportunity to improve commercialization and market access of small farms, which in turn will result in improvement of rural livelihoods. However, little is known about the determinants of RPO success. Currently, there is a broad demand for detailed analyses of RPO performance and for ex-ante assessments of the developmental interventions and policies of RPO support. This thesis focuses on the provision of high-resolution quantitative data for the design of such interventions using a case study of coffee producers in the lake-shore Uganda and their RPO. This work demonstrates the effective ways to increase farmers' welfare through the network of RPO and analyzes the associated risks and opportunities.

This work applies agent-based computer simulation to analyze the RPO. Designed virtual simulation experiments assess the broad portfolio of development interventions and economic scenarios that are challenging to investigate by means of real-world empirical research. The agent-based nature of the model allows for a holistic integration of several modeling concepts in the developed model application. This leads to the inclusion into the model of a number of important aspects of the bio-economic system of coffee production in Uganda. The first aspect is the heterogeneity among farming households, reflected by differences in natural conditions, resource endowments, production and market constraints, time and consumption preferences. The second aspect is the inseparability of decisions that are taken on the farm (i.e. investment, production, consumption and marketing) from one another. The third aspect is human-environment interaction cycles and the dynamics of the bio-economic system, including interactions across levels of hierarchy (here: individual farmers and RPO).

The constructed model is parameterized, calibrated and validated using the empirical data from project and country-level surveys. The set-up of the model and the results of simulation experiments are further complemented by (i) a detailed review of relevant literature, (ii) community-based participatory research with members of RPO and (iii) interviews with key informants.

Results of simulation experiments indicate that RPO activities can cause significant increases in members' sales revenues and consequently can improve their household incomes. The pos-

itive impacts of RPO can be amplified through external assistance. Recommended RPO-level interventions include (i) on-the-spot payments for RPO members' transactions and (ii) support for group certification. Both are expected to have high cost efficiency and a low risk of failure. In addition, results of this thesis suggest that improvement of agricultural productivity through the provision of quality planting material and the promotion of good agricultural practices is likely to be highly beneficial for the rural households. In order to stream the related development policies to smallholder farmers it is recommended to use RPO networks.

Findings of the participatory research in Ugandan RPO indicate that the establishment of transparent rules of reception of RPO services and allocation of earned benefits, together with frequent and formal reporting of RPO administration might increase members' cooperation within an RPO.

This thesis also shows the vulnerability of coffee producing households and their RPO to the risks imposed by the volatility of agricultural prices. The role of development policy is, therefore, to provide price risk insurance for smallholder farmers and to facilitate the formation of accurate price expectations. However, viable and sustainable models of smallholder risk insurance are yet to be found.

Zusammenfassung

Die Entwicklung von kleinbäuerlicher Agrarwirtschaft ist weithin als eine wichtige Strategie zur Armutsbekämpfung in ländlichen Gebieten anerkannt, insbesondere in denen südlich der Sahara. Viele Wissenschaftler, die sich mit diesem Thema beschäftigen, halten kollektives Handeln von Kleinbauern in ländlichen Produzenten-Organisationen (RPO) für einen vielversprechenden Ansatz, um Kommerzialisierung und Marktzugang und damit die Erwerbsfähigkeit landwirtschaftlicher Kleinbetriebe zu verbessern. Allerdings ist das Wissen in Bezug auf die Erfolgsfaktoren von RPO noch sehr beschränkt. Derzeit besteht ein großer Bedarf an detaillierten Analysen der Leistungen, die von den RPO erbracht werden, sowie an ex-ante Bewertungen von Entwicklungs- und Politikmaßnahmen zur Unterstützung von RPO. Der Schwerpunkt der vorliegenden Dissertation liegt in der Bereitstellung von hochaufgelösten quantitativen Methoden und Daten für die Planung solcher Entwicklungsmaßnahmen. Die Studie nutzt ein Fallbeispiel von Kaffeeproduzenten und ihrer RPO in der Region Victoriasee in Westuganda. Die Arbeit zeigt effiziente Verfahren zur Wohlfahrtssteigerung der Kleinbauern durch das Netzwerk der RPO auf und analysiert die damit verbundenen Potenziale und Risiken.

In der vorliegenden Forschungsarbeit werden die RPO mit Hilfe von agenten-basierten Computersimulationen untersucht. Anhand virtueller Experimente wird ein breites Portfolio von Entwicklungsmaßnahmen und ökonomischen Szenarien erforscht, deren Analyse mit klassischen empirischen Methoden problematisch wäre. Die agenten-basierte Beschaffenheit des Modells erlaubt die Integration von verschiedenen Modellierungskonzepten während der Modellentwicklung. Somit konnten einige wichtige bio-ökonomische Aspekte der Kaffeeproduktion in Uganda durch das Modell dargestellt werden. Zum einen konnte der Heterogenität der landwirtschaftlichen Haushalte bezüglich ihrer agrar-ökologischen Bedingungen, Ressourcenausstattung, Produktions- und Marktbeschränkungen, sowie Zeit- und Konsumpräferenzen Rechnung getragen werden. Der zweite Aspekt ist die Komplexität und gegenseitige Abhängigkeit der im Haushalt getroffenen Entscheidungen bezüglich Investitionen, Produktionsverfahren, Marketing und Konsum. Der dritte wichtige Aspekt ist die Integration der Kreisläufe und Interaktionen zwischen den Akteuren und der sie umgebenden Umwelt, sowie die Dynamik des bio-ökonomischen Systems. Dies schließt die Interaktionen über die verschiedenen hierarchische Ebenen (in diesem Fall: individuelle Landwirte und RPO) mit ein.

Das Modell wird mit Hilfe von empirischen Daten parametrisiert, kalibriert und validiert,

wobei die Modellentwicklung und die Ergebnisse der Simulationsexperimente durch (i) Literaturrecherche, (ii) partizipative Forschung mit den RPO-Mitgliedern und (iii) Expertenbefragungen ergänzt werden.

Die Ergebnisse der Simulationsexperimente zeigen, dass die RPO-Aktivitäten eine wesentliche Steigerung der Verkaufserlöse der RPO-Mitglieder und eine sich daraus ergebende Verbesserung der Haushaltseinkommen bewirken können. Diese positiven Auswirkungen der RPO können durch externe Entwicklungsmaßnahmen weiter verstärkt werden. Folgende zusätzliche Maßnahmen werden empfohlen: (i) die Organisation von "Auf-dem-Feld"-Zahlungen an die RPO-Mitglieder und (ii) die Unterstützung von RPO zum Aufbau der Gruppenzertifizierung. Beide Maßnahmen lassen eine hohe Kosteneffizienz bei gleichzeitig niedrigem Ausfallrisiko erwarten. Weitere Ergebnisse der vorliegenden Arbeit deuten darauf hin, dass sich die Steigerung der landwirtschaftlichen Produktivität durch die Bereitstellung verbesserten Pflanzmaterials und die Förderung optimierter Anbauverfahren sehr vorteilhaft auf die Wohlfahrt der ländlichen Haushalte auswirken. Diesbezüglich erscheint es empfehlenswert, die RPO-Netzwerke als Medium zu nutzen, um die Kleinbauern mit entsprechenden Entwicklungsprogrammen zu erreichen.

Die Ergebnisse der partizipativen Forschung mit den ugandischen RPO ergeben, dass die Einrichtung transparenter Regeln für die Inanspruchnahme von RPO-Dienstleistungen, die Verteilung der erwirtschafteten Gewinne, sowie die regelmäßige und formelle administrative Berichterstattung die Zusammenarbeit zwischen den RPO und ihren Mitgliedern deutlich verbessern kann.

Außerdem zeigt diese Dissertation die Risikoanfälligkeit der kaffeeproduzierenden Haushalte und ihrer RPO hinsichtlich hoher Volatilität der Agrarpreise auf. Deshalb sollten die entwicklungspolitischen Entscheidungsträger Versicherungen gegen Preisschwankungen für Kleinbauern bereitstellen und sie bei der Bildung von korrekten Preiserwartungen unterstützen. Allerdings müssen realisierbare und nachhaltige Modelle zur Risikoversicherung für Kleinbauern erst noch erfunden werden.

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List of Abbreviations

ACE	area cooperative enterprise
ABM	agent-based models
BCR	benefit-cost ratio
BOU	Bank of Uganda
BMZ	German Federal Ministry of Economic Cooperation
CGIAR	Consortium of International Agricultural Research Centers
CIA	Central Intelligence Agency
coef	coefficient
COREC	Coffee Research Center
CSI	Consortium for Spatial Information
CWD	coffee wilt disease
cv	cofficient of variation
DC	depot commitee
dcov	distance covariance
DEM	digital elevation model
DFG	Deutsche Forschungsgemeinschaft (German Research Foundation)
EANB	equivalent annual net benefit
ERR	economic rate of return
FAO	Food and Agriculture Organization of United Nations
FAQ	fair average quality
IFAD	International Fund for Agriculture and Development
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
ILO	International Labor Organization
IGM	Integrating Governance and Modeling
iqr	interquartile range
IZA	Institute for the Study of Labor
GIS	geographic information system

GPS	global positioning system
kt.	kiloton
LP	linear programming
MAS	multi-agent system
MAS/LUCC	multi-agent systems applied to land use/cover change
masl	meters above sea level
MILP	mixed-integer linear programming
MOST	Ministry of Science and Technology, Vietnam
MP	Mathematical Programming
MP-MAS	Mathematical Programming-based Multi Agent Systems
NGO	non-governmental organization
NRCT	National Research Council of Thailand
NSE	Nash-Sutcliffe model efficiency coefficient
NUCAFE	National Union of Coffee Agribusinesses and Farm Enterprises
obs	observation
PO	producer organization (village-level organization)
rho	Spearman's rank correlation coefficient
RPO	rural producer organization (general term)
SACCO	savings and credit cooperative organization
SSA	Sub-Saharan Africa
stdev	standard deviation
SWOT	strengths, weaknesses, opportunities and threats
tau	Kendall's rank correlation coefficient
TSPC	tropical soil productivity calculator
UCDA	Uganda Coffee Development Authority
UCRA	Uganda Coffee Roasters Association
UCTF	Uganda Coffee Trade Federation
UHOH	Universitaet Hohenheim
UNAIDS	Joint United Nations Programme on HIV/AIDS
UNFFE	Uganda National Farmers Federation
ugx	Ugandan shilling
usd	United States dollar
UTZ	UTZ CERTIFIED
WTO	World Trade Organization

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Introduction

This Ph.D. thesis is a contribution to the international research project "Working together for market access: Strengthening rural producer organizations in Sub-Saharan Africa" conducted from 2009 to 2012 in Senegal and Uganda. Project partners included the International Food Policy Research Institute (IFPRI), the Institute for the Study of Labor (IZA) and Universität Hohenheim (UHOH). The project implemented a novel research approach of combining economic experiments with computer simulation in order to support the economic performance of rural producer organizations (RPO). By means of virtual simulation experiments, the author assessed the effectiveness of Ugandan RPO in marketing of robusta coffee under various "what-if" scenarios and identified suitable measures of development support. Virtual experiments were designed based on participatory research involving project stakeholders and empirical data obtained by the project partners. Specifically for this research, the author created an application of the agent-based simulation model MP-MAS, which was developed at the Chair of Land Use Economics in the Tropics and Subtropics at Hohenheim. The simulation model was constructed to capture the empirical heterogeneity between farm households, and to explicitly simulate interactions between farm households and RPO as well as between farm households and their biophysical environment. This work aims to deliver quantitative information for policy development and to contribute to the improvement of livelihoods of smallholder farmers by strengthening the ability of RPO to improve their members' access to input and output markets. The software application is available as freeware and can be reused for further quantitative assessments, decision-support and other academic and applied purposes. This thesis describes in detail the methods and data used for the virtual experiments and presents the simulation results and empirical findings.

Problem statement and research motivation

World Bank (2007) emphasizes the vital role of the smallholder farming sector as "one of the cornerstones of an agriculture-for-development strategy", and estimates that 1.5 billion people in the world are involved in smallholder agriculture (i.e. farm households with 2 hectares or less). One reason for such emphasis is that the development of smallholder agriculture is currently seen as key poverty reduction in developing countries (Hazell et al. 2010). Experience with the "Green Revolution" in Asian countries shows that reaching smallholder farmers through agricultural growth can greatly develop rural economies and significantly decrease the share of people living in poverty (Evenson & Gollin 2003), since the majority of the rural poor reside on small farms (Hazell 2005). Also, as Heltberg (1998) demonstrates, smallholders provide more employment opportunities (in per unit of land calculation) compared with large farms, because of the lower costs of labor supervision and the labor-intensive nature of production. Moreover, the expenditure patterns of smallholder households are oriented towards locally produced goods and services (Hazell & Roell 1983), which serve as an additional catalyst for economic growth in rural areas. Land productivity is another reason for focusing the attention of the development authorities on small farms. An inverse relationship between farm size and land productivity (i.e. decline in productivity with increasing farm size) is a widely observed fact (Chen et al. 2011, Heltberg 1998, Lipton 1993).

Despite being more efficient in production, smallholder agriculture is often subject to inefficient allocation of goods and services, as well as other forms of market failures. Smallholder agricultural producers face high transaction costs that are associated with dis-economies of scale (Poulton et al. 2010, Key et al. 2000). Relatively high (in comparison with large farms) transaction costs for small farms may be observed in most non-labor transactions, such as input purchases, capital access or selling of output, which may outweigh the efficiency advantages (Poulton et al. 2010). These costs are further aggravated by the poor infrastructure of rural areas. With rising intensification of agricultural production, the cost of access to inputs, finance and equipment becomes increasingly important (Poulton et al. 2010). When it comes to marketing, low levels of market access and bargaining power, as well as imperfect information, prevent many rural producers from benefiting from high agricultural commodity prices (Fafchamps & Hill 2008). Market access constraints are especially strong in Sub-Saharan African (SSA) countries like Uganda, where market liberalization reforms of the 1980's and 1990's led to the disengagement of the state from marketing agricultural commodities and providing factors of production. Organization of respective services by the private sector, however, remains underdeveloped (World Bank 2007, Kherallah et al. 2002).

Organized stakeholder groups have demonstrated their capacity for contribution to natural resource management (Kirsten et al. 2009, Meinzen-Dick et al. 2002). They succeeded in overcoming market imperfections (Kirsten et al. 2009, Thorp et al. 2005), and in pro-poor agricultural development (Kirsten et al. 2009, Mwangi & Markelova 2009). Recent scientific works underline the potential of collective action for developing countries; rural producer organizations (RPO) have great potential to overcome smallholders' obstacles in input procurement and produce marketing (Markelova & Mwangi 2010, Markelova et al. 2009, Shiferaw et al. 2008). Uniting small- and medium-scale farmers under the umbrella of RPO can potentially create linkages to market, decrease per-unit transaction costs, and improve farmers' bargaining power (Bernard & Taffesse 2012, Shiferaw et al. 2008, Bacon 2005). Aggregation of smallholders' produce at the RPO level is a widely recognized way of improving commercialization of small farms through: (i) reduction of transaction costs, (ii) negotiation of better terms of trade, (iii) improvement in co-ordination of operations (Markelova & Mwangi 2010, Bernard & Spielman 2009). Therefore, over the past decade, governments and development agencies have come to see collective action institutions as important partners in implementation of agricultural programs and key to the empowerement of rural farmers (IFAD 2010, World Bank 2007, IFAD 2001). A need to respond to market and government failures constitutes a driving force for RPO formation and development. It has recently led to the emergence of many grassroots farmer-controlled organizations in developing countries (Wanyama 2008, Uphoff 1993, Arcand 2002).

Sttudies show, however, that in Sub-Saharan Africa RPO have had mixed success (Bernard & Taffesse 2012, Bernard et al. 2008, Gabre-Madhin 2001, Akwabi-Ameyaw 1997). Scientific explanations of these varying results are scarce. Little is known about what exactly determines the effectiveness of RPO in developing countries and the extent to which RPO provide benefits for their members. This knowledge gap is caused by the high degree of complexity and diversity among RPO (Ragasa & Golan 2012). At the same time, especially in the case of Sub-Saharan Africa, there is a broad demand for thorough quantitative studies of RPO performance. These are required in order to design adequate measures for effective RPO support (Ragasa & Golan 2012, Bernard & Spielman 2009). Ex-ante assessments are a vital prerequisite for effective targeting and case-specific design of development interventions that would help RPO to fully tap their potential in terms of pro-poor agricultural development.

The need for improvement of understanding of RPO and the identification of effective types of RPO support is the motivation of this study. This thesis contributes to the development of RPO-related knowledge, on which donor organizations and governments rely when designing respective policies, programs and projects. The study establishes practical tools for the analysis of RPO, and with their application provides quantitative information on RPO functioning. Based on this information the author derives concrete recommendations on RPO improvement and empowerment.

Case study introduction

This research focuses on smallholder coffee producers in Uganda and their RPO. The question of smallholder empowerment is very relevant for coffee growers from Uganda. Coffee is a major source of income for 74% of households residing in the regions of Uganda that are suitable for coffee production (UCTF 2010). It is mostly grown by smallholders (according to Hill (2010*b*) 70.3% of coffee-growing households in Uganda have less than five acres of land). Farmers market their coffee either individually or collectively through RPO (Kwapong & Korugyendo 2010). In total, sales of coffee constitute on average 23% of farm revenue of coffee-growing households (Hill 2006) and there are around 500,000 households engaged in coffee production in Uganda (UCTF 2013). In total, the coffee production sector employs around three and a half million households in Uganda (UCDA 2013). So, having a strong and effective network of RPO in the sector will benefit a large number of people, a significant share of whom live below the poverty line (latest estimates of IFAD (2010) indicate that 51.5% of the Ugandan population lives under the 1.25 usd per day poverty line and 75.6% lives under the 2 usd per day line). Findings of Fafchamps & Hill (2005) suggest that collective selling and the resulting reduction in per unit transaction costs can provide significant benefits for Ugandan coffee producers.

Choice of the research methodology

This research was done in collaboration with an IFPRI project on RPO in Uganda. The IFPRI counterparts conducted the field experiments with RPO members. They were testing the impacts of various treatments that could have improved RPO functioning, such as provision of actual market information or advancing the portion of money paid by the RPO to its member producers. But of course, experiments with human subjects in the real-world setting have certain limitations: (i) not all factors can be controlled and varied, (ii) treatments that carry the risk of negatively affecting participants have to be avoided, (iii) the realization of some effects may take an impractical amount of time, (iv) implementation costs and budget constraints may be prohibitively high. Hence, many of the possible interventions and scenarios could not been tested with the field experiments. In order to broaden the portfolio of assessed interventions and improve the project results, it was decided to set up virtual experiments by means of simulation modeling. Outcomes of simulation modeling were intended to complement the findings of other project partners and generate information that is useful for RPO administrators, government authorities working on improvement of local markets, and donor agencies involved in agricultural development.

Typically, development studies have to deal with a high heterogeneity among farming households in developing countries. There, it is common to observe large variations in yields, input application intensity, crop mixes, and crop management practices, which is caused by significant differences in resource endowments, and knowledge, market and infrastructural constraints (Ruben & Pender 2004, Schreinemachers & Berger 2006). Effective targeting of development policies and interventions in less-favored areas requires that the diversity of farming households be taken into account (Ruben & Pender 2004, Berger et al. 2006). A suitable way of reflecting this heterogeneity in a simulation model is the agent-based modeling (ABM) approach (Berger et al. 2006), which makes possible a direct implementation of each farming household as a model agent without any aggregation, so called *one-to-one correspondence*. The review of Boulanger & Brechet (2005), who compares various modeling approaches from the perspective of their suitability for the purposes of sustainable development policy making, also supports this choice of modeling method. Boulanger & Brechet (2005) evaluates modeling alternatives according to five different criteria and ranks multi-agent models as the most appropriate tool for this purpose (see Table 1).

Table 1: Relative suitability of modeling approaches with respect to sustainable development policy making

Approach	Criteria					Ranking
	Inter-disciplinary potential	Long-term, intergenera-tional	Uncertainty management	Local-global	Participation	
Multi-agent	0.29	0.27	0.3	0.34	0.4	1
System dynamics	0.29	0.27	0.08	0.11	0.2	2
Bayesian networks	0.17	0.07	0.39	0.17	0.13	3
Optimization	0.05	0.07	0.06	0.17	0.08	6
General equilibrium	0.1	0.21	0.08	0.11	0.08	4
Macro-econometric	0.1	0.1	0.1	0.09	0.1	5

Source: Boulanger & Brechet (2005)
*criteria scores are defined on [0,1] interval, where 1 stays for the only appropriate tool and 0 – for not appropriate tool at all

In recent years, a number of ABM software packages were designed for application in agricultural economics. Schreinemachers & Berger (2011) compare these packages and describe their main features. Based on this comparison, the software MP-MAS (Mathematical Programming-based Multi-Agent Systems) was selected as a framework for implementation of the agent-based simulation model of RPO. This software is being developed at the Chair of Land Use Economics in the Tropics and Subtropics (Josef G. Knoll Professorship) by the development team (team members are listed in Schreinemachers & Berger (2011)) based on the earlier work of Berger (2001). MP-MAS software is suitable for the modeling of semi-subsistence agriculture (Schreinemachers & Berger 2011), which is the type of agriculture practiced in the case study of this research. Most importantly, MP-MAS was already applied for modeling the coffee-banana production system of the lake-shore Uganda in the research of Schreinemachers & Berger (2006). Therefore, some parts of its parameterization were suitable for reuse in this study. Additionally, the implementation of the author's modeling concepts in the software code in the form of extensions was negotiated with the MP-MAS developement team.

Before proceeding with the elaboration of RPO-modeling concepts, a thorough literature review was conducted and a field visit to Uganda was made. Community-based participatory research with members of RPO was conducted and key informants were interviewed. The findings of the field work helped to structure and parameterize the simulation model. They also enriched the final results of the research through provision of invaluable insights into issues that the model was not able to address.

Goal and objectives of the work

The particular goals of this research are **to determine the effective ways of increasing RPO members' welfare and to provide quantitative information for the development of the respective policies and interventions of RPO support**. Achievement of the research goals required sequential fulfillment of the following objectives:

1. Provision of a knowledge base on RPO functionality and their roles in terms of rural development
2. Formulation and implementation of the agent-based simulation model for modeling the activities of RPO and their member farmers
3. Model parameterization, calibration and validation on the example of the selected coffee RPO from Uganda
4. Application of the developed model to analyze sensitivity of the RPO and its members with respect to production and price factors
5. Identification of development interventions that can improve the livelihoods of RPO members and assessment of the impact of interventions via simulation modeling

With regard to the first objective, this work reviews, synthesizes and discusses the experiences of various scientific studies and development projects. An in-depth analysis of coffee RPO in Uganda is performed using various statistical, participatory and modeling techniques. RPO and their networks of involvement constitute systems that are too complex for analytic analysis and solutions. Therefore, the construction of computer simulation models (the second objective) is required. Issues of model flexibility and re-usability are in focus during model choice and building. The author seeks to implement a model that could be adapted for use in cases outside of the related research project. This thesis aims to demonstrate how the applied model could be parameterized, calibrated and validated using available sources of empirical data, stakeholder knowledge and expert opinions (the third objective). It provides an example of how to overcome problems of data scarcity and incompleteness. Sensitivity analysis (the fourth objective) is required to understand the risks that variation of the production and price factors imposes on the coffee producers and their organizations in Uganda. Results of the sensitivity analysis underline the importance of creating safety nets and risk-coping mechanisms among smallholder farmers in SSA. Results of the impact assessment supply policy makers with insights into the potential effects of RPO empowerment measures and support selection or rejection of respective interventions for practical application (the fifth objective).

Research questions

The above listed objectives can be fulfilled once the following six research questions are answered:

What are RPO and what is their place in the context of sustainable development? The subject of this research is RPO. Therefore, it is important to define the notion of an RPO, to understand which goals it may have, which functions it may perform and which services it may provide. Identification of different types of RPO and provision of dimensions for their comparison will provide a framework for understanding the RPO in question. Review of historical facts, recent empirical evidence and theoretical concepts will identify current and potential roles of the RPO in the development agenda.

How can RPO be researched? Review of the implemented and proposed approaches for the research of RPO as well as documentation of other-party researches on RPO will help to structure this research, and to consider possible limitations and extensions. Justification of the applied methodology must consider strengths and weaknesses of alternative methods. A niche for the effective application of a multi-agent approach has to be identified. A toolbox for participatory assessment of the state of affairs in the Ugandan coffee RPO must be included.

What are the characteristics and specifics of coffee RPO in Uganda? Understanding the characteristics of local agriculture, the cooperative sector and the institutional framework as well as the specifics of the coffee business is important for the identification of problems, bottlenecks and potential for improvement. The modeling process requires having a clear picture of aspects and actors that are influential for decision making and performance of real RPO and its members. Community-based participatory research and expert interviews together with the literature review are expected to draw this picture. Findings obtained during the field work in Uganda will undergo a qualitative and quantitative analysis, the results of which will highlight the current situation in Ugandan RPO and assist in the organization of measures of their support.

How can RPO be modeled as multi-agent systems? Agent-based modeling is a relatively new approach in agricultural economics. Therefore, its application for the case of RPO has not yet been established. This work must develop a respective framework for modeling RPO and provide an example of its application with a case study. Suitable modeling concepts that can mimic the actual behavior of the study area have to be found. Implementation of the model must be feasible given the available data. Empirical validity of the model has to be ensured and characterized. The results that the model produces must be able to support practical measures.

What impact does the varying of production and price factors have on coffee farmers and RPO in Uganda? Sensitivity analysis is expected to reveal the relationship and vulnerability of rural households and RPO with respect to external factors. Such analysis computes the impacts of factor change and factor variability and quantifies the risks related to these factor alterations. The ABM approach allows the analysis to be conducted on different scales (e.g. organization, household). Also, there are few dimensions on which effects of factor changes can be analyzed (e.g. income, food security, etc.). Results of the respective simulation modeling experiments will yield information and practical recommendations that are useful for decision making.

What are the likely impacts of the development interventions on Ugandan coffee farmers and their organizations? Such an assessment will at first require the translation of interventions to the form of model simulation scenarios. Virtual experiments will simulate the effects of interventions on model agents, which reflect real-world households and RPO. As mentioned above the analysis of simulation results must be done on several dimensions and scales. Analysis of the results will show the impacts of various interventions, cross-compare their efficiency and help in selecting appropriate ones for real-world implementation.

Quick guide to this thesis

This Ph.D. dissertation contains six chapters. Their contents are briefly outlined in this section.

Chapter 1 provides the reader with important background information on the research topics, applied methodology and research setting. This chapter gives definitions of *rural producer organization* and *collective action* and introduces different classifications of RPO. Here, the author finds a niche for RPO in the context of rural development and poverty reduction, discusses the common problems that can occur under RPO set-up and draws lessons from empirical evidence on RPO support and empowerment measures. Chapter 1 also presents the main methodological concepts and approaches used in this work and characterizes the research setting: the research project in which frames this work was conducted, the past and present RPO in Uganda, and important specifics of coffee production and marketing.

Chapter 2 explains the methodology and organization of the participatory research conducted with farmers from the study area and other key informants. By summarizing the results of the assessment the author provides additional insights on Ugandan coffee farmers and their RPO. The structure of the RPO was visualized by stakeholder-created maps of the socioeconomic network, which indicated the actors involved and their importance and located problems and weak linkages. Based on the assessment results, Chapter 2 analyzes the functionality of coffee RPO in Uganda and indicates the points where development interventions might have a positive impact. The gathered insights on farmer decision making and RPO activities were later considered when setting up the simulation model.

Chapter 3 presents the application of the MP-MAS simulation modeling framework constructed for this study and discusses its capabilities, structure, main modules and components. The model description addresses the topics of generation of agent populations and landscapes, model representation of household decision alternatives and preferences, simulation of crop yields, household dynamics and learning of agents from past experience. This chapter explains the process of the model's empirical parameterization. It describes the implementation of coffee marketing and RPO activities in the MP-MAS modeling framework.

Chapter 4 develops the principle for calibration of the MP-MAS Uganda simulation model and discusses its application in practice. In this chapter the validity of the entire simulation model is assessed. Model validation is discussed with respect to various relevant validity types outlined by the author. Selected model components are statistically validated using the empirical data.

Chapter 5 describes the set-up of computer simulation experiments that were conducted. Results of these experiments are reported and analyzed in this chapter.

Finally, Chapter 6 interprets the outcomes of simulation modeling, summarizes the main findings and the experience gained during this research, and discusses the results of the entire research. The chapter develops practical recommendations for policy makers concerning RPO empowerment measures. The chapter also outlines perspectives for future research related to RPO empowerment and proposes possible extensions of the constructed model application.

Chapter 1

Background information

The overall aim of the research project, within which this work was conducted, was to derive and evaluate possible development treatments that could improve the performance of agricultural RPO and increase the welfare of its members. This thesis develops an empirically-based computer simulation for intervention assessments in organizations of rural producers. To understand the functioning, as well as the challenges faced by RPO, and to learn lessons from previous experiences in supporting RPO, this chapter reviews the related theoretical concepts and empirical evidences. It introduces the reader to the world of RPO and explains the specifics of the undertaken case study.

1.1 Role of rural producer organizations in the development context

Before proceeding to in-depth analysis of the case study, let us first uncover the role of the rural producer organization within the development context by providing some fundamental definitions and facts from the literature.

1.1.1 Definitions

Rural producer organization (RPO) in agriculture is an either formal or informal social arrangement with voluntary membership that pursues the goal of provision of economic benefits to its member producers. Agricultural RPO can appear in different structural set-ups, such as farmer unions, agricultural cooperatives, village groups, bargaining associations among others, and exist on various levels (from village to international). It can perform an assortment of economic, political and social activities aimed at support of its members, such as:

- Bulking of produce, marketing and collective sales
- Coordination of transport and logistics

- Input supply
- Processing
- Extension and capacity building
- Granting access to financial services
- Quality improvement and control
- Collective certification
- Risk management

An RPO can be narrowly specialized, but they usually perform a broad set of activities and operate in multiple agricultural sub-sectors. In contrast to other kinds of organizations that are promoted and supported by governments or NGOs, an RPO is a business-oriented entity that has to generate additional utility for its members with cost recovery. However, this does not mean that an RPO cannot receive external grants, subsidies or preferential loans. In the long term, an RPO has to be financially sustainable, like any other type of business. Unlike corporation shareholders, RPO shareholders typically make a contribution into the share capital of the organization in order to receive certain services and goods, rather than seeking profits down the line. RPO can be distinguished from private-public partnerships and other externally controlled structures by that producers are the main shareholders of RPO.

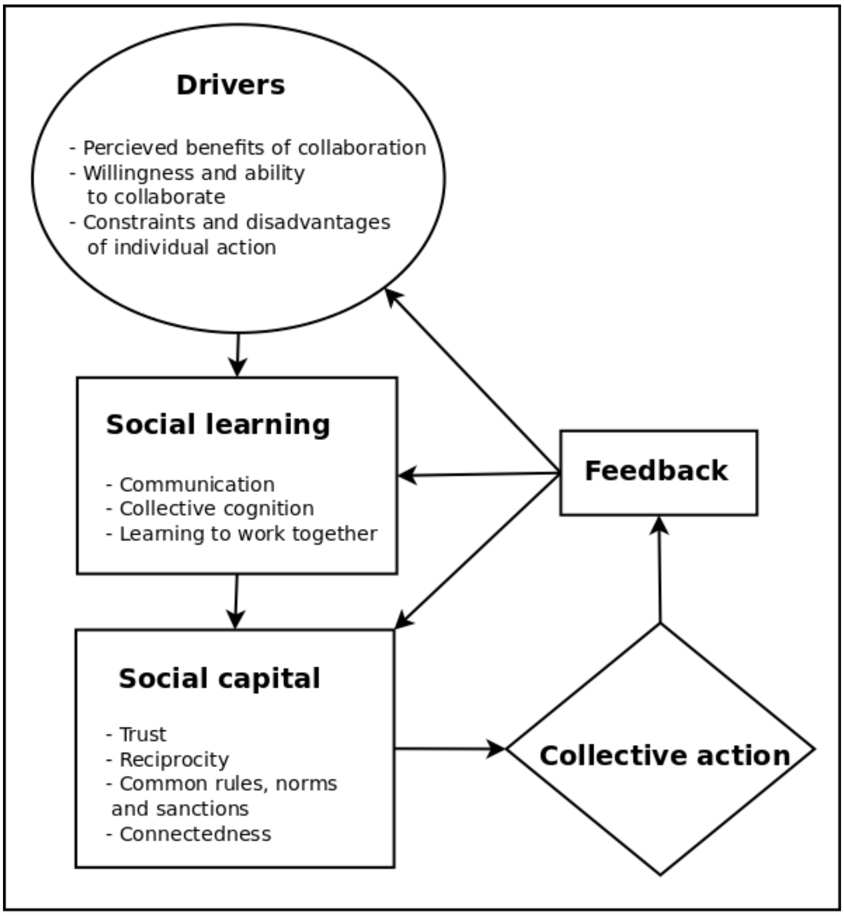
In the literature, the type of organization that is defined here as a *rural producer organization* (RPO) can appear under different names, such as ”agricultural cooperative” (Hussi et al. 1993), ”farmer organization” (Chamala & Shingi 1997), ”agricultural producer organization” (Rondot & Collion 2001) and others.

According to Bijman & Ton (2008), an RPO can be defined by two principles: utility and identity. The utility principle states that an RPO is useful to its members, and they are contributing towards the achievement of common goals. The identity principle underlines that members typically have similar backgrounds, share common values and visions, and agree upon the rules within the organization and external communication with the outside world. This shared identity serves as a social instrument that sustains and further develops interactions between members. So, in order to be a member of an RPO, individuals have to meet certain criteria (e.g. membership fees, being of certain ethnicity etc.), which can discern them from other farmers (Bijman & Ton 2008).

Since RPO actions are usually performed by a group of people, not individuals, the term *rural producer organization* is closely related to the term *collective action*.

Collective action is an action taken by more than one person in pursuit of common goal or set of goals. From the perspective of group formation, collective action can be explained using the concepts of *social learning* and *social capital* (Kruijssen et al. 2009, Uphoff 1993). Collective action is defined and triggered by social learning and social capital through various drivers. This process is schematically described in Figure 1.1. As shown in the figure, in order to start acting as a group, individuals, firstly, need to have the ability and the need to collaborate. Secondly, individuals expect to receive certain benefits from the collective action. Groups continuously go through social learning: through communication, members learn to interact and work as a collective and form collective cognition (Jordan et al. 2003). Social capital is a structure of relations inside the group. Among characteristics of social capital, Pretty & Ward (2001) distinguish (i) trust within the group, (ii) reciprocity, (iii) common rules, norms, sanctions, and (iv) group connectedness (i.e. a set of internal and external connections of group members). Social capital lowers the costs of working together and, therefore, serves as a catalyst of collective action (Pretty & Ward 2001). For investing their assets in collective activities individuals have to agree with the activities and be confident that others would invest their assets as well.

Figure 1.1: Process of collective action



Source: Author

1.1.2 Typology

RPO are complex organizations differentiated by the political, economic, social and juridical environments in which they function. Hence, RPO can be categorized by several attributes:

Cause of origin There are various forces that can spark the creation of an RPO. Sometimes, it can be formed autonomously as farmers' reaction to unfavorable circumstances (low bargaining power, high risks, absence of certain public goods, etc.). In this case, RPO emerge from existing social structures (for example, neighborhoods or religious communities). In other cases, RPO are created by external initiatives of the state, NGOs, or international development organizations. RPO can be formed directly or be developed from other externally created networks, like natural research management organizations or micro-finance institutions.

Provided goods RPO can be distinguished by the types of goods they provide. Generally, RPO can provide any type of good of a rivalry-excludability classification: private (inputs, draft power), club (certification), common (irrigation water) and public (rural infrastructure).

Provided services RPO can provide a wide range of services. According to Bosc et al. (2002) they can be grouped into five categories:

- Economic: Management and procurement of production factors, production, processing and marketing.
- Social: Improvement of education, health, cultural issues, etc.
- Representative: Defense of the members' and the group's interests and advocacy.
- Coordination: Systematic organization of members' activities in time and space, making them work efficiently for the achievement of common goals.
- Knowledge and information sharing: Dissemination of knowledge and information among group members, establishment of internal and external communication channels and capacity building.

Marketable products Four groups of marketable products and related markets on which RPO may concentrate can be defined (based on Markelova & Mwangi (2010), Poulton et al. (2010)):

- Staple crops: Products have limited opportunities in terms of value addition; somewhat easy to store and transport. In most cases, there is a demand for these products on the local market. Substantial portions of the harvest can be also consumed on farms.
- Cash crops: Typically require processing and, therefore, are often sold to large agribusinesses that possess the necessary equipment.
- Perishables: Associated with high risks, these require sophisticated storage and transportation mechanisms, and are subject to complex quality requirements, but have high revenue potential.
- Livestock products: Multiple by-products, and are easy to sell locally.

Degree of specialization RPO can have a narrow specialization (often focused on a specific commodity or function) or perform a broad set of activities. Because of the sophisticated livelihood structure of farmers in the developing countries, RPO may aim to tackle several issues (like marketing, education of farmers, quality control) at the same time.

Level of operation The stakeholders of RPO are local level actors – agricultural producers. However, RPO can be represented on various levels. One way of doing so is forming region- or county-wide federations/associations/unions. Also, RPO can be directly linked to large exporters, importers, processors or retailers, thus also operating on various levels. Finally, in some cases, RPO can take part in international certification schemes or development programs.

Organizational structure Membership conditions, internal rules, regulations and sanctions, and management types can vary significantly.

Organizational form There is a wide range of legal forms under which RPO can be registered. RPO may also exist only as informal groups and may not be officially registered.

Mode of group operation In an RPO, group objectives might not be fully shared by individual members of the group. Therefore, a group must use certain mechanisms in order to keep individual activities in line with the objectives of the group. Hence, Thorp et al. (2005) distinguish between the following three mechanisms of group operation:

- Power and control: One or several dominant members (leaders) dictate their decisions to other members using threats and/or sanctions. By consenting to these decisions, regular members release themselves from the responsibilities of participation in management and decision making.
- Material incentives: Members participate in the group and contribute to achieving group objectives because in doing so they get a material reward or expect to be rewarded in the future.
- Cooperation: Members are concerned with the well-being of others in the group. Members agree that group objectives prevail over their individual interests.

In practice, groups do not apply only one mechanism, but rather certain mixtures of them (Thorp et al. 2005).

Internal composition RPO can be distinguished by the demographic characteristics of its members. For example, there are women's RPO, youth RPO, etc.

Evolution path RPO are dynamic groups and their activities, inter- and intra- relations, evolve over time. In many cases, such evolution is the outcome of adaptation to changes in surrounding economic, social, political, institutional, technical and technological environments.

1.1.3 Relevance for the development agenda

Currently, there are about 1.5-2 billion people involved in smallholder agriculture worldwide; this group of people mostly resides in rural areas of developing countries and includes the majority of the world's rural poor and undernourished (Hazell et al. 2010, Bailey et al. 2009, World Bank 2007, Hazell 2005). Despite many expectations, the number of small farms in developing countries and the share of agricultural land under their operation has not fallen, but keeps on growing (Hazell et al. 2010). Thereby, the livelihoods of an enormous number of rural people continue to be dependent on smallholder agriculture. This consideration makes enhancing the profitability and sustainability of smallholder agriculture, and the subsequent improvement of the rural livelihoods, one of the primary pathways of poverty reduction (World Bank 2007).

Smallholder agriculture in developing countries is subject to a number of cases of inefficient allocation of goods and services by the free market (also known as *market failures*), such as:

- High price dispersion due to poor transportation infrastructure
- Credit constraints due to a lack of formal financial institutions
- Under-developed labor markets
- Weak insurance mechanisms
- Inefficient management of common resources due to communal property rights

Inefficient policies and bad governance may widen the listed market imperfections and create additional negative externalities. Responding to the market and government failures is a driving force for RPO formation and development in developing countries.

Smallholder farmers all over the world are facing two main challenges, which are related to the size of their enterprises (Valentinov 2007). They are (i) the inability to reach benefits of external economies of scale when acting independently on the market and (ii) much less bargaining power in comparison with upstream and downstream industries. Networks of RPO can potentially unite farmers and help them to overcome these two problems. Through RPO, farmers may acquire the missing capacities, and bridge existing knowledge and technology gaps with today's leading producers. The importance of RPO is that they provide links between producers and consumers, which increase farmers' market access (Shiferaw et al. 2008, Bacon 2005). On paper, RPO have clear advantages over individual action:

- Benefits of economies of scale
- Knowledge and information sharing
- More bargaining and political power

- Safety nets and lower costs for externalities management
- Access to larger markets
- Access to financial services
- Group certification

In terms of rural development that also means:

- Improvement of rural livelihoods
- Linking small producers to national economies
- Improvement of competition in rural areas by provision of alternative sales channels
- Vulnerability reduction through organization of community-based institutions and self-help groups

By reducing market transaction costs and increasing market power, collective action through RPO is a development opportunity. Hypothetically, rural farmers can better solve some of their problems by acting as a group than they could if acting individually. But can RPO in developing countries indeed tap this potential and make a difference for rural farmers and communities? What do the facts say?

The literature assesses the contribution that RPO make to farmer welfare. Some studies reveal that participation in RPO serves to increase selling prices of member producers, thus improving household incomes (Shiferaw et al. 2008, Wollni & Zeller 2007, Calkins & Ngo 2005). For example, Shiferaw et al. (2008) observe pigeon-pea prices offered by Kenyan RPO to be 22–24 % higher than the respective prices offered by middlemen traders. With regards to price differences, Kruijssen et al. (2009) report the different situation observed in the groups of Indian horticultural producers: in order to save time coordinating sales and free up labor to be used elsewhere, farmers accepted lower prices offered by their RPO.

Creation of employment opportunities in the rural areas is an important effect of RPO presence. According to Develtere & Pollet (2008), these effects can be (i) direct (staff of RPO and related institutions), (ii) indirect (support of members' self-employment), or (iii) spillover (non-members, whose employment is dependent on the existence of cooperatives). A study by the International Labor Organization (ILO) (Schwettmann 1997), estimated that the cooperative sector in 15 selected African countries provided around 159,000 direct and 468,000 indirect employment opportunities. In certain areas, the cooperative sector can be the only suitable employer for farmers. In the South African province of KwaZulu-Natal 70% of interviewed RPO members had never been employed prior to joining the RPO (Theron 2008). The spillover effects are difficult to quantify, but it is clear that jobs of certain economic actors (like seed, input or transportation providers) are dependent on the activities of the RPO (Develtere & Pollet 2008).

The RPO-induced financial and social capital improvements can allow members to use RPO networks to organize investments into the socio-economic infrastructure of the community (for example, building a school or small water reservoir), as the findings of Calkins & Ngo (2005) show. RPO networks can also be used as an effective means of information transmission (health messages, fertilizer recommendations, etc.). For example, around 100,000 farmers were given information about AIDS during an agricultural intervention on input provision in Zambia (Uliwa & Fischer 2004).

An ordered probit model by Wollni et al. (2010) estimated that in the case of small-scale farmers in Honduras, RPO membership had a positive effect on the adoption of soil conservation practices. Devaux et al. (2009) argue that market chain innovations for indigenous products promoted through collective action efforts can support biodiversity conservation in rural areas. Findings of Kruijssen et al. (2009) concluded from four different case studies that RPO contribute to the sustainable management of natural resources.

There are a few study cases that support the hypothesis that RPO make a positive impact on the market access of their members. The results of the analysis by Wollni et al. (2010) suggest that RPO members are more likely to be involved in organic markets, therefore, RPO were able to improve market access. Myers (2004) notes that Ethiopian RPO successfully linked farmers to the international coffee market. Evidence from the Meso-American setting shows that, even if RPO do not provide better access to output markets, they mainly serve their members by facilitating access to production inputs (Hellin et al. 2009). The statistical evidence from cocoa producing RPO in Ghana and Cote d'Ivore presented by Calkins & Ngo (2005) shows that RPO members (in comparison with non-members) get significantly better access, not only to marketing, but also to such services as credit, input procurement, extension and health services. Therefore, RPO members interviewed by Calkins & Ngo (2005) agreed with the expression "a cocoa cooperative in the village benefits community development".

Results of Bernard et al. (2008) demonstrate that RPO provide a channel for governments and development organizations to stream their development assistance. This forms a channel for reaching the rural poor and targeting development policies.

1.1.4 Problems and challenges of rural producer organizations

The related literature underlines a wide set of problems that RPO in developing countries have to deal with. Some of these problems (free-riding, limited planning horizon) are linked to the nature of the cooperative firm type, some (inclusion of the poor, gender inequality) are defined by the development context specifics and some (efficiency/equality trade-off) are matters of priority setting. In order to be successful, development policies have to find the respective solutions to the problems discussed in this section.

Dealing with heterogeneous membership Differences in values, visions, judgments of RPO members and resulting potential clashes between individual and group motivations can form the base for cooperative failures. That is especially relevant for the groups with large numbers of members (Nilsson 2001). For the RPO management it may be hard to weight members' opinions, and improper decisions on treatment of individual preferences may lead to the discontentment of members (Richards et al. 1998). Usually, managerial decisions are taken according to some kind of ”average” of members’ preferences (Nilsson 2001), which may not always be optimal for the cooperative as a whole.

Free-riding This problem is associated with a situation in which certain members consume group resources while paying less than their fair share of the full cost of production. The cooperative structure of the firm often creates optimal conditions for such free-riding. For example, growing RPO have internal incentives to borrow capital, since part of the debt and principal service will be covered by members that will join the RPO later. The opposite situation occurs in RPO with decreasing membership. Likewise, when a new member joins the RPO, he can immediately use all assets that were accumulated in the RPO past. Thus, free-riding behavior results in sub-optimal resource allocation.

Limited planning horizon Heterogeneity of members’ ages and their respective time preferences results in variance of their planning horizons. In general, since the individual planning horizon is always constrained by the proximate duration of membership, they tend to be shorter than usual (Nilsson 2001). Also, the horizons of RPO management are limited to the length of their elective terms. All these limitations may hinder the implementation of long-term investments (Chibanda et al. 2009) and result in the choice of development pathways that offer short-term achievements. Thus, the issues of sustainable development may be overlooked.

Need for strong leadership The issue of coordination and mediation of members’ interests and actions creates a need for effective RPO leadership and management. In order to generate more value addition, produce of RPO members must meet complex requirements of national and international value chains. RPO leaders have to possess adequate managerial capacities to ensure the satisfaction of such demands (Arcand 2002, Berdegue 2001). After having synthesized the empirical evidence from 20 African villages, Arcand (2002) concludes that effective RPO leadership is vital for the creation of an RPO’s formal structure, development of RPO activities, and facilitation of access to external networks. Yet, the leaders in the traditional communities often lack the necessary organizational skills (World Bank 2007).

Adaptation to liberalized markets Due to recent developments in the liberalization of markets and the resulting suppression of protective domestic agricultural policies, rural producers around the globe have entered international competition. International agreements of the WTO and the reduction of state influence in the agricultural sector opened domestic markets to imports, and led to the reduction of subsidies and price stabilization mechanisms. In order to be competitive in today’s liberalized economic environment, rural producers have to improve their efficiency through productivity increase and cost reduction. This stipulates one of the major challenges of RPO – improvement of adaptation and innovation capacities.

Openness and participation Not every rural farmer can be included in the RPO, and not all included farmers can affect RPO decision making. Bernard & Spielman (2009), when analyzing reasons of malfunctioning of marketing cooperatives in Ethiopia, revealed a trade-off between a degree of heterogeneity (or openness of membership) between RPO members and the level of positive economic performance of the RPO. Bernard & Spielman (2009) also empirically analyzed decision making within the cooperatives by identifying the decision makers in various collective decisions. This research estimated low levels of participation of RPO members in collective decision making: only 19% of cooperative decisions were open to all RPO members and around 40% of cooperatives excluded their regular members from any decision making. Thus, despite being self-regulating organizations, RPO could fail to include members into the decision-making process, which could be dominated by the interests of the management committee.

Gender inequality The issue of gender equality is relevant for many developing countries. Often opinions and interests of women are neglected. After analyzing the Uganda coffee sector, Golan & Lay (2008) conclude that women face complications in entering markets of high value crops (which are the ones usually linked to RPO) due to significant social barriers. Fair representation of female members and their inclusion in RPO decision making must be ensured.

Reaching the poor From the perspective of rural development, low inclusion of the poor into existing RPO and inhibited potential for formation of the new groups is a problem of cooperative movement in developing countries (Thorp et al. 2005). The lack of assets is the main factor that limits participation of the poorest population segments in RPO. First of all, land ownership is a very important factor: rural landless in many cases are excluded from membership in RPO (Thorp et al. 2005) or are not favored by RPO regulations (Copestake 2002). Low capacities of other assets, such as labor, education, and financial and social capital, results in the inability to make significant contributions to group capital, therefore, such members may not be considered valuable by the rest of the group and as a result may not be included in the group (Molinas 1998). Remoteness of poor areas from markets, transport infrastructure, financial institutions and information about opportunities significantly hinders group formation processes (Meinzen-Dick et al. 2002, Lam 2001), thus also limiting the participation of the poor in RPO. Findings of Bernard & Spielman (2009) suggest that the poor tend to be excluded from membership in RPO, although they receive some benefits from the existence of RPO in the form of spillovers. Also, this research discovered that poorer members of RPO have lower influence in RPO decision making.

Efficiency versus equality Efficiency versus equality is a general subject of the political discussions on various socio-economic levels. This problem also has relevance, when talking about RPO. Ties of social inclusion and solidarity, that are typical for the traditional communities, may cause such conflict (World Bank 2007). On one hand, support of poorer members by wealthier ones is an important income insurance mechanism. On the other hand, obligations to deliver public goods to a community pull the resources from individual households and, therefore, slower their economic growth (Bernard, De Janvry & Sadoulet 2010).

1.1.5 Supporting producer organizations: Lessons from history

In the past, African governments saw and widely used RPO as instruments for implementation of economic policies and, therefore, RPO were closely linked with the state bureaucracy, as Develtere & Pollet (2008) conclude. They state that in the last decades the situation has greatly changed: reforms of economic deregulation that happened in African countries in the early 1990's also changed the perception of RPO. Now, RPO in most African countries are considered profit-generating private entities driven by market demand. This business-oriented approach requires governments to put emphasis on issues like financial viability, solvency, profitability and sustainability of RPO.

Markelova & Mwangi (2010), Chibanda et al. (2009), Hellin et al. (2009), Shiferaw et al. (2008) propose that institutions and governance are the important determinants of RPO performance. Availability and strength of financial institutions define RPO ability to access capital resources, which are needed for investments in durable assets. Government influence is in the determination of rules of the market and in setting up conditions for cooperative operations. Government is responsible for facilitating transmission of market information and developing infrastructure systems. The report of Hussi et al. (1993) stresses that RPO are more likely to succeed in liberalized business environments, where private initiatives are encouraged. It is important to ensure the improvement of the legal and institutional environments of RPO, which will allow for such value adding actions as certification, standardization, fair trade, etc. Stabilization of these environments together with fair rules of competition can form a good investment climate, which would allow for additional financial leverages.

Support for RPO is especially important during the formative and early stages of an RPO's existence (Hellin et al. 2009). Linking organizations with private sector partners is the role of support providers during this period. It is important to remember, that RPO-supporting opportunities often create an additional incentive for RPO to emerge. In these cases, producers are aware that external opportunities exist and that they have to form an RPO in order to benefit from them. Thus, some RPO may appear and function only as rent-seekers from these opportunities, as research by Arcand (2002) shows. Support measures that stimulate opportunistic behavior of RPO lead to the formation of inefficient and unsustainable organizations and waste of resources. For example, Lyon (2003), in analyzing RPO in rural Ghana, concluded that assisting RPO by giving credit privileges is rarely sustainable, since there is no incentive for producers to act as a group after the privileges are withdrawn. Therefore, the matter of effective targeting is relevant for implementation of the RPO-supporting mechanisms. The aim of the support is to trigger RPO formation and to guide their transition to economic independence and sustainability. The key issue in assessing RPO sustainability is an estimation of organizational and operational costs that an RPO would have to bear (Markelova & Mwangi 2010).

One could argue that external support and government assistance are vital for RPO viability. But, the history of cooperative movements in African countries has proven that streaming the support through governmental institutions is likely to be ineffective: instead of empowering RPO, it strengthened government control over them (Hussi et al. 1993). Also, recent evidence from Africa (Wanyama 2008) shows that despite tendencies of state withdrawal from development efforts the cooperative sector in Africa still exists and influences a large part of the economy. In some countries (Egypt, Senegal, Kenya, Uganda) the number of RPO members significantly increased with economic liberalization, which serves as proof for RPO' potential for self-propelling development. One can therefore conclude that the rural development community, donor organizations and government authorities should concentrate on RPO interventions that would target capacity building, rather than temporary resource provisions, which is only justifiable in emergency situations. Investments in group social infrastructure can result in tangible long-term benefits (as the research of Uphoff & Wijayaratna (2000) demonstrates).

As targets for capacity building, Rondot & Collion (2001) propose either technical (functional literacy and numeracy, accounting and financial planning, project implementation skills, etc.) or strategic (strategic planning, analytical skills, etc.) capacities. These actions can stimulate voluntary initiatives for group formation and ensure group sustainability and market orientation, which would lead to a higher demand of rural financial services and trigger the formation and growth of this market. The reduction of external influence can result in the emergence of networks that are more adaptive to changing markets and attentive to members' needs. Lyon (2003) suggests that facilitating information exchange, transparency and mutual monitoring of group activities by establishing understandable accounting procedures is important for fostering cooperation between cooperative members. RPO have to function under self-developed rules, rather than just following externally imposed instructions. This would develop a sense of ownership and members' loyalty, which are essential prerequisites for effective RPO functioning (Markelova et al. 2009, Thorp et al. 2005)).

Markelova et al. (2009), Shiferaw et al. (2008) outline the potentials in involving private sector actors (processors, supermarkets, exporters) in RPO empowerment. The private sector may be interested in ensuring reliable supplies of agricultural products, as well as in enabling farmers to meet certain quality requirements, safety regulations and certification standards. Therefore, agribusiness may be willing to contribute some financial or physical resources to RPO capacities through contract farming, outgrower schemes, warehouse credit systems, etc. According to

Shiferaw et al. (2008), the viability of such arrangements depends on three factors:

- Farmers' ability to comply with quantity, quality and time requirements
- RPO ability to coordinate production and marketing
- Legal and institutional framework for composition and enforcement of agreements

Researchers (Markelova & Mwangi 2010, Bernard & Spielman 2009, Bernard et al. 2008, Lyon 2003) seem to agree that previously followed panacea-like support strategies (one intervention benefits all RPO) have to be replaced with case-specific treatment designs. Due to the functional and organizational diversity of RPO (see Section 1.1.2) they each have different demands in terms of support. For example, for market-oriented organizations the key issue is managerial capacity and for community-oriented organizations it is access to finance (Bernard et al. 2008). Besides, the research of Bernard et al. (2008) shows that RPO response to support measures may vary depending on the country specifics. Also, one has always to take into account, as it is reasonably noted by Markelova & Mwangi (2010), that cooperative mechanisms are not always able to correct market imperfections; other development measures also have to be considered by the donors.

1.2 Main methodological concepts

This section describes core methodological approaches used in this work and justifies their application. The complexity of RPO and the specifics of agriculture in developing countries induced the choice of ABM as the main research tool of this study. This section explains the choice, identifies a place for the approach in the RPO-focused research and outlines its potential in comparison with alternative methods. Therefore, the author also familiarizes the reader with existing approaches of RPO analysis and their specifics: indicators that were used and results that were obtained.

In order to understand the functioning of RPO well, the author met with RPO members and other key informants. This section describes the benefits of stakeholder inclusion and of learning from them by means of participatory methods.

It is clear that cross-fertilization of individual scientific efforts is a major issue in collaborative research projects. With this regard, the author sees the constructed simulation model as an opportunity for possible integration with the work of other collaborators from the project that frames this thesis (see Section 1.3.1). Therefore, the issue of linking computer simulation with empirical research using survey techniques and field experiments was reviewed.

1.2.1 Analyzing rural producer organizations

The application of criteria used in economic analysis of profit-maximizing firms may have its limitations, because of the social orientation of many RPO. Due to the wide range of RPO types (see Section 1.1.2), limited data records, and the multi-objective nature of RPO, various approaches for analyzing RPO performance have been developed in socio-economic research. In analyzing RPO efficiency and the impacts of measures of RPO support it is essential to come up with an assessment system to determine performance indicators. However, little is published about such empirical assessments, especially for the case of Sub-Saharan Africa. Nevertheless, some approaches can be distinguished.

Examining differences in quantitative factors The basic approach of assessing RPO contribution to rural development is capturing income differences between RPO-members and non-members. (Likewise, members of RPO that receive and do not receive support can be compared). This basic and straightforward approach is able to provide informative results as the study of Kenyan pigeon-pea producers of Shiferaw et al. (2008) demonstrates. Shiferaw et al. (2008) inspected the recorded selling prices in different sales channels. By doing so the researchers calculated the price advantages that collective action created. Further, the authors estimated the differences in revenue that appear when using RPO-offered prices. Then these differences were matched with costs of collective action that include membership subscriptions and annual fees and opportunity costs of delayed payments (which occur when selling through RPO). The result of the comparison was a change in income caused by collective marketing. Analogously, Bernard, Spielman, Taffesse & Gabre-Madhin (2010) reviewed differences in output prices and sales volumes between members and non-members of RPO in Ethiopia.

Ranking on quantitative factors To evaluate the effectiveness of collective marketing, Shiferaw et al. (2008) considered two factors: the per capita value of assets produced by an RPO over time and the per capita volume of total sales. To assess the level of collective action within an RPO, the following quantitative factors were used in that study: the attendance of meetings, the share of members respecting bylaws, the number of board elections since formation, the size of annual voluntary contributions, the size of annual membership fees, and the amount of cash at the RPO disposal. RPO then were ranked according to their factor scores. Aggregate mean ranks for the level of and effectiveness of collective action were used as a final evaluation marks.

Members' own assessment Bernard et al. (2008) used the proportion of RPO members that claim to benefit from the organization's presence as an indicator of RPO performance. Thus, the performance measure was based on a subjective assessment of the RPO members. The researchers defined two models for the description of the performance indicator. The first model related it to two independent dummy variables: "control" variable stated whether the RPO has a control commission or a written code of conduct, and "professional management" which stated whether the RPO kept accounting and registration records. For market-oriented RPO, researchers added two more dummy variables: whether the RPO provided public goods (e.g. management of a collective field, casual labor exchange, maintenance of a cereal bank, etc.) and whether it did multitasking. The second model assessed the impacts of development assistance to RPO; it described the performance indicator by three variables that stood for RPO reception of external grants, trainings and loans. After testing both described models on datasets from Senegal and Burkina Faso for two types of RPO (community-oriented and market-oriented), authors were able to draw several case-specific conclusions on parameter correlates, but none of the regression estimates were significant in all of the analyzed cases.

Binary indicators Chibanda et al. (2009), for estimation of RPO performance in their paper, defined 21 indicators related to (i) RPO economic performance, (ii) internal regulations, and (iii) governance of an RPO. Indicators were derived from suggestions of various literature on institutional economics. Indicators could only take values of either 1 or 0 depending on the actual observation. For example, if an RPO was able to generate a positive net surplus to its members, it would get 1 for the "surplus" indicator. Later, based on the scores, RPO were ranked and a cluster analysis was performed. Results of the analysis were also compared with self-assessments of RPO members. Interestingly, Chibanda et al. (2009) observed that RPO members' perception of RPO performance was based only on a few out of many selected indicators. This observation made authors conclude that basing indicators only on the subjective assessment of RPO members (as in the case of Bernard et al. (2008)) may not give the full picture of RPO functionality and efficiency. Results of cluster analysis of Chibanda et al. (2009) conveyed that institutional and governance problems have significance for RPO performance.

SWOT analysis Uliwa & Fischer (2004) performed analysis of Tanzanian RPO from the perspective of their strengths, weaknesses, opportunities and threats (SWOT). In the study, SWOT analysis was used to summarize the authors' opinions obtained from discussion interviews with RPO members. Based on the results of the SWOT analysis, Uliwa & Fischer (2004) drew recommendations for the design of the RPO promoting and supporting program.

Every method from the examples given above has its limitations. For example, both methods applied in the research of Shiferaw et al. (2008) are only considering marketing-related impacts of an RPO. However, the functions of many RPO lie far beyond marketing. Only the approach from the first example (estimation of changes in income) can yield the cost-benefit assessment of external interventions. Members themselves may not connect some of the RPO-inflicted impacts with their RPO (as noticed by Chibanda et al. (2009)). Scores and ranks represent arbitrary expert opinions. SWOT analysis is a highly subjective assessment tool. So, the outcomes of this literature review suggest that existing methods are specific to the goals and objectives of the respective studies and projects. Any comprehensive RPO-exploring approach most likely has to combine various assessment methods, mostly because of wide typology of RPO roles and actions. Such combining requires a certain framework under which the findings of various research activities can be integrated. The advantages of using computer simulation and ABM for this purpose are discussed in the next sections.

1.2.2 Using agent-based simulation for researching RPO

There are certain distinct advantages to using computer simulation for assessing the impacts of the interventions of RPO support and the related policies. Firstly, in the setting of computer simulation, the researcher has all factors under control, which is different in the case of empirical research that use survey techniques and field experiments. Secondly, implementing the simulation model can be much less costly than conducting a survey or socio-economic experiments. Thirdly, real-world experiments typically require substantial waiting time between its implementation and the point, where the results become available. There is also always a risk that the experiment will bring negative effects to a treatment group. Finally, once a model concept is created and a source code is implemented, the model can be scaled up, adapted and reused with minor adjustments.

Capturing heterogeneity The choice of a suitable modeling approach for modeling rural RPO requires deep understanding of household-level heterogeneity and complexity that are common for agricultural systems in developing countries. It is typical to observe large variations in yields, input and labor intensity, etc., as well as a big diversity of land use decisions and choices of farming practices between households in developing countries (Ruben & Pender 2004, Schreinemachers & Berger 2006). For example, an IFPRI household survey conducted in Uganda in 2010 (IFPRI 2010) shows that a Ugandan rural household can sell up to nine different crops and five livestock products in one agricultural season. There are a lot of constraining factors that are causing such diversity: limited resource endowments, poor rural infrastructure, climatic uncertainty, soil degradation, imperfect markets, and so on (Berger et al. 2006). Capturing these variations with aggregate top-down approaches and models may be infeasible, since it would require a large number of control variables. (As it is admitted by Berger (2001), aggregated models cannot capture the individual behavior and, therefore, assume the absence of information and transaction costs.) Breaking the system down into its basic components (agents, networks, environments etc.) and simple rules, frees modeling from prior application of sophisticated mathematical translations (Boulanger & Brechet 2005). In this respect, bottom-up systems modeling (or ABM in other words) is an appropriate tool. Agent-based models (ABM) have played a role in the social sciences since the 1990's. Its use is mostly linked to situations where the complexity of a studied system results in the analytical intractability of the research problems (Nolan et al. 2009). Such problems are too difficult to solve when considering a system as an indivisible object. Multi-agent implementation of the system may provide a solution in these cases. ABM serves well for the incorporation of bounded rationality – assumptions of limited information, constrained resources and analytical capabilities of agents. As Section 1 showed, RPO are the systems for which all these issues apply.

Precision and multidimensionality Given the heterogeneity of biophysical and socio-economic constraints, ”one size fits all” type of policies are unlikely to be effective in the less-favored areas (Ruben & Pender 2004, Berger et al. 2006). Development interventions are required to be precisely targeted on removing most binding constraints and supporting most vulnerable households and groups. ABM can support the design of development policies providing information for ex-ante evaluation of possible interventions (Berger et al. 2006). For example, Latynskiy et al. (2010) and Troost et al. (2010) used multi-agent systems (MAS) to identify households whose incomes were sensitive to variability in irrigation water supply. Table 1 provided in the introduction to this thesis characterizes the suitability of MAS for the purposes of sustainable development policy making.

ABM allows for multi-level analysis of agricultural systems: starting from crop, plot and farm levels it can go to household, community and regional levels (Schreinemachers & Berger 2011, Boulanger & Brechet 2005), thus adequately representing micro-macro relationships. One-to-one correspondence between model agents and their real-world prototypes (typical for ABM), will ease the interpretation of simulation results Schreinemachers et al. (2010). Hence, ABM of RPO will allow for the capturing of interventions effects on individual households and, therefore, improve the assessments of intervention efficiency. Likewise, MAS implementation allows for the assessment of the impact of point interventions in terms of the entire system. For example, Troost (2009) applied MAS for analyzing the effects of public subsidies for advanced irrigation technologies in Chile. Hoffmann et al. (2002) tackled impacts of deforestation and reforestation policies. Works of Schreinemachers et al. (2007), Latynskiy et al. (2010) and Wossen et al. (2010) also showed the ability of MAS to provide information for multi-indicator assessments. These authors quantified impacts of changes in terms of income, poverty, inequality, productivity, etc. Such multidimensional analysis is desirable for the current research, since (i) the impact of interventions has to be assessed on both household and organizational levels and (ii) different impact indicators have to be taken into account.

Limited knowledge and learning The agent-based set-up of the model is well-suited to the cases that assume agents’ limited knowledge and learning abilities. The assumption about limited knowledge is reasonable, since real-world economic actors cannot give perfect predictions for the uncertain parameters such as prices, climate and crop yields, and cannot account for all of the factors that define them. With regards to the second assumption, it is clear that individuals consider at least their personal experience in their decision making. The fine resolution of MAS allows for the registration of disaggregated household experiences with regard to prices, yields and other uncertain factors (Latynskiy et al. 2010, Wossen et al. 2010, Schreinemachers 2006).

The implementation of learning in the model enables simulations of adaptive behavior, since an agent would base its decisions on constantly updated information.

Interactions Rural communities and their RPO are characterized by complex systems of interactions. The modeling of representative households may miss these interactions, while in MAS they can be included explicitly (Lobianco & Esposti 2010, Schreinemachers et al. 2010, Berger 2001, Deffuant et al. 2002). Therefore, ABM has strong advantages over conventional equation-based modeling aggregated on the levels of region or sector, when dealing with problems of agent coordination and strategic interaction (Janssen 2005). The formulation of an RPO-model in an agent-based way is expected to simulate endogenously formation of RPO member surplus and price advantages, depending on agent decisions.

Agents may not only interact with each other, but also with an environment, thus redefining its state. This feature of ABM will allow inclusion of agent-specific external factors (Schreinemachers et al. 2007).

Data integration In developing countries like Uganda, reliable aggregate data are hardly available. The flexibility of ABM permits the incorporation of segmented information from various sources, such as nation-wide population censuses, project-specific sample surveys, expert opinions, researchers' own experience, and so on (Berger 2001). This is a strong advantage for this study, which has limited resources for the collection of own datasets and must incorporate sets of external data.

There are several technical solutions that can potentially serve for implementation of the ABM approach for modeling of agricultural systems (Schreinemachers & Berger 2011), such as AgriPoliS (Balmann 1997, Happe et al. 2006), PALM (Matthews 2006), RegMAS (Lobianco & Esposti 2010) and others. As mentioned in the introduction (page 5), for the implementation of the ABM of Ugandan RPO the author chose MP-MAS (Mathematical Programming-based Multi-Agent Systems). This software was designed by the development team (team members are listed in Schreinemachers & Berger (2011)) stationed at the UHOH chair of Land Use Economics in the Tropics and Subtropics (Josef G. Knoll Professorship). A detailed description of MP-MAS software can be found in Schreinemachers & Berger (2011) and a description of its adaptation and extensions for current research is in Chapter 3 of this thesis. The software choice was made for a number of practical reasons:

- MP-MAS is most suitable for semi-subsistence agriculture (Schreinemachers & Berger 2011), which is the type of agriculture in the current research case study. The software has an integrated sub-model of household own consumption, which is important in the case of semi-subsistence farming.

- MP-MAS was previously successfully applied by Schreinemachers & Berger (2006) for modeling the coffee-banana production system of the lake-shore area of Uganda. Hence, some parts of software parameterization and methodology could be reused (e.g. the integrated crop growth model).
- The author has experience in modeling with MP-MAS from previous research (see Latynskiy et al. (2010)). Therefore, he was familiar with some of the theoretical concepts and equation forms, that lie behind the software, as well as with the structure and formatting of MP-MAS input and output files.
- MP-MAS programmers agreed to assist in making the necessary changes to the software code that were necessary for the RPO-modeling of the current research. At the same time, flexible MP-based structure of the MP-MAS decision module (see Chapter 3) allowed many extensions and adaptations to be done without having the software code changed.

1.2.3 Linking computer simulation with empirical research

For decades empirical research methods have been widely used in agricultural and social sciences, while simulation modeling is a relatively new, but dynamically developing instrument of research in these fields. These two approaches have much in common, because they both test the impact of certain interventions on the studied object (or system) with the goal of describing it. Therefore, some authors (Eck & Liu 2008, Duffy 2006) use the terms ”empirical” and ”simulated” experimentation, when referring to real-world experiments and computer simulations. The ability to address similar research problems raised issues of choice between empirical methods and computer simulations and the identification of opportunities for joint usage of both approaches. For example, Duffy (2006) compared the empirically obtained results from real-world controlled experiments (performed with human subjects) with simulated results from its virtual imitation (performed with artificial agents in computer simulation) and did so in different conceptual set-ups. His findings show that in some study cases, computer simulation and empirical methods can be good substitutes, in others they provide complementary results. Table 1.1 analytically compares simulation modeling with common methods of empirical research in agricultural economics: analysis of field data using statistical techniques, field and laboratory experimentation. From the table it can be seen that, despite some similarities, the approaches are different and, therefore, may serve different purposes.

As Table 1.1 suggests, the advantage of model simulation over experiment is the low requirement in terms of research arrangements. Firstly, modeling does not demand real world implementation of interventions. Secondly, in order to investigate the impact of certain changes, computer simulation models do not necessary demand the collection of real-world data, since they simulate the required data themselves. Empirical research methods, in turn, rely only on real-world observations. Respectively, computer modeling provides almost unlimited opportun-

Table 1.1: Comparison of computer simulation and empirical research

	Simulation	Field data	Field experiment	Lab experiment
Mechanism	required	not required	not required	not required
Data collection	not required	required	required	required
Real-world implementation	not required	happened naturally	required	required
Manipulation	extensive	restricted	limited	limited
Internal validity	varies	low	medium	high
External validity	varies	high	high	low
Replicability	high	low	medium	high

Source: Author, based on Eck & Liu (2008), Roe & Just (2009)

ities in factor manipulation, which is limited in real-world settings. However, empirical research methods have strong advantages, when the system mechanism (rules of behavior, interactions, rationality bounds, etc.) is unclear, while simulation modeling requires a solid theoretical concept as its foundation. In cases in which computer simulations and empirical research methods are equally powerful in analyzing studied phenomenon, cost and time requirements of method application have to be taken into account.

When talking about possible complementation, there are several ways to integrate simulation models and empirical research. Firstly, empirical evidence can be used as an input for model development: findings from empirical research can provide simulation models with basic assumptions regarding the system mechanism. Secondly, empirical data and experimental results may serve as an external calibration and validation benchmark for simulation models. In this case, during the construction of a simulation model one seeks to reproduce empirically-obtained results; Janssen et al. (2009) calls this procedure ”pattern-oriented modeling”. Current research practice in linking computer simulation and experimental findings is mostly related to this technique. Likewise, Ebenhoeh & Pahl-Wostl (2008) reproduces several social experiments on dictator and investor-trustee games with their MAS built on the assumptions drawn from the Ostrom (2004) theory of collective action, Janssen & Ahn (2006) models with MAS learning and signaling in public good games. By comparing simulation outputs with the results of analogous empirical work, researchers judge the validity and applicability of the theoretical framework based on which simulation model was constructed. If a model can accurately replicate a certain empirically-observed behavior, then such a model can be used for the related simulations over time-frames that are substantially longer than in experimental studies. Also, such models validated on empirical findings can be extended to simulate the circumstances for which representative empirical settings cannot be designed, because of overwhelming costs and the inability to manipulate certain factors because of ethical or other reasons. Simulations, in their turn, may help to better design the empirical research, by providing the precautionary information on expected outcomes and their distribution in time and space. Such information may support data collection, the selection and targeting of interventions, and the organization of post-experimental surveys. Finally, simulations can extrapolate empirical findings on larger scales, thus revealing system effects of the relationships.

As this section shows, computer simulation is not a substitute for the empirical approach. It is rather an instrument that can extend, support and complement empirical methods. Therefore, the researcher's role in this regard is to make practical use of the potential synergy of these two approaches.

1.2.4 Learning from stakeholders

One of the particulars of scientific computer models is that often at the beginning of model development not all the specifics of the studied system are clear: many issues and complications may be unanticipated. This implies that the research has to be designed in an adaptive (*agile*) fashion, instead of using a predictive loom with strict frames, which is more common for business computer models. Collaborative research is the fundamental stone of this *agile modeling* approach. Joint learning helps to ensure the relevance and usefulness of the study and stimulates practical applications of its results. Starting in the late 1980's, many development studies began to emerge that concentrated on such issues as stakeholder ownership of policies, targeting and cost-efficiency, inclusiveness of the poor, transparency and accountability (Pretty 1995). Therefore, participation of stakeholders and scientific approaches ensuring it came in focus. Considering that stakeholders of research projects in applied sciences are often the ones to bear the effects of practical applications of the findings, in the author's opinion they have the moral right to participate in the research activities or at least to be informed about the research progress. Therefore, D'Aquino et al. (2003) see workshops, discussions, social experiments and games as "an interface between computer modeling and people" that supports mutual understanding and dialogue between stakeholders and researchers. Participatory approaches help to build more trust between the researcher and respondents (Castella et al. 2005), thus stimulating better information exchange. With regard to modeling, Berger et al. (2010) note that collaborative scientist-stakeholder research helps to achieve the following objectives:

- Improvement of model input data
- Ensuring the relevance of the model to posed research questions
- Provision and demonstration of created decision support systems for the local users

Boulanger & Brechet (2005) argue that, in order to be able to allow for stakeholder participation, a simulation model has to be capable of (i) integration of the insights obtained from the participants and (ii) communication of model results. Given the specifics of MAS (discussed in the Section 1.2.2), it is a suitable set-up for the integration of various types of knowledge and ensuring stakeholder participation at different stages of the research (Berger et al. 2010, Becu et al. 2008, Boulanger & Brechet 2005).

In order to make the MAS valid and simulation results applicable, one has to assess and incorporate real-world decision alternatives and the rules of decision making and interactions. Since stakeholders are often the prototypes of MAS agents, who can better explain these rules and alternatives than the stakeholders themselves? Works of Berger et al. (2010), Troost et al. (2010) and Castella et al. (2005) show that the involvement of stakeholders in different stages for modeling may be very beneficial for the quality of MAS. There are different ways to use stakeholder knowledge while constructing a simulation model. For example, Castella et al. (2005) drew the rules for agent behavior in MAS from stakeholder actions in the role-playing game. D'Aquino et al. (2003) organized members of a rural community to self-design a MAS by sketching GIS-maps and defining behavioral rules. Berger et al. (2010), Latynskiy et al. (2010) and Walz et al. (2007) captured the knowledge of the participants during discussion interviews or a workshop. The "Integrating Governance and Modeling" (IGM) project within the CGIAR Challenge Program on Water & Food led by Berger et al. (2010) organized interactive model validation sessions with stakeholders during which the MAS structure and assumptions were discussed and revised. The close interaction with stakeholders helped the IGM project team to create MAS-based decision-support tools for local water user associations (see Latynskiy et al. (2010) and Troost et al. (2010)). During the later sessions, the tool was distributed among the respective authorities. Some research (Walz et al. 2007, Castella et al. 2005, D'Aquino et al. 2003) incorporated stakeholders into the identification of model use cases and design of simulation scenarios.

A variety of modern participatory approaches have been developed in recent years: participatory rural appraisal, rapid rural appraisal, soft systems methodology etc. These approaches commonly lean on one or several of the following cornerstones (based on Pretty (1995)):

- Facilitation: Employed methods have to create an awareness of studied issues, provide an environment for thinking and discussion, and stimulate stakeholder participation.
- Group learning: An interactive group set-up ensures that different opinions are represented. Learning in such a set-up is more efficient. Also, group work produces more output, since group member ideas spread inside the group and facilitate the emergence of follow-up ideas.
- Visualization: The aim is to record the flow of the participatory work, to provide a better and a simpler understanding, and to support deeper analysis. Visualization in comparison with discussion involves respondents better and focuses the dialogue. Replacing the writing communication channel with symbols can bridge literacy gaps and ensure the inclusion of all participants in the group work.
- Adaptation to context: Flexibility of research methods and tools have to allow to adapt them to different conditions and respondents.
- Multiple perspectives: Different views on the research questions provided by different individual responses create a more complete picture of the studied phenomena in compar-

ison with aggregated data.

The implementation of the participatory approaches could be done through various scientific methods and techniques for sampling, interviewing, group work and visualization. Any participatory approach is nothing more than a package, a selection of particular methods and techniques. The choice of the methods is defined by specifics of the given study frame and research questions. The participatory methods used in this study are described in Section 2.1.

Along with all the benefits that participatory approaches may bring to agricultural studies, one also has to be cautious about the challenges associated with stakeholder-led research. Van Asten et al. (2009) classifies these challenges into three categories:

- Insufficient understanding of system complexity: Stakeholders' understanding of the system may be incomplete or mistaken.
- Different reference frameworks: Scientists are usually interested in obtaining generalized knowledge on the studied phenomenon, but stakeholders' knowledge is likely to refer to particular locations (e.g. each farmer would describe his own field), situations and cultural paradigms. Farmer responses may be unclear and difficult to analyze quantitatively.
- Methodological errors: Methods of data collection may lead to biased responses. Farmers may provide false information if they think that a particular response would attract development assistance from the research project. Another well-known example of information distortion happens when respondents, in order to appear competent, fabricate answers instead of declining to respond.

The above listed matters may result in extra degrees of model uncertainty linked to the inaccuracy of the model input data. With this it can be concluded that the acquisition of valuable stakeholder knowledge also demands that the researcher cross check for possible biases in responses and weaknesses in the participatory research methods applied.

1.3 Characteristics of the research setting

This thesis was written in the frames of international research project (described in Section 1.3.1) in Senegal and Uganda. This chapter describes the placement of author's individual research in Uganda within the framework of a broader project and links it to project objectives and research activities. The chapter characterizes the specifics of Ugandan context by guiding the reader through country-wide, industry sector and study area levels. Historical and current phenomena, developments and tendencies observed on these levels are described here.

1.3.1 IFPRI–IZA–UHOH Project "Working together for market access"

The three-year joint research project "Working together for market access: strengthening rural producer organizations in Sub-Saharan Africa", funded by the German Federal Ministry of Economic Cooperation (BMZ), was implemented in the period of 2009–2012. This project was part of a larger IFPRI-led research program "Institutions and Infrastructure for Market Development". The program explores various policy and development topics related to the role of rural infrastructure and institutions in improvement of market access of smallholder farmers. Apart from rural producer organizations, the program investigates aspects of contract farming, urban-rural linkages, poverty reduction, weather securities, irrigation and power subsidies, etc. The results of the program are open to the public; they provide strategic knowledge on addressing the needs of rural households in developing countries through institutional and infrastructural improvements. The main collaborators of the "Working together for market access" project were: (i) the International Food Policy Research Institute (IFPRI), Washington, DC, (ii) the Institute for the Study of Labor (IZA), Bonn and (iii) Universitaet Hohenheim (UHOH), Stuttgart. The project's field work took place in two Sub-Saharan African countries: Senegal and Uganda. Since the support of smallholder commercialization through RPO is recognized as critical for rural agricultural development (it is one of three development strategies identified in World Bank (2007) Development Report dedicated to agriculture), the findings of the project may be relevant in other developing countries.

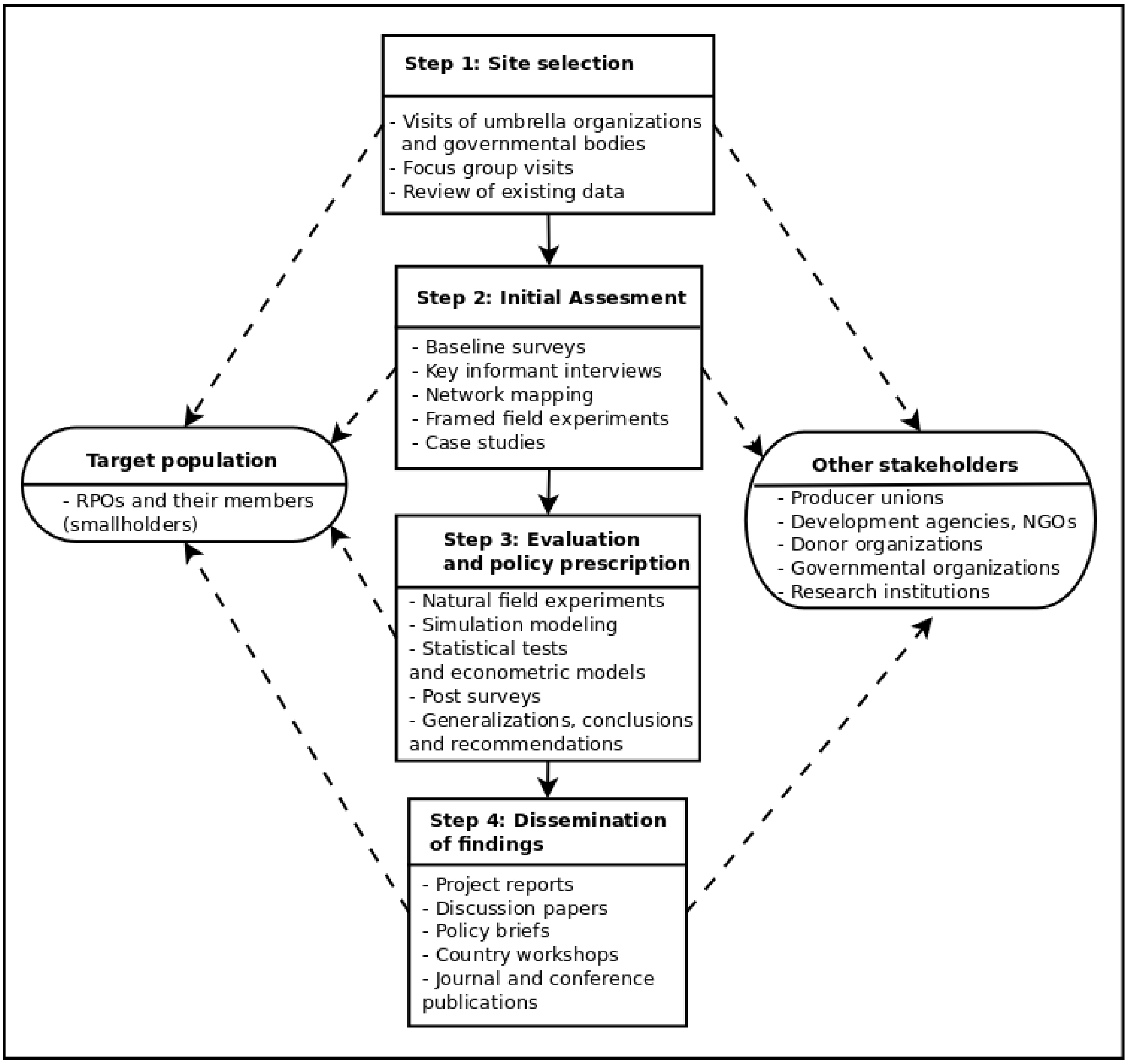
The main goal of the project was **analysis of the abilities of RPO to improve their members' access to input and output markets**. The project research objectives were formulated as follows:

- Identification of interventions that can improve RPO members' capacity to access and benefit from input and output markets
- Elaborating and testing universal schemes of RPO-leadership and members' collectivization that can improve RPO performance
- Assessing the impact of RPO-empowering measures on rural livelihoods and local input and output markets

The present research focuses on the Ugandan case, and was linked under one framework with the research activities of other project collaborators (see Figure 1.2).

The baseline project survey (IFPRI 2010) was conducted in Uganda from March to April 2010 on three different levels: county or sub-county level RPO (typically called in Uganda either "depot committee" – DC or "area cooperative enterprise" – ACE), village level primary RPO (called simply "producer organization" – PO) and household (for the distinction between DC/ACE and PO see Section 1.3.2). The survey covered 21 DC/ACEs from different districts of the country; each of the DC/ACE from the sample is focused on the marketing of one specific agricultural commodity. The majority of the sample DC/ACEs (12 out of 21) were occupied with marketing of robusta coffee, 4 – with marketing of arabica coffee, 4 – maize and 1 – plantains. The PO part of the survey was conducted in 375 POs, which are located under the umbrellas of sample DC/ACEs. The questionnaires for the POs and the DC/ACEs were similar in structure

Figure 1.2: Project framework



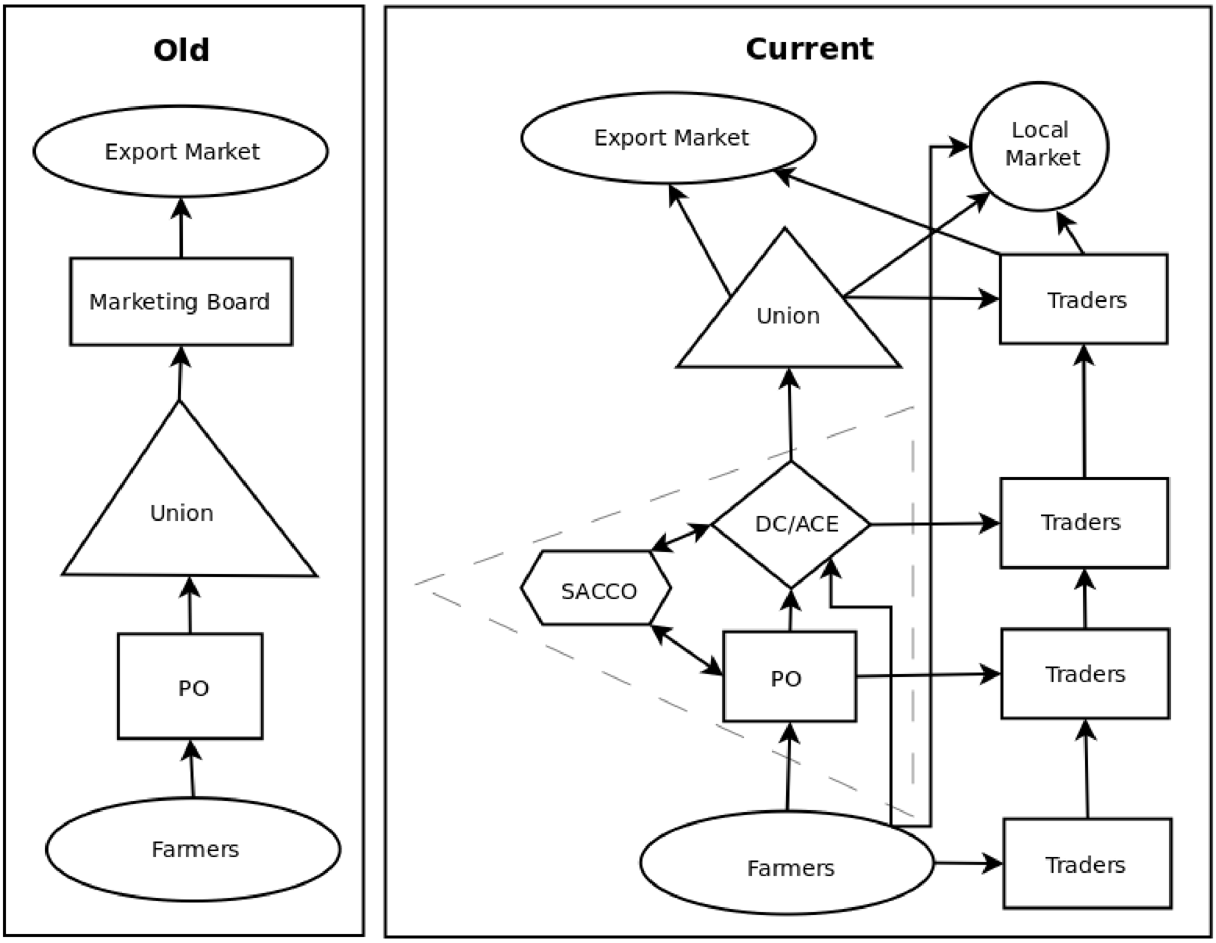
Source: Author, based on project documentation

and their main topics were: leadership, membership, group activities and decision making, financial and information services, trade partners, and sales quantities. The questionnaire used simple exercises to assess the leaders' capabilities in basic financial mathematics. The dictator game was played with leaders and members. In addition, the DC/ACE part of the survey addressed the topic of group certification. The household sub-survey approached two randomly selected households from each PO from the sample. This household sub-survey addressed questions of labor and land use, agricultural production systems with the main focus on coffee growing, marketing and consumption of the produce, income structure, household relationships with RPO, and use of its services. Also, the household part of the survey recorded farmers' time preferences in coffee transactions.

1.3.2 Rural producer organizations in Uganda

Historical development Organizations of agricultural producers were first formed in Uganda in the beginning of the 20th century and were traditionally involved in the marketing of coffee and cotton. For a long time local RPO were mostly state-managed, until market liberalization reforms were undertaken by the Ugandan government in 1990's. Rapid liberalization of markets and the consequent increase of market competition led to the excessive failures of those existing organizations (Kasozi 2008, Mrema 2008). The strict hierarchical top-down structures of the organizations (see Figure 1.3) of that time were not efficient in the free market (Kwapong & Korugyendo 2010, Kasozi 2008). In that old market configuration farmers delivered their produce to the PO and then it was aggregated at the level of producer unions and delivered to marketing boards. Government-owned marketing boards served as exclusive market regulators, buyers, processors and exporters for agricultural commodities. As Kasozi (2008) states, that administrative power of marketing boards stimulated them to behave as rent-extractors from farmers and primary processors by dictating prices and controlling quality.

Figure 1.3: Configurations of collective marketing in Uganda

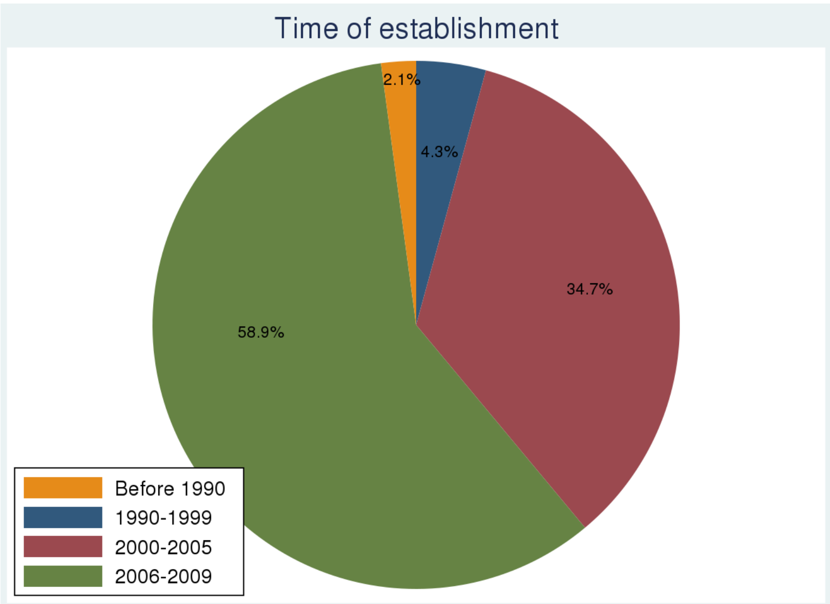


Source: Kwapong & Korugyendo (2010)

With the liberalization, a class of intermediate commodity traders appeared in the market, providing alternative selling opportunities for the farmers, which resulted in reduced turnover of unions and their unprofitability. The relaxation of market restrictions led to the emergence of a large number of processors and exporters (Kasozi 2008). In response to new market circumstances a new decentralized and self-regulated framework of agricultural cooperative marketing emerged (see Figure 1.3). In this new market configuration farmers have more sales channels at their disposal and, therefore, more bargaining power. Strong competition for farmers' produce among exporters and middlemen resulted in better trade conditions for farmers and their organizations (Kasozi 2008, Baffes 2006).

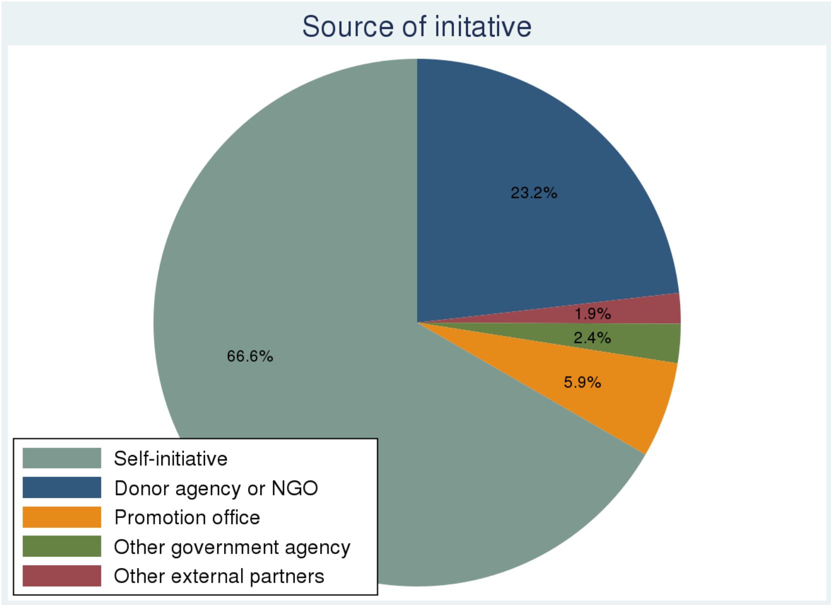
Despite the reduction of the state development support in the cooperative sector, the new market configuration led to a quick expansion of RPO marketing schemes in Uganda in the 2000's. As the IFPRI (2010) survey discovered (see Figure 1.4), the vast majority of functioning RPO were established after 2000. This survey outcome supports earlier findings of Wanyama (2008), who estimated that with the economic liberalization, the cooperative sector in African countries (Egypt, Senegal, Kenya, Uganda) had grown. Figure 1.5 reports that most of the RPO were self-organized, which underlines RPO potential for self-propelling development.

Figure 1.4: Time of RPO establishment



Source: Own calculations, based on IFPRI (2010)

Figure 1.5: Initiative to establish a RPO



Source: Own calculations, based on IFPRI (2010)

Functions and services As assessed during the project, RPO in Uganda are mainly occupied with the marketing of produce and the generation of additional value by means of product transformation, grading and/or packing. Commonly, they are formed according to the one or several agricultural commodities that they market (coffee, maize, sunflower, etc.). In most cases, producers are organized on two levels:

1. Primary farmer society (PO) unifying farmers from the same village or parish
2. Sub-county or county level associations, usually called depot committees (DC) or area cooperative enterprises (ACE)

Typically, the PO is responsible for bulking the produce of individual farmers and coordinating transport for delivering produce to the DC/ACE. Collection of PO-gathered quantities, product transformation, value addition, coordination of market sales and input procurement is organized at the DC/ACE level. Farmers may deliver their produce to the DC/ACE individually, bypassing the first level of the organization. DC/ACE is a small-scale producer union consisting of several POs from the same sub-county or county. It is usually not tied to a certain buyer and is able to bargain for better deals. Furthermore, the DC/ACE may be a member of a country- or region-wide union or federation, like the National Union of Coffee Agribusinesses and Farm Enterprises (NUCAFE), the Uganda National Farmers Federation (UNFFE) and others. These umbrella unions have advocacy and representative functions, they serve the lobbying interests of agricultural producers, facilitating access to buyers, financial services and certification schemes. Also, if a competitive marketing chain has already been developed, the umbrella organizations can buy agricultural commodities from the DC/ACE, but are not obliged to do so, contrary to unions from the past that collapsed because of this.

As shown in Figure 1.3, DC/ACE faces competition from middlemen traders. DC/ACE competitive advantage is efficiency (in comparison with individual sales to traders), which is gained by reducing transportation and marketing costs. Members of the DC/ACE save on the commission of village traders, since the DC/ACE performs bulking and transportation services by itself. But on the other hand, additional costs may arise. They are associated with time delays during bulking, when farmers have to wait for a coordinated sale to be made. Therefore, in order to attain a higher turnover rate and stimulate farmers to sell their produce through the DC/ACE, it offers a range of additional services (listed in Table 1.2). The most common services are associated with agricultural extension (95.2% of sample DC/ACEs), marketing (90.5%), and the provision of market information (81%). With regard to service provision, Kwapong & Korugyendo (2010) underlined an important role of savings and credit cooperative organizations (SACCOs) in the restructured model of cooperative marketing. SACCO provides financial services for its registered members. DC/ACE may use SACCO accounts to transfer payments for the produce delivered by the farmers. Also, producers may acquire short-term loans in SACCOs by using their delivery records at DC/ACE as a guarantee of repayment. Together with POs and DC/ACEs, SACCOs form a triangular system of cooperative marketing. These organizations supply farmers with material inputs, financial resources and market linkages. However, as noted during field work in Uganda, in the majority of rural areas SACCOs are still not present.

Table 1.2: DC/ACE services

	Frequency	Percentage
Agricultural extension	20	95.2
Marketing	19	90.5
Provision of market information	17	81.0
Paying cash on delivery	11	52.4
Transporting	11	52.4
Input procurement	10	47.6
Processing	8	38.1
Savings accounts	7	33.3
Credit provision	5	23.8
Certification	5	23.8
Warehouse receipt system	4	19.0
Grading	3	14.3
Emergency funds	2	9.5

Source: Own calculations, based on IFPRI (2010)

Membership Table 1.3 provides some statistics on cooperative membership. One DC/ACE unites 23 POs on average and 17 on median. The number of members in a DC/ACE varies significantly from around 150 persons in the smallest DC/ACEs, up to around 3000 in larger ones. The number of members in a PO is not so differential and is around 10–40 members. The presence of women and youth in cooperatives also varies; on average sample DC/ACEs are 36.4% female and 25.3% young (24 years of age and younger) members, 31.4% and 29.8% on median, respectively.

Table 1.3: DC/ACE membership

	Members total	Percent of women	Percent of youth	PO total	PO size, members
Mean	1006.6	36.4	25.3	23.3	33.8
Median	550.0	31.4	29.8	17.0	24.0
10th percentile	154.5	18.4	8.3	9.0	12.0
25th percentile	251.5	25.7	10.0	12.0	16.0
75th percentile	857.5	44.4	36.6	27.0	30.0
90th percentile	2975.0	70.0	40.0	35.0	37.0

Source: Own calculations, based on IFPRI (2010)

Constraints There are several constraints that are hindering the development of the DC/ACE-based system of cooperative marketing. During the IFPRI (2010) survey, administrations of DC/ACEs were asked to list the three most important constraints that the DC/ACE was facing. Table 1.4) provides the results of the self-assessment. The most frequently mentioned constraint was ongoing liquidity (reported by 57.1%of DC/ACEs) and transportation (52.4 %). Low liquidity forces DC/ACE to delay payments to farmers for the delivered quantities; such delays may prevent farmers from selling their produce through the DC/ACE. Low transportation capacities lead to additional transaction costs, which are associated with vehicle hire. There are also matters, which, despite being rarely mentioned, receive the highest importance rankings. This means that their occurrence might lead to a notable decrease in market efficiency for the DC/ACE. Such constraints include mistrust among members, poor management skills, and limited access to market information.

Table 1.4: Constraints faced by DC/ACEs

	Frequency	Percent	Mean Rank *
Liquidity	12	57.1	1.9
Transportation	11	52.4	1.7
Lack of storage capacity and packaging materials	8	38.1	1.6
Capital	5	23.8	1.8
Lack of processing facilities	3	14.3	2.3
Low quality of produce	3	14.3	2.0
Price uncertainty	2	9.5	2.5
Inability to offer competitive price	2	9.5	2.0
Lack of market information	2	9.5	1.5
Lack of production-related information	1	4.8	3.0
Crop diseases	1	4.8	3.0
Competition from middlemen	1	4.8	3.0
Bad image of RPO from the past	1	4.8	3.0
Low qualification of personnel	1	4.8	2.0
Limited trust among members	1	4.8	1.0
Poor management skills	1	4.8	1.0
Problems with electricity supply	1	4.8	1.0

Source: Own calculations, based on IFPRI (2010)

* Rank 1 indicates most important constraint; 2 – second most important; 3 – third most important

1.3.3 Coffee sector in Uganda

Economic and social role For decades, coffee has remained the most important cash crop and the main export product in Uganda. The latest statistics of BOU (2013) estimated that coffee comprises 15.1% of the total value of Ugandan formal exports. According to FAO (2013) data from 2011, Uganda is the second largest coffee producer in Africa (after Ethiopia) and the 11th largest in the world. There are approximately 500,000 coffee producing households in Uganda (UCTF 2013). In total, the coffee sector provides jobs for around three and a half million people (UCDA 2013). In the regions of Uganda that are suitable for coffee growing, coffee sales are a major source of income for 74% of households (UCTF 2010). Around 23% of farm revenue of coffee-growing households comes from coffee sales (Hill 2006). These numbers indicate the vital role of Uganda's coffee sector for the well-being of its citizens.

According to ICO (2013), in 2011, 95.3% of the country's coffee production was exported. Of this export volume, 78.4% is robusta coffee (*coffea canephora*) (ICO 2013), which is an indigenous variety of Central Uganda that can still be found growing in the wild. The remaining 21.6% of export volume is arabica (*coffea arabica*). Large areas of Uganda are home to robusta trees, especially the periphery of Lake Victoria and the western and eastern areas of the country. Arabica is common at higher elevations (1500–2300 m): Mount Elgon region at the Kenyan border, Mount Rwenzori region and the West Nile region (Masiga & Ruhweza 2007, Musoli et al. 2001). Estimates of average coffee production are given in Table 1.5.

Table 1.5: Average annual coffee production in Uganda

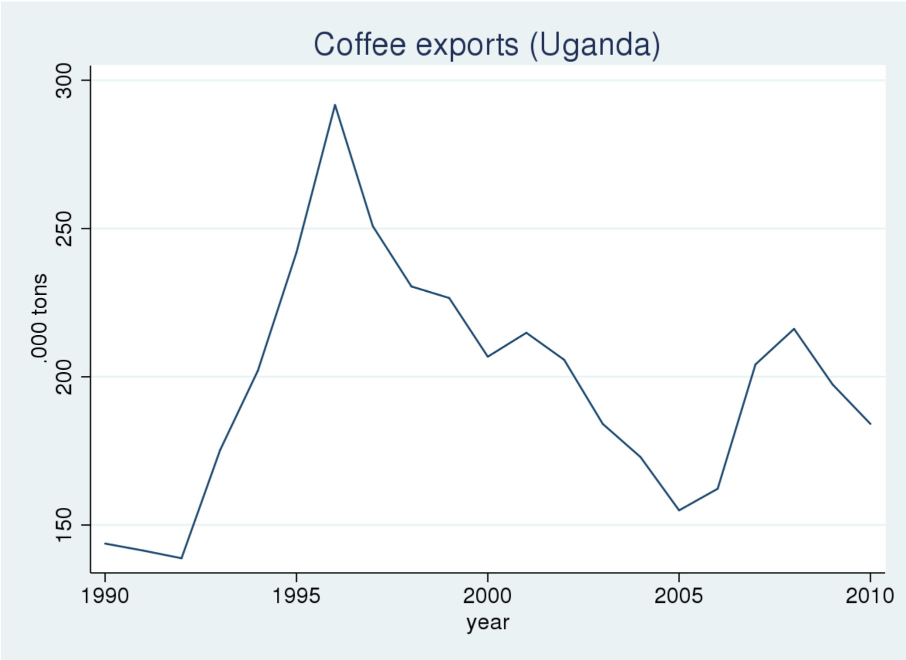
	Robusta		Arabica	
Region	Acreage, ha	Production, tons	Acreage, ha	Production, tons
Central	190,000	113,000	0	0
Eastern	21,000	12,600	21,000	12,600
Northern	0	0	1,700	1,030
Western	32,600	19,610	5,700	3,420

Source: Own calculations, based on Musoli et al. (2001)

History of the sector Coffee-growing in Uganda has a long tradition. In ancient Buganda, beans of robusta coffee were used for ritual and ceremonial purposes (Musoli et al. 2001). Commercial coffee cultivation (of the arabica variety) was introduced in Uganda at the beginning of 20th century by British colonial authorities. In parallel with arabica, smallholder farmers started to focus on market-oriented robusta growing, since this variety requires fewer inputs and can be grown in lower altitude areas, which typically have better market access (Baffes 2006). Until the time of the civil wars, coffee production in Uganda expanded constantly and reached 220,000 tons of export quality coffee in 1972, and then reduced substantially because of conflicts and poor government policies (Musoli et al. 2001). In the 1980s, the coffee industry recovered and returned to previously achieved levels. The sector improved steadily in the early 1990s, when it underwent a series of successful liberalization reforms: the abolishment of export taxes and minimum prices, the reduction of non-tariff barriers and ensuring competitiveness in sales to the government. As a result, the producer share of export revenues rose from 20% to 75% (Kasozi 2008, Baffes 2006), which led to a significant improvement in growers' livelihoods and decreased poverty rates (Deininger & Okidi (2003) and Bussolo et al. (2006) revealed increases in income elasticities and poverty reduction in relation to coffee price).

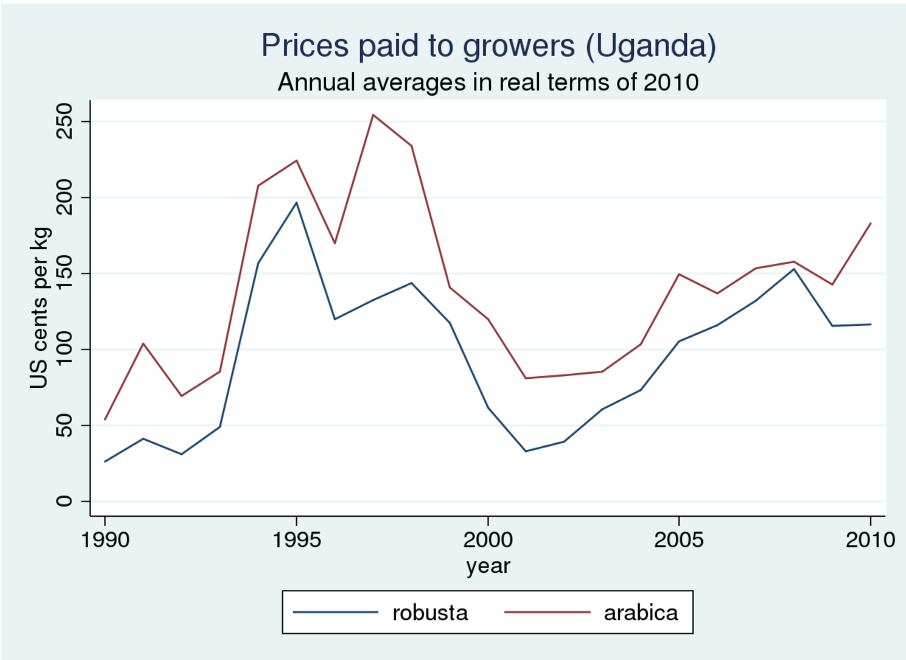
The liberalized market, however, tends to be vulnerable to global price shocks, because of the export orientation of coffee production, as around 95–97% of Ugandan coffee is sold for export (ICO 2013). Figure 1.7 displays the changes in producer prices in Uganda (as recorded by ICO (2013)). The reforms of 1991 led to high variation in local coffee prices: the relative standard deviation of producer prices of 1992–2010 was 49.6% for robusta and 38.9% for arabica. Because of such price fluctuations, farmers, traders and exporters are exposed to a price risk. Coffee is mostly grown by smallholders: 70.3% of coffee-growing households have fewer than five acres of land (Hill 2010*b*). Small subsistence-oriented farmers in developing countries (like most of Uganda's coffee growers) typically have low risk coping capacities. As a result,

Figure 1.6: Exports of all forms of coffee from Uganda



Source: Author from ICO (2013) data

Figure 1.7: Producer prices of coffee in Uganda



Source: Author from ICO (2013) data

90% of the coffee farmers during 2000–2003 were unable to satisfy their basic needs during the period of the low coffee prices (Hill 2006). Figures 1.7 and 1.6 suggest that coffee exports (i.e. production) respond to the price changes, which are driven by the price movements on the world market. The production response is likely to have a lag of one to two years with respect to the price changes.

Value chain and common production practices Drinking coffee-based brewed beverages is the most popular form of coffee consumption. Prior to this consumption a coffee bean goes through several stages of product transformation and value addition. Some of the steps, like brewing or roasting, are often performed by the end consumers themselves. Figure F.1 shows the value chain of robusta coffee and provides definitions for products that appear on different stages of the chain (by-products such as coffee husks are not considered in the figure).

Local coffee is usually grown without the application of fertilizers. Mineral fertilizers are rarely applied (relevant for 2% of the plots Pender et al. (2009)); typically manure, compost, crop residues and household refuse are used instead. Van Asten et al. (2011) reported that manure is applied on 60% of intercropped robusta/banana plots and 62% of mono-cropped robusta plots. Other soil management practices include investment in drainage trenches (27% of plots) and tree sheds on the plot boarders (14%), rarely in grass strips, terraces or irrigation canals (Pender et al. 2009). Smallholders traditionally intercrop coffee with food crops, mainly banana (in this case coffee is grown in the shade of banana leaves) (Oduol & Aluma 1990): approximately 80% of coffee plots in the country contain banana plants (Pender et al. 2009). The results of the partial budget comparison done by Van Asten et al. (2011) explains this pattern: the authors estimated investment in plots with intercropped robusta and banana to have a 100% higher rate of return (on current price and wage levels) than plots with robusta as a monocrop. Besides, the presence of shade trees on a coffee plantation might be beneficial, because it is natural for the coffee plant to grow in shade, but there is a lack of experimental findings in the Ugandan context to make a distinct conclusion on this issue. The general recommendation of the national Coffee Research Center (COREC) is to intercrop coffee with banana at a 1:3 ratio for robusta coffee (Musoli et al. 2001). Therefore, most coffee producers also have surplus bananas for sale and/or home consumption. However, monoculture coffee plots also exist, probably because farmers were discouraged from coffee intercropping in the past, before liberalization, when the government was more interested in coffee output for export than in crops for household subsistence and local markets (Van Asten et al. 2011).

Uganda exports only graded green robusta (green coffee export quality) (FAO 2013), further product transformations are done only for the locally consumed coffee. Coffee beans in Uganda are harvested twice per year (November–January and June–July). Picking has to be done manually, which creates seasonal labor demands in the growing areas. Robusta coffee is dry-processed and the drying is usually organized by the grower, unless he wants to sell the harvest quickly. Smallholders perform sun-drying, which takes around four weeks. Hence, selling wet coffee results in earlier cash inflows, but excludes farmers from the opportunity of value addition by drying. According to the calculations presented in Table 1.6, robusta growers generally avoid selling wet coffee – it constitutes only 0,5% of total sales volume. All of the wet coffee is sold to traders, since DC/ACE regulations do not typically accept it. Mostly coffee is sold in the form of dried cherries (known locally as ”kiboko”). Such sales make up 93.2% of total sales volume. The rest, 6.3% of sales, are dehusked beans called ”fair average quality” coffee (FAQ), prevailingly through DC/ACEs (92.2% of all FAQ). Selling as FAQ can be only achieved, when a farmer is able to access a coffee mill for dehusking either individually or through DC/ACE. Six out of 11 robusta-dealing DC/ACEs contacted by the IFPRI (2010) survey provide such processing opportunities. Just 52.1% of total robusta produce is sold through DC/ACE channel: this fact signifies tough competition for supply from local traders.

Table 1.6: Sales channels of robusta coffee (as % of total sales)

	Sales channel		
Product	To traders	Through DC/ACEs	Total
Wet	0.5	0.0	0.5
Kiboko	46.9	46.3	93.2
FAQ	0.5	5.8	6.3
Total	47.9	52.1	100.0

Source: Own calculations, based on IFPRI (2010)

Production constraints Coffee wilt disease (CWD) creates an important production constraint for coffee-growers in Central and Eastern Africa (Uganda in particular). Hill (2010*a*) found out that 81% of coffee farmers had cases of coffee wilt on their plantations. Also, Hill (2010*a*) estimated that the average coffee-growing household lost 45 coffee trees due to CWD in the period of 1999–2002. The disease is caused by a soil inhabiting fungus that blocks water and nutrient transport within a plant. CWD is spread by air, water and human activity. Therefore, prevention of the disease has to be undertaken on scales that are larger than the individual. Unlike other coffee diseases, CWD leads to a total yield loss. It may kill an infected tree within just six months (Rutherford 2006) – making an enormous negative impact on potential revenue. Baffes (2006) estimated CWD-related losses of Ugandan export revenue at around 40–50 million usd per annum. The spread and impact of other coffee diseases and pests in Uganda (e.g. coffee leaf rust) is either not significant or can be easily managed by individual farmer efforts (Musoli et al. 2001).

Another production-related weakness of the Ugandan coffee sector is the old age of coffee plantations (Musoli et al. 2001). This results in lower plot revenues, because of the declined yield potential of old trees and the backlog (in terms of yield and quality) of volunteer seedlings used in the past from modern clonal planting material. The planting material (seed, seedling or cutting) of sufficient quality cannot be produced on the farm (Musoli et al. 2001). Hence, propagation of new trees has to be paid using the farmer's budget. Furthermore, there is a three year period between the planting of coffee trees and the point when they start to yield. Therefore, due to limited liquidity, farmers are not always able to replace their trees with the optimal frequency. Also, the hired labor has to be paid six months prior to harvesting, so relatively large capital investments and liquid means are required for launching coffee production.

Women are heavily involved in coffee production as well as in production of other agricultural commodities in Uganda, but it is traditionally men who are in control of coffee-generated income (Bantebya-Kyomuhendo & McIntosh 2006). Female labor is often used in weeding, water fetching and product transformation. Female-managed households are facing additional social and institutional hurdles when looking to acquire production factors, such as credit, inputs or land for sharecropping, which makes their entry into the sector of production of cash crops, such as coffee, more complicated. Golan & Lay (2008), in their examination of Uganda's coffee sector, estimated that when the household head is female, the probability of the household engaging in coffee production is reduced by 16%. Given the fact that around 30% of the farming households in Uganda are female-managed (Golan & Lay 2008), the gender issue (low female social power) may constitute a significant constraint for household efficiency.

Institutional framework Research of Kasozi (2008) showed that the institutional framework historically plays a central role in forming and reshaping the coffee sector in Uganda. Table F.4 from the Appendix describes the main influential institutions that exist in Uganda nowadays. The key entity in the sector is UCDA (for a description of abbreviations see Table F.4). It was founded during liberalization reforms in the early 1990's. Currently, it is financed by the 1% tax put on all coffee exports. UCDA is responsible for the regulatory and monitoring aspects of the sector. It often engages in broad collaborations with other institutions listed in Table F.4 (Baffes 2006). Different players of the coffee industry are united under the umbrellas of nationwide organizations: producers are under NUCAFE, traders and exporters are under UCTF, roasters are under UCRA, and RPO in general (not only coffee-related ones) are under UCA. State budget is streamed to the coffee industry through two ministries: MAAIF and MFPED. MAAIF finances national advisory (NAADS) and research (NARO) public bodies, and MFPED implements development projects in rural areas. With regards to the research institutions, UCTF (2010) stated that local coffee research efforts are weak due to low funding. Indeed, in comparison with other large African coffee producers, the number of coffee-focused research staff and the budgets with which they operate are very small (see Table F.5). In recent years, a national coffee research institute (CORI) was downgraded to a research center (COREC), despite there being a need for local research, in particular dedicated to the selection of productive and resistant coffee varieties (UCTF 2010).

1.3.4 Description of a study frame

The agent-based simulation model constructed within this Ph.D. research comprises the depot committee (DC) called "Kibinge coffee farmers association" and all related primary producer organizations (POs) (n=46), DC member farming households (n=1716) and their household members (n=11911). Kibinge DC is a farmer-owned organization that specializes in the processing and marketing of robusta coffee. The Kibinge association was chosen for modeling for three reasons:

- In comparison with other DC/ACEs from the initial project survey (IFPRI 2010), it has a relatively large sample of interviewed farming households (71 households). Thus, more precision can be obtained in the estimation of empirical distributions for further generation of model agents.
- The specifics of the applied equations for soil properties prediction (discussed in detail in Section 3.3), make it more applicable to the lake-shore robusta coffee/banana production system.
- Incomes and livelihoods of a great number of Ugandan farmers depend on the successful marketing of robusta coffee (see Section 1.3.3). Therefore, there is a big potential in terms of country-wide extrapolation of research findings.

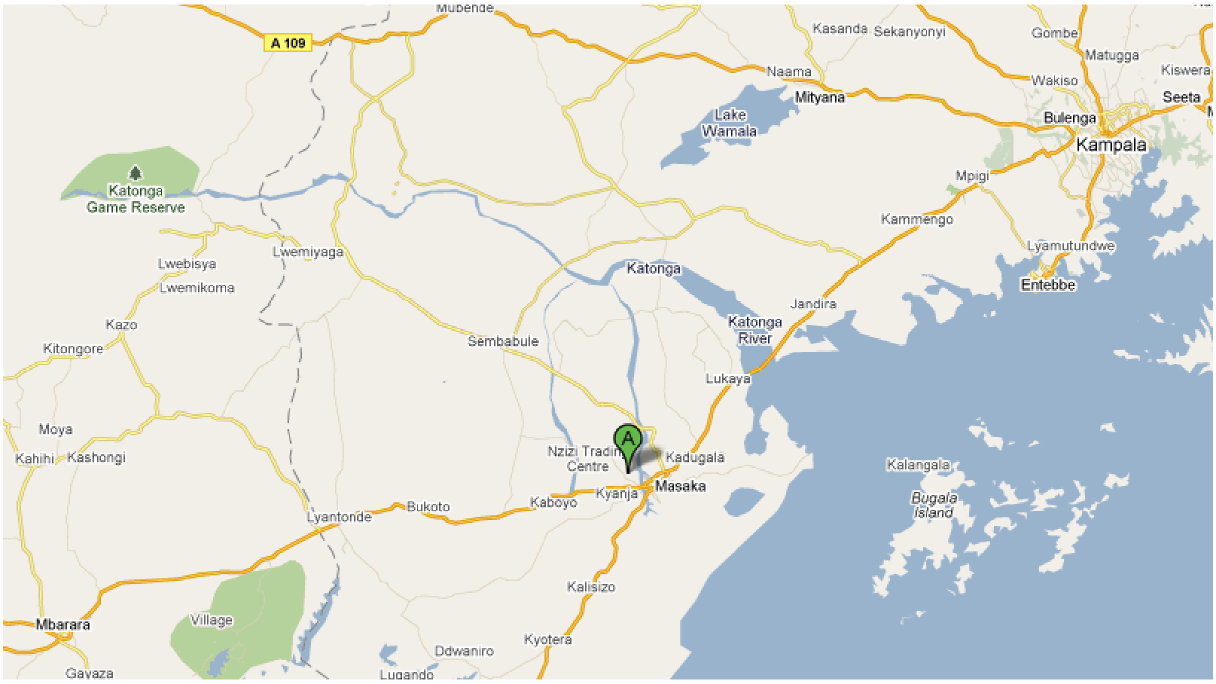
The project survey (IFPRI 2010) included only households, which were members of POs at the time of the survey, and did not include other farm households from the areas of survey coverage. Therefore, these other farm households were neither modeled nor visited during the author's fieldwork in Uganda.

Kibinge DC and its members are situated in the Central Region of Uganda, Masaka District, Bukomansibi county, Kibinge sub-county, in a traditional coffee-growing area. It lies in the central part of the Lake Victoria Crescent at the elevation of around 1250 masl, about 150 km southwest of Kampala, about 25 km from Masaka, and 5 km away from the Masaka–Mbarara highway (see Figure 1.8) in a peri-urban area.

Table 1.7 provides the characteristics of the development domain (spatial strata according to advantages and disadvantages for certain agricultural activities) in which Kibinge sub-county is located (according to the hierarchical classification of Ruecker et al. (2003)).

Kibinge DC is a sub-county level farmer-owned organization. It was founded in 1995 and registered as a cooperative in 2008. DC is a member of the National Union of Coffee Agribusinesses and Farm Enterprises (NUCAFE). It offers a wide range of services, such as training in agricultural practices, provision of planting material and transport management (a more detailed description of services can be found in Section 2.2). The group claims to be one of the first in Uganda to engage in coffee certification (Dejene-Aredo et al. 2009).

Figure 1.8: Location of Kibinge DC



Source: `http://maps.google.com/`

Table 1.7: Characteristics of Kibinge development domain

Districts *	Environmental and socio-economic conditions	Comparative advantages	Comparative disadvantages
– Iganga – Kampala – Masaka – Mpigi – Mukono – Rakai	– lowland – binomodal seasonality – high agricultural potential – high population density – high market access – 10–12 month growing period – intensive banana coffee lake shore farming system	– Favorable agro-climatic conditions for cultivation of annual and perennial crops – High market access for cash crops and inputs – Intensive farming due to access to credit, technology and extension services – Favorable agro-climatic and market conditions for dairy and other livestock production	– High soil degradation due to intensive farming – Strong erodibility due to heavy rainfalls – Pest and disease pressure – High land fragmentation

Source: Ruecker et al. (2003)
* district division of 1998

Chapter 2

Participatory assessment and expert opinions

Given the benefits of stakeholder involvement in the research that were discussed earlier in Section 1.2.4, this study employed a number of participatory methods: (i) participatory mapping of networks and processes, (ii) group discussions with farmers and (iii) public goods games. These methods, together with discussions with key expert informants, formed a toolbox for qualitative assessment that was conducted in the research. The qualitative assessment was carried out during the author's fieldwork in Uganda and was focused on the achievement of the several objectives:

- Systematization of knowledge on the topic of coffee production and marketing in Uganda
- Acquaintance with specifics of the study area and local RPO
- Assessment of investment, production, transportation, marketing decisions and alternatives of robusta coffee farmers and their organizations
- Mapping of the social and economic networks and processes happening within villages POs and respective DC/ACEs, assessment of relationship networks and influences, identification of hot spots, problems and potentials for improvements
- Elaboration of concepts, assumptions and parameter estimates for the multi-agent model (described in Chapter 3)
- Elaboration of applied scenarios for simulation modeling
- Capture of important issues that model simulations are not able to replicate

In general, it could be concluded that the application of participatory techniques provided numerous insights and explanations (summarized in Sections 2.2, 2.3 and 2.5) that improved the author's understanding of the study topics and made a good introduction into study area problematics.

2.1 Fieldwork in Uganda

The fieldwork took place from March to April 2011 and consisted of two major parts:

1. Meetings with key informants: 30- to 90-minute discussions with experts from various relevant fields (farming, agronomy, economics, marketing, rural sociology) and organizations (cooperative alliances, research centers, exporters, survey coordinators). Meetings took place in Kampala, Masaka and the surroundings of these cities.
2. Field visits with the administration of Kibinge DC and ten selected POs from this DC: all together 11 interactive sessions of participatory research. The length of one session was approximately 2–2.5 hours (with communication through a translator). A major part of the session was dedicated to a Net-map exercise (explained below) with a follow-up group discussion on coffee production and marketing systems. In addition, a public goods game was conducted during the sessions with selected POs.

Research activities for the fieldwork were designed by the author prior to the fieldwork and were pretested with students of UHOH. This section describes the set-up of the applied fieldwork methods and explains the selection of participants.

2.1.1 Methods description

Interviews with key expert informants Experts from various organizations related to robusta coffee RPO were approached for semi-structured discussion interviews. The selection of experts was arbitrary, based on the research contacts of the author and availability of the informants. Table A.1 lists the approached informants. For each interview an individual discussion outline was prepared. In order to utilize the different expert knowledge of respondents and broaden the obtained insights, covered topics and asked questions were respondent specific. Table A.2 contains information about discussion topics of each interview.

Net-map The sessions with RPO-members started with participatory mapping of the coffee marketing system. From Section 1.3.2 it can be concluded that POs and DC/ACEs are parts of multi-level marketing networks consisting of various actors. Moreover, POs and DC/ACEs can be viewed as social networks by themselves. For this research it was important to understand the structure of processes, relations, influences and power balances in these complex socio-economic networks. For this purpose, the author adapted Net-Map Toolbox (Net-map) (for description see Schiffer (2007)). Net-map is a visualized participatory method of systems and networks mapping. This interview-based tool was developed by Schiffer (2007) and was successfully utilized by its creator in Ghana and Ethiopia for research of different stakeholder groups (water user associations, education commission, fishermen community, etc) (Schiffer 2013, Schiffer & Hauck 2010). The output of the interactive Net-map session is the map of the socio-economic network, where actors, their links and roles are reflected. The provided visualization serves to improve system understanding for the author and the interviewed persons. The map facilitates a follow-up discussion about the state of the social system and future possibilities of its development, especially when the exercise is conducted with the group of people (Schiffer 2007).

With slight extensions the tool can be used for mapping processes (Raabe et al. 2010). Instead of focusing on the static network, one can look for system dynamics and ask interviewees to depict a particular process by identifying interactions between actors of the mapped network in time. In such a way the Net-map method was applied in this research. The application of the tool had several benefits in comparison with the possible alternative use of "classical" focus group discussions:

- Provision of systems view and process-understanding
- Visualization of the differences between groups
- Identification of process leaks, weak linkages, overlaps in responsibilities and potentials for improvement
- Assessment of the production and marketing network in an agent-based way consistent with a chosen modeling approach
- Facilitation of the follow-up discussion

In practice, the Net-map session was implemented in the following steps:

1. Introduction: PO members invited to the session were briefly introduced to the aims of the research. The goal of the Net-map was formulated to them as "mapping the system of coffee production and marketing in Kibinge". The author wrote the goal on a blank sheet of paper that was used for setting up the map.
2. Description: PO members were asked to describe the step-by-step process of coffee production and marketing. Each time a new actor (e.g. farmer, trader, PO leader, etc.) was mentioned, the participants were asked to write the actor's name and draw a symbol representing the actor on a card. (Drawing ensured the inclusion of illiterate respondents.) Each card was pinned to the map sheet and each step of the process was depicted by a link between actor cards. Each link was chronologically numbered and its description was written in the legend on the side of the map. All process steps (i.e. map links) were defined either as necessary or optional.
3. Re-assessment: After the map was completed, respondents were asked to check whether certain actors or links were missing. The missing ones were then added to the map. The participants were also asked about important actors in the coffee production and marketing process with whom the group did not have access (e.g. distributor of mineral fertilizers or extension service).
4. Assigning importance: After the description of the process was finished, the participants assigned importance (on a scale of 1 to 5) using dot stickers to the process actors with

regards to their influence on the success of coffee production and marketing. The participants were asked to explain reasons for the attributed level of importance to every actor.

5. Identification of hot-spots: The participants were asked to mark the possible complications and risks in coffee production and marketing on the respective process links and to explain them.

Follow-up group discussion After finishing the Net-map activity, participants were asked to clarify certain aspects of the map and some production and marketing issues in general (e.g. intercropping, rate of fertilizer application, etc.). The answers were written down on the side of the map.

The paper output of the follow-up discussion and the Net-map was later converted to a commented diagram in MS Powerpoint. The Powerpoint version of the map was animated in a way that displayed the process dynamics. The computer files were revised to identify and correct errors.

Public goods game The interactive sessions in POs continued with public goods games that were conducted with five participating individuals. (In the meeting with DC administration this part was omitted.) The public goods games were used to test whether trust and cooperation among members influence their eagerness to sell their coffee produce through the PO. The results of the game could be used as a proxy for the degree of trust between members and their willingness to cooperate and contribute to the achievement of the common goals. The game used rewards for participation in the fieldwork (10,000 ugx per person). Monetary payoffs in public goods stimulated thoughtful behavior of the players. The game was set up as follows:

- At the beginning of the session five participants received envelopes containing 10,000 ugx in 1,000 ugx notes.
- Each participant was given an option to contribute any part of the reward to the common pool under the condition that the sum of the individual contributions would be multiplied by 1.5 and distributed among every member at the end of the session.
- So individual payoffs (P) could be derived from individual contributions (C) as:

$$P_n = 10,000 - C_n + \sum_{i=1}^{5} C_i \times 1.5/5 \tag{2.1}$$

- Members were informed that their contributions would remain confidential (handled in sealed envelopes).

2.1.2 Selection of participants for group meetings

From 36 POs of Kibinge DC covered by the initial IFPRI (2010) survey, 10 were selected for the group sessions. From the selected POs five members were invited to participate in the session.

In order to make a selection that could provide a good statistical representation of different POs and also meet the requirements of data availability, a combination of cluster and purposeful sampling was used. Selection was done as follows in a statistical software package (Stata):

1. Creation of a dataset with variables containing criteria for PO selection (listed in Table A.3) from the IFPRI (2010) project survey
2. Factor analysis with factor selection bound of $Eigenvalue \geq 1$
3. Hierarchical clustering with average linkage and Euclidean distance based on the factors from Step 1
4. Assignment of POs to clusters based on factors by k-means clustering method with Euclidean distance
5. Calculation of Euclidean distance from each PO to the respective cluster center
6. Definition of a number of POs to be invited for group visits from each cluster according to the weight of the cluster in the survey sample
7. Selection of a required number of POs according to their proximity to the cluster center (in order to choose typical POs for the clusters)
8. POs with no information on group sales of coffee in the IFPRI (2010) survey were discarded from the selection and replaced with the next closest to the cluster center (the final PO selection is provided in Table A.4)
9. PO chairperson and four random members from the PO roster (from those with available information on coffee sales) were invited to the participatory session

2.2 Delineation of the RPO network

2.2.1 Structure

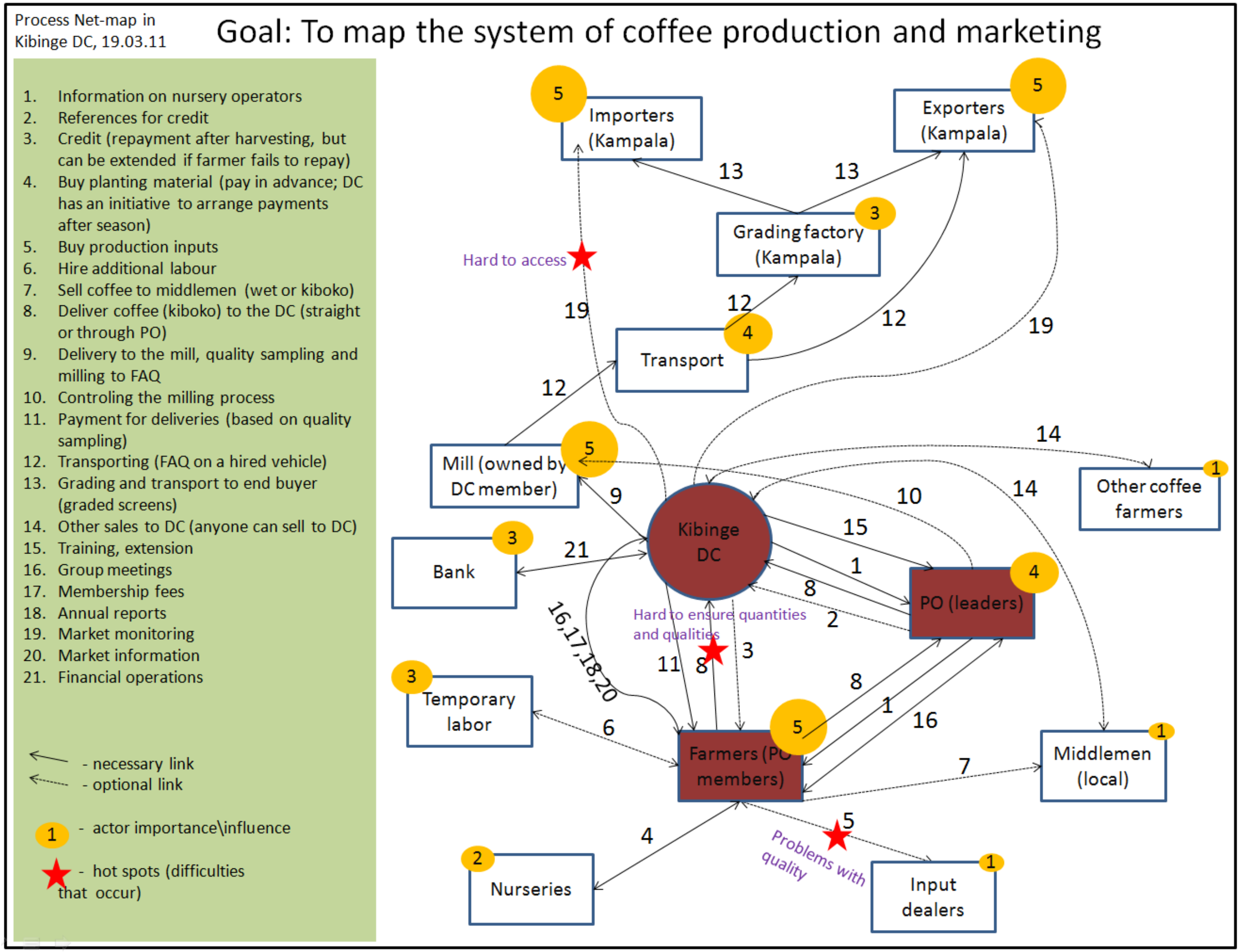
Kibinge DC is a formal organization with open voluntary membership. It is the organization of robusta coffee growers and deals only with this commodity. In order to be a member of the DC, a farmer must possess at least two shares of the DC (worth 5,000 ugx each) and pay the annual membership fee of 2,000 ugx. These fees are used for administration salaries, maintenance of the DC office and storage facilities, organization of member meetings and payment of electricity and telephone bills. DC profits are usually spent on dividends or small investments in the DC capital (stationery, office equipment). Important decisions (e.g. board elections) are taken at the annual meeting or at special meetings. Members vote on these decisions; each member has one vote, irrespective of the number of shares they hold. DC's organizational structure comprises a chairperson, a vice-chairperson, a secretary, a treasurer and an executive committee, all elected by the farmers' assembly. The executive committee includes an executive manager, a field officer and an accountant, whose salaries are paid with the DC budget.

Figure 2.1 contains the output map of the Net-map session conducted with the DC administration. It displays the process of coffee production and marketing in Kibinge sub-county and characterizes the involvement of RPO. The legend of the map is organized in a sequential way, reading it in the numbered order will give an idea of the process flow from procurement of production inputs to final sales. The map also indicates the importance of particular actors attributed to them by the participants, and identifies hot spots in the business system of DC.

From Figure 2.1 it can be seen, that the DC and POs provide important linkages for farmers. Through the DC, farmers are connected with big buyers, equipped with milling and transportation facilities, and get access to current market information. Also, PO members have an opportunity to get short-term credits from the DC operational capital. PO-leaders participate in capacity building events organized by the DC and disseminate the new knowledge to the members of their POs during group meetings.

Net-map sessions in the ten selected primary POs produced maps similar to the one depicted on Figure 2.1. Some of the POs did not have linkages to certain services (e.g. nurseries or input providers), while some were linked to additional nodes (e.g. development support or parish administration). Table A.5 from the Appendix characterizes the POs that were visited, according to the information received during the Net-map sessions and follow-up discussions. This table informs of such PO characteristics as PO access to manufactured production inputs (i.e. fertilizers and pesticides) and financial institutions, on approval and reference scheme on credits from DC (i.e. authority to assure repayment of credits taken by members), on labor scarcity and work allocation by gender (i.e. if women and men perform different farm duties), etc. Also, Table A.5 states whether a certain PO uses DC services, such as provision of planting material and payment on delivery (see Section 2.2.3 for a detailed description of services).

Figure 2.1: Kibinge DC. Process map



Source: Author, based on Net-map results

2.2.2 Linkages and actor importance

Table 2.1: Actors in coffee production and marketing

Actor	Mentions (n=10)	Mean importance
DC	10	**4.8**
Farmers (PO members)	10	**4**
Local middlemen traders	10	2.6
DC-affiliated mill	10	**4.8**
Temporary labor	10	2.6
Transport for coffee	10	3.1
PO (leader)	9	3.8
DC-affiliated nurseries	8	3.6
PO (board)	8	3.9
Other local nurseries	7	2.7
Providers of agrochemicals	6	3
Providers of manure	5	3.8
Other farmers (non-members)	5	2
Financial institutions	4	3
Promoter (parish administration)	3	3.3
Development support	2	3
Field officer	2	3

Source: Author, based on Net-map results

Table 2.1 lists actors, who, as reported by PO members, are involved in the production and marketing of coffee. This table shows how many times actors were mentioned during the Net-map sessions and their mean importance rankings (on a scale of 1 to 5, 5 being the most important). As seen in the table, DC and milling facility have the highest importance of 4.8. Such high importance was given due to a large value addition that is achieved in processing and collective marketing of the coffee. In other words, these actors are very influential in terms of farmer profits. In terms of importance they are followed by PO members, because PO members define the coffee product quantities that DC sells and have collective control over the DC management. Table 2.1, shows that, as discussed before, farmers in some POs may not have access to such important determinants of agricultural production as agrochemicals (linked in six maps) and financial services (linked in four maps).

2.2.3 Services provided by the RPO network

From the Net-map and follow-up discussion with the DC administration and PO members the author outlined the following portfolio of services that the DC currently provides to its members:

- Provision of planting material: DC provides farmers with coffee seedlings and cuttings produced in some local nurseries. The planting material provided by the DC passes the quality control done by the DC officer. Therefore, farmers reported that the quality of the material provided by the DC is significantly higher than that of other nurseries, however its price is also higher.

- Seasonal credits: Zero-interest credits for productive purposes may be provided to member farmers at the beginning of the growing season from DC operational capital. Field officers decide on an case by case basis which farmers will be offered these credits, based on the farmer's past sales through the DC and their expected coffee harvest.
- Market information: Farmers may request actual coffee prices from the DC by telephone call.
- Transportation of farmers' produce: Several times per season DC organizes a pickup of dried coffee from the PO members with a hired truck. The pickup schedule depends on the quantities that are ready for transportation at the POs.
- Milling: DC organizes milling of kiboko coffee to FAQ on the local mill owned by one of the DC members. The cost of milling is subtracted from the sales price that farmers receive.
- Group certification: Through NUCAFE, Kibinge DC was linked to the "UTZ CERTIFIED" quality certification scheme. Several PO members underwent the initial training and currently are able to sell their coffee under the "UTZ CERTIFIED" label and, thus, increase the value of their produce. DC field officers have to ensure farmers' compliance with UTZ standards.
- Payment at the time of delivery: On specific informal arrangements with certain POs, The DC may occasionally provide payment for the coffee on the day farmers deliver it to the DC (normally the payment is postponed for up to 14 days). However, if having enough operational capital, the DC would be ready to organize payment "on the spot" for all members.
- Occasional bonuses and promotions: Depending on the operational profit, in order to motivate the farmers to sell their produce through it, the DC occasionally pays price premiums for large quantities delivered or hands out various useful materials (e.g. drying tents).

Surprisingly, there is not much collective action and decision making taking place at the village PO level, since members usually do not perform any activities collectively (only one out of the ten POs that were visited reported undertaking communal activities by making collective investments in transport and storage).

2.3 Problems in coffee production and marketing

During the Net-map sessions, PO members indicated and mapped several problems that occur in producing and marketing of coffee. These are listed in Table 2.2.

Table 2.2: Problems in coffee production and marketing

Problem description	Mentions (n=10)
Fertilizers	**8**
Fertilizers are not always affordable (price)	7
No access to fertilizers	1
Planting material	**8**
DC cuttings/seedlings are not always affordable (price)	3
Nurseries are not easily accessible (distance, price)	2
Cannot get sufficient cuttings/seedlings from the DC	1
No capacity to have own nurseries	1
DC does not provide cuttings/seedlings at right time (too late)	1
Sales through middlemen	**6**
Middlemen traders encourage bad practices and low quality	2
Unfair prices from traders (farmers have no bargaining power)	2
Traders cheat with weighing scales	1
Traders take advantage of farmers' problems (urgent cash needs)	1
Transport	**5**
Transport is expensive, prefer DC to have own vehicle	3
Price for DC transport is not fair	1
Transport is not very reliable, when the PO organizes it for itself	1
Labor	**2**
Laborers are scarce and costly	1
Liquidity problems do not allow for the hiring sufficient labor	1
Credits	**2**
High interest on microfinance credits	1
No link to long-term credits	1
Other issues	**8**
Coffee wilt disease	3
Coffee thefts	1
DC management does not treat members equally	1
Hard to attract other farmers to join RPO	1
Milling is expensive, prefer DC to own a mill	1
Weak link to large buyers	1

Source: Author, based on Net-map results

Inputs As seen in Table 2.2, for many POs (eight out of ten) complications arise during fertilizer and seed procurement. As PO members explained, access to inputs is limited because of price, distance or restricted capacities of the DC.

Liquidity and access to capital Six out of ten POs complained about sales to middlemen (Table 2.2), because middlemen buy at considerably lower prices and encourage bad production practices (e.g., by buying coffee that has not been dried properly). Nevertheless, PO members said that in many cases they still choose to sell to middlemen. Farmers do so mainly because of urgent cash needs (food requirements, school fees, funeral services, etc.); middlemen always pay on the spot and even may take coffee from the farmstead, while the DC usually delays payments, and farmers have to wait for transportation and milling to be organized. Also, middlemen provide informal credits (to be repaid with coffee produce) for farmers in the middle of the season. Therefore, farmers often have to sell through middlemen because of their credit obligations. These informal credits cannot be fully substituted by DC credits, which only finance input purchases (not consumption needs) and are generally small and difficult to obtain, nor by microfinance credits, which are also small and difficult for POs to access.

Knowledge capacity In their interviews, key informants admitted their lack of knowledge on fertilizer application. Due to improper fertilizer choice and/or use the yield potential is not realized. Many farmers do not fully understand the benefits of mineral fertilizer application for their coffee. Also, absence of knowledge on soil properties of farmer plots results in suboptimal fertilizer practices by farmers. There are only two stations for soil analysis in the country (in Kawanda and Makerere). Hence, Kibinge farmers do not have the option of getting information about their soils nor receiving site-specific fertilizer recommendations.

Besides, three out of the ten POs visited said that their inability to cope with coffee wilt was a major problem.

PO leadership As administration of Kibinge DC reported, PO leaders play a big role in attracting farmers to the RPO marketing channel. They promote DC services at the village level and provide understanding of their benefits for the farmers and as a result farmers sell more produce through the DC. This in turn directly influences DC profits, because the DC benefits from increased quantities (fixed cost degression, higher bargaining power). But because DC bulked quantities is a sum of production volumes of many POs (46 in Kibinge case), the monetary gains of PO leaders that result from their efforts are negligible. Therefore, the leaders, due to the opportunity cost of time, are not contributing much to the empowerment of the PO network.

Transparency and information exchange Follow-up discussions in POs revealed a lack of understanding among members regarding the functionality of the DC, which leads to mistrust.

The reason is the absence of clearly communicated rules and transparency regarding the provision of DC services and benefits. For example, the DC provision of planting material and seasonal credit does not follow any systematic rules. The DC officers decide on their own about every service request. Further, transportation and payment schedules are absent. Therefore, firstly, PO members cannot plan their cash flows and production in advance and, secondly, it creates rumors of the DC favoring certain farmers and discriminating against others. According to the farmers, similar issues apply to the ongoing certification program that, as they stated, was not well communicated to them. The benefits of certification and ways to get the produce certified were unclear to most of the interviewed POs. Apparently, the existing information system of the DC via member meetings and PO leaders is not effective in communicating to farmers the services that the RPO network provides.

Low physical capital of RPO and reluctance for long-term investments Since milling and transportation facilities are often used in DC operations, it might be profitable for the DC to own mills and vehicles. Such propositions were made by the DC administration and some village PO (four out of ten prefer their DC to own its vehicles or mill). But, as the DC administration described, members are reluctant to make long-term investments in the organization, and the largest part of the DC profits are redistributed among members. Therefore, up to the time of this research no significant collective investment projects took place in the DC.

In fact, as explained in Section 1.1.4, this is a recognized problem of RPO and other co-operative firms in general (Chibanda et al. 2009, Nilsson 2001). It is caused by the limited planning horizons of RPO members (limited to the proximate duration of membership) and the administration (limited to the length of their elective terms).

2.4 Outcomes of public goods games

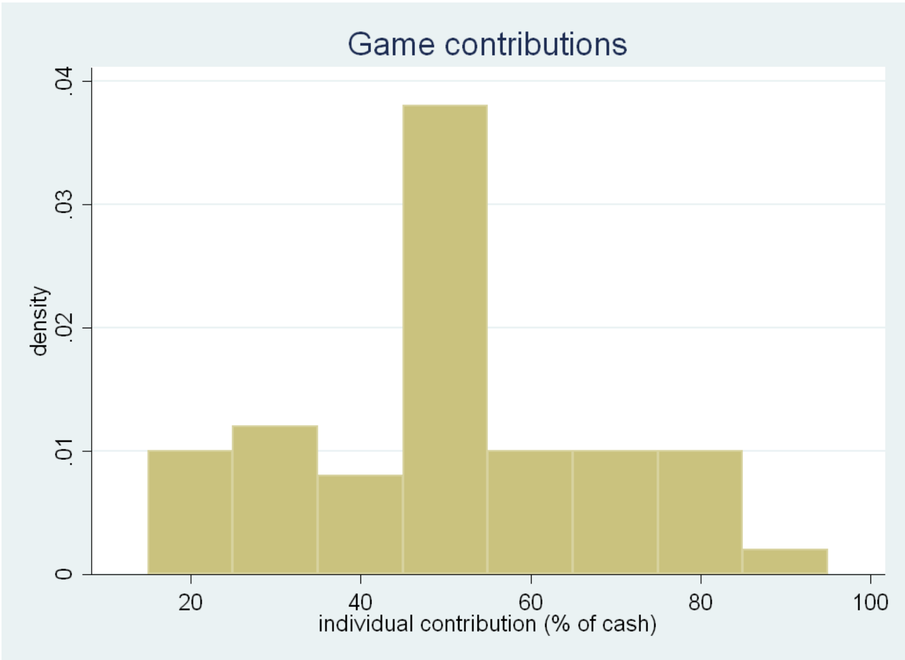
Public goods games contributions of participated individuals varied. As can be seen from Figure 2.2, PO members decided to contribute between 20% and 90% of the received amount of cash into the common pool. Figure 2.2 also shows that 50% contribution was by far the most popular choice among the participants. This "fifty-fifty" strategy was used by 38% of the sample. Table 2.3 characterizes contributions of the participating groups of PO members. From Table 2.3 it can be seen that contribution characteristics varied across the POs. On average, each group collected 25,300 ugx from the distributed 50,000 ugx in the common pool, which is a mean member contribution of 5,100.

The results of public goods games were linked with the statistics on coffee sales collected by the IFPRI (2010) survey. Since only two members of each PO were approached by the household part of the IFPRI (2010) survey and not every member was willing and/or able to provide estimates about his or her sales to middlemen, the data on member coffee production was limited.

Nevertheless, linking public goods game outcomes with production and delivery data from the survey provided three data frames for analysis:

- Individual game contributions of the PO member and his or her individual sales through the PO in absolute terms (48 observations)
- Group contributions and group sales through the PO in absolute terms ("group sale" refers

Figure 2.2: Public goods game. Individual contributions



Source: Author, based on public goods game results

Table 2.3: Public goods game. Contributions (in th. ugx)

PO name	Sum	Mean	Min	Max	Stdev
Bunyenya farmers group	24	4.8	3	6	1.1
Kalubaya farmers group	30	6	5	8	1.4
Kamanda coffee farmers group	30	6	5	7	1.0
Katoma coffee farmers group	19	3.8	2	6	1.6
Kiryasaka farmers group b	26	5.2	3	8	1.8
Kisojo farmers group	17	3.4	2	9	3.1
Kyetume farmers group	27	5.4	4	7	1.1
Maleku farmers group	21	4.2	3	5	0.8
Mitugo farmers club	27	5.4	4	8	1.5
Serinya Twekembe UTZ kapeh group	32	6.4	3	8	2.1
Mean	25.3	5.1	3.4	7.2	0.334

Source: Author, based on public goods game results to the sum of sales by participants of the game, not all PO members) (10 observations)

- Individual game contributions of the PO member and individual sales through the RPO as a share of total coffee sales of the respective PO member (12 observations)

In order to reveal the correlations between game contributions and coffee sales in the listed data frames, three non-parametric tests were applied: Spearman's rho, Kendall's tau and distance covariance (dcov) of Szekely (2007). Table 2.4 reports test error probabilities for rejecting the null hypothesis of selected variables, x and y being statistically independent. Test results in Table 2.4 show that rho and tau tests may reject the null hypothesis at 5% significance level in case of testing group sales (y) versus standard deviation of PO member contribution at the group level (x). Hypothesis rejection at the 10% level could be done by both tests in the case of group sales (y) versus range of PO member contribution at the group level (x). In addition, dcov test, since (unlike the other two tests) it accounts not only for relationships that can be explained by monotonic functions, determined two more pairs as potentially dependent. Figure A.1 scatters variable pairs that were identified as statistically dependent. An econometric estimation of the relationship within the respective variable pairs was attempted.

Table 2.4: Tests for statistical dependency. Error probabilities

Variable y	Variable x	N obs	Rho test	Tau test	Dcov test
Individual delivery	Individual game contribution	48	0.821	0.734	0.690
% of individual delivery in total sales	Individual game contribution	12	0.392	0.477	**0.005**
Group delivery (sum)	Group game contribution (mean)	10	0.443	0.589	0.305
Group delivery (sum)	Group game contribution (max)	10	0.356	0.350	**0.005**
Group delivery (sum)	Group game contribution (min)	10	0.247	0.302	0.600
Group delivery (sum)	Group game contribution (stdev)	10	**0.054**	**0.049**	**0.100**
Group delivery (sum)	Group game contribution (range)	10	**0.077**	**0.098**	**0.005**

Source: Author, based on public goods game results

After evaluating the model fit (R-squared) using different combination of variable pairs, it was concluded that out of all independent variable tested (see Table 2.4), "standard deviation of group contribution" is the best descriptor of the dependent variable "group coffee delivery". Probably, because it is less affected by the norm "fifty-fifty" response of the game displayed in Figure 2.2.) Table 2.5 presents the estimated simple linear regression model. F-test statistics of the model are significant at the 5% level and both constant and intercept terms are also significant at the 5% level. As expected, the sign of the intercept term is negative. If we take the standard deviation of member game contributions within a group as a proxy for the diversity of members within the respective PO, then this negative sign shows us that in selected POs diversity is negatively related to the total coffee sales done through the PO (expressed by sales of the group).

Table 2.5: Simple linear model of group coffee deliveries

Dependent Variable = Sum of participant deliveries to PO, kg	Coef.	SE
Log10(Stdev of group contributions)	- 1811.6**	(770.2)
Constant	14883.3**	(5616.6)
F-test (1,8)	5.53**	
R-squared	0.4087	
N obs	10	

Source: Author, based on public goods game results
** implies significance at 5%-level

There was no correlation detected between individual game contributions (y) and the volume of individual sales through PO in absolute terms (x) (see Table 2.4). This probably happened because the independent variable in this case do not consider the total production of the member, unlike the case in which contribution is expressed in relative terms as a share of production sold through PO. Unfortunately, due to the lack of information in the survey, calculation of this relative measure was possible only for a very small sample (12 observations), and, therefore, no interval data dependency was discovered. Nevertheless, some causality estimation was possible when a statistical classification analysis was conducted with a probit model. For estimation of the probit model, the dependent variable was expressed in binary format: 1 – if member sold more than 50% of his or her coffee production through PO, 0 – otherwise. From the estimated probit model (Table 2.6) it can be seen that the size of member contribution in a public goods game is positively related (on a 5% significance level) to the probability to sell the majority of coffee produce through PO. The probit model indicates that individual decisions on the share of coffee produce to sell through RPO to a certain extent can be explained by member contribution in public goods games. However, because of the small number of observations, the model should be applied with caution.

So far the results of public goods games analysis outlined two preliminary hypotheses: (i) of negative relationship between diversity of members within an RPO and the amount of produce sold through this RPO by members and (ii) of positive relationship between individual cooperativeness and willingness to contribute to the common pool and the share of produce sold by the individual through RPO. However, both hypotheses are yet to be tested with a sufficiently large sample. It would be interesting to inspect the relationship between member contributions in public goods games and RPO sales statistics, once the larger sample data is available.

Table 2.6: Probit estimates on decision to sell most of the coffee through RPO

Dependent Variable = 1 if member sells more than 50% of coffee produce through RPO, 0 – otherwise	coef	se
Log10(Individual contribution)	6.002**	(2.853)
Constant	2.988**	(1.325)
LR-test	6.86***	
Pseudo R-squared	0.4489	
N obs	12	

Source: Author, based on public goods game results
** implies a significance at 5%-level, *** – at 1%

2.5 Insights on farmers' decision making

This section shortly provides insights on the factors influencing farm-level decision making gathered from discussions with key informants and farmers from selected POs. The listed insights were used during designing and structuring of the farm decision model (see Section 3.4).

Production There are three types of planting material available: seeds (beans), seedlings and cuttings. Seeds can be obtained for free from UCDA, therefore, farmers, who established their own nurseries do so. The rest decide between seedlings and cuttings. Most farmers prefer seedlings, because of the lower price and because seedlings can better sustain droughts and transportation. On the other hand, cutting is easier to manage after planting. In general, seedlings are more or less always available in DC or local nurseries, while cuttings could be scarce.

Production decisions are usually determined by input availability and production habits of farmers. For fertilization, coffee farmers generally choose between mineral fertilizers (CAN and NPK, separately or jointly) or manure and coffee husks. The common rate of application of mineral fertilizer is 100 kg per acre (which is lower than the 220 kg recommended by COREC) or 1.5 ton of manure per acre.

Most of the interviewed POs (six out of the seven that were asked this question) prefer to intercrop with plantains once their coffee trees reach maturity. Young coffee is usually intercropped with maize, beans or cassava. On coffee/plantain plots intercrop ratios and plant densities vary between POs, but within one PO they remain the same. So farmers do not decide upon ratio and spacing individually, but rather follow the practice which is well-established for the PO. The usual number of coffee trees per acre is 400-450, and the number of banana plants varies from 0 to 200 per acre. In general (at the current price levels), intercropping is more beneficial than monocropping as it provides a higher margin from plot and a constant income from bananas (see the partial budget comparisons of Van Asten et al. (2011)).

Credit There are some general problems with credit access. Few POs (four out of ten) are linked to financial institutions. Four out of six POs without this link regularly take short-term credits from local traders. These credits have to be repaid with coffee after harvest. For the repayment of such credit contracts farmers spend up to 40% of their coffee produce (respondents' estimate).

Labor Labor scarcity depends on the location of the PO. Four out of eight POs who had answered the question said that labor is not scarce in their village at any period of time, two out of eight reported that labor is scarce in general, the remaining two said that labor scarcity depends on the season (e.g. labor is scarce during land preparation and planting, because laborers have to work in their own fields, and abundant in the coffee harvesting period). All interviewed farmers tend to hire additional labor at least for harvesting in order to be able to sell their coffee sooner, thus minimizing the risk of coffee theft. In general, household members of coffee farms do not work as casual laborers on other farms. Off-farm employment occurs when a member has a permanent job elsewhere. In most cases, farm duties are not allocated according to gender. Men and women together perform such activities as land preparation (traditionally a male activity) or weeding (traditionally a female activity) and other work as well. Usually labor is paid per workload, but not per hour. Therefore, wage differences are defined only by the different labor capacities that the workers have.

Sales channels There are two options in terms of coffee sales between which a household can select: PO/DC channel (as dry, shelled, ungraded coffee beans – FAQ) and local traders (as wet or dry cherries). PO members reported to generally prefer selling their produce through DC, mainly because it is able to offer higher prices (because of extra value addition). However, in reality POs are facing a strong competition for member produce from local middlemen traders and, despite the price incentive, farmers often choose to sell through middlemen. The main reasons (more detailed in Section 3.10.1) for taking such a decision are:

- Lack of operational capital and low credit availability: Forces farmers to make informal future contracts with middlemen in order to obtain cash before the harvesting season.
- High time preference: Waiting for the DC sale takes time (up to several weeks), while traders could be accessed immediately.
- Small trader margins: The prices that middlemen offer are highly competitive.
- Unexpected cash needs: Farmers have to take the discussed informal contracts or sell unmilled or even wet coffee to traders in order to get cash quickly in case of emergency.

Farmers sell their other crop produce individually, mostly to local traders (small share to village inhabitants). These sales are characterized by low farmer bargaining power when dealing with traders, because of the absence of alternative sales channels.

Risk adversity When investing in coffee production, the farmers consciously expose themselves to certain risks: price risks (export price dropdown), production risks (coffee wilt disease) and financial risks (inability to cover liabilities as a consequence of a bad harvest). Because of these risks and household nutrition security reasons, and despite the fact that coffee (according to farmers and experts) is by far the most profitable cropping activity, farmers follow risk-averse strategies and allocate parts of their land resources to other activities (plantains, maize, cassava, etc.). During group visits, 30 farmers were asked about their willingness to invest in coffee (maximum share of land they would allocate for coffee production) under the current price expectations (positive for all respondents), Table 2.7 summarizes the responses.

Table 2.7: Willingness to invest in coffee

	Mean	Min	10%	25%	50%	75%	90%	Max
Land share, %	62.8	40.0	50.0	50.0	62.5	70.0	80.0	80.0

Source: Author, based on farmer interviews

Chapter 3

Structure and parameterization of the bio-economic model

As mentioned in the earlier chapters, for computer simulations this study employed MP-MAS, which is a multi-agent software package for household-based economic decision-making (for an in-depth description of the software, see Schreinemachers & Berger (2011)). The purpose of this software package is identification (through scenario-based analysis) of the effects of technological, environmental, policy and other changes and interventions on the studied population and the related resource pools (natural, labor, financial, technical etc.). This chapter explains the structure of the MP-MAS application, which was set up by the author specifically for this research, and describes integrated sub-models and discusses their empirical parameterization.

3.1 The MP-MAS Uganda application

The MP-MAS framework was originally designed by Berger (2001) to analyze the diffusion of technological innovations in Central Chile. Later, the team of MP-MAS developers constructed several country-specific versions of the software and applied them for different scientific purposes in a number of developing countries: Uganda (Berger et al. 2006, Schreinemachers et al. 2007), Ghana (Wossen et al. 2010), Thailand (Schreinemachers et al. 2010, 2009) and Vietnam (Dang Viet 2012).

The simulation models of the MP-MAS framework build upon the empirical and theoretical parameterizations of natural environments, populations of farm households, markets for agricultural commodities, and biophysical and social interactions. MP-MAS applications belong to the family of models called *multi-agent systems applied to land use/cover change* (MAS/LUCC) (see Parker et al. (2003), Janssen (2003)). The MAS of this type combine two major parts: (i) a landscape model represented by cellular automata and (ii) a model replicating decision-making of agricultural enterprises represented in an agent-based way. Integration of the two components is implemented through the interactions and interdependence between the agents and the landscape.

The landscape-related part of the MP-MAS version applied in this research (MP-MAS Uganda application) has a three-level hierarchy:

- Pixel: Is a cell of a raster grid map. It is the smallest spatial unit in the model. For this study the pixel size was set to a quarter of an acre, since it is the size of the smallest land plot in the study area according to the IFPRI (2010) survey records. Each pixel contains information about land ownership, soil properties (available nutrients, organic matter content and acidity) and slope length factor. The state of soil property attributes of the pixel define actual yields that are achieved when growing a certain crop on that pixel (see Section 3.6).
- Soil vector: All pixels that belong to one agent form an agent's soil vector. At the start of the simulation, all pixels of one agent have the same soil properties, but that may change in the next periods, depending on agent decisions on land use and fertilization with regard to different pixels (the mechanism of soil property updating is explained in Section 3.6).
- Soil type: Mathematical programming (MP) calculations (see Section 3.4) required attribution of expected crop yields to model pixels, hence, pixels were classified into a finite number of soil types. At the start of the simulation agents expect same crop yields from the pixels of the same soil type and later adjust their expectations based on their experience (explained in Section 3.9). Such a mechanism is consistent with the empirical world, since in reality farmers do not have perfect information about the soil properties. Therefore, a soil type consists of several pixels that are similar to a certain extent. The classifying rule of pixel allocation among the soil types was defined by taking into account the coffee focus of this work: pixels were classified according to coffee yields that could be achieved on them under the conditions of no mineral fertilization and unconstrained labor input.

The agent part of the simulation model has a two-level hierarchy:

- Agent: Represents a real-world farming household. Each agent is defined by a set of variables. These variables are related to (i) land property rights (creating a link with the landscape part), (ii) household composition (number of household members, their age and sex), (iii) available resources (livestock herd, perennial crop plantations, cash) and (iv) access capacities (access to fertilizers).
- Population: Corresponds to agent interaction and communication boundaries. Agents can interact only with other agents from their population. In the applied model version all agents belong to the same population, which reflect their membership in the same sub-county level organization (Kibinge DC).

Because of the necessity to adapt MP-MAS for different study contexts, the structure of MP-MAS software is modular (i.e. model components and features can be activated depending on the requirements of the particular research). The modules are either integrated or externally coupled (examples are discussed in (Schreinemachers & Berger 2011)). Such structure makes MP-MAS flexible and adaptive with regards to additional extensions, which is a big advantage considering the aims of the current research: incorporation of RPO activities into the empirical model.

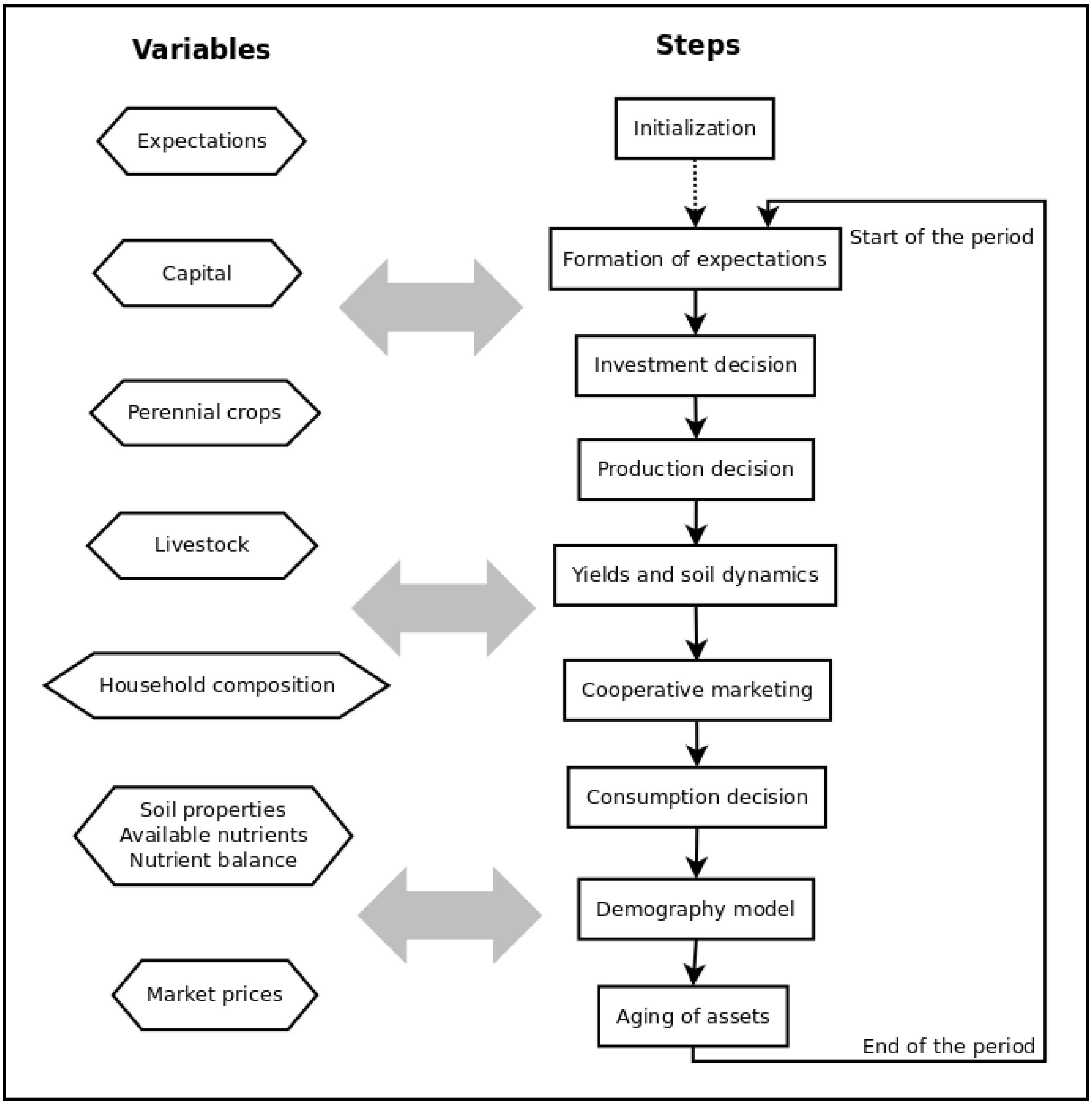
Table 3.1: Structure of the MP-MAS Uganda application

Layers	Components
Population	Demography model
Networks	RPO-decision model
Property rights	Asset registry
Factor endowment	
Land use	Agent decision model
	Crop growth model
Soil quality	Soil nutrient model

Source: Author

The simulation of behavior of economic agents and complex networks in MP-MAS starts with biophysical properties of agricultural plots. From the plot level it scales up all the way to the level of the studied population. Table 3.1 shows layers and respective components that are activated in the respective MP-MAS application. The developed simulation model makes use of biophysical modules of crop growth and soil dynamics, as well as of livestock and demographic modules (building on the study of Schreinemachers et al. (2007)). Each of the model components listed in Table 3.1 follows annual time resolution: every component is recomputed and updated once per modeling period that represents one calendar year in the real-world. MP-MAS integrates its components by calculating and updating the respective coefficients (crop yields, prices, etc.) and right-hand side values in the agent-specific MP-tableaus (see Section 3.4). Figure 3.1 displays the flow chart of the simulation model. After the MAS is initialized, the evolution of a large number of variables and processes is simulated over time (such as soil properties, household characteristics, market prices, etc.). Respective calculations supply information for the next steps and redefine variables, thus providing interactions between the various components of the MAS.

Figure 3.1: Simulation cycle of the MP-MAS Uganda application



Source: Author

3.2 Generating model agents from empirical data

The part which any MAS requires are the agents themselves (i.e. agent definition). The MP-MAS Uganda application is a household-based model. Hence, the basic agent type in MP-MAS Uganda is a farming household. The definition of agents was intended to be empirical, rather than abstractive, which means that a one-to-one correspondence between model agents and real-world households had to be ensured. In other words, every model agent represents an existing real-world prototype. This way of setting up the MAS improves the practical applicability potential of simulation results (Berger et al. 2006). But there is one complication related to such implementation of the agents: often the respective data collection does not cover the full population that is being modeled. Like in the case of the current research, when (IFPRI 2010) project survey covered only a 4% fraction of the study population, and therefore an extrapolation of the survey sample fraction to the size of the study population was needed. Moreover, input sensitivity analysis and application of Monte Carlo techniques required a set of such extrapolated populations (Berger & Schreinemachers 2006).

There is always a trade-off between close statistical match and heterogeneity. One obtains the closest match, when simply multiplying agents from the sample survey, but looses all possible values, that were out of the sampling fraction. Hence, the solution to the problem lies somewhere between taking the model agents from the sample survey only and doing a complete random generation (which leads to unrepresentative agents). Therefore any approach should go through the following steps:

1. Estimation of distribution functions
2. Assignment of parameters to computational agents
3. Validation of statistical consistency

The research reported in this thesis used statistical methods (see Section 3.2), the application of which for creating of agent populations for agent-based models is novel. The estimation of multivariate distribution functions, and sampling from them, is common in financial economics (for example, in assessment of financial risk), but currently is not used in population modeling. The author recreated the full agent population for the simulation model by data sampling and interpolation using multivariate distributions estimated from the project survey and described by copula (this approach improves the original Monte-Carlo technique of Berger & Schreinemachers (2006)).

The original approach of Berger & Schreinemachers (2006) operates with univariate empirical distributions, and therefore does not capture correlations between the parameters endogenously. However, such correlations may exist. Let us inspect whether they exist in the research case. Table F.2 shows calculated values of Spearman's rho and the results of the correlation analysis of main relevant household variables and geographical properties estimated from the IFPRI (2010) survey and the digital elevation model (DEM) of CGIAR-CSI (2011). From Table F.2 it can be concluded that the number of coffee trees is strongly positively correlated with land size (spearman coef = 0.719). Two other evident correlations, according to Table F.2, are (i) land size and number of household members and (ii) number of household members and mean age of a household. Classical Pearson's or Spearman's correlation coefficients fail in detecting non-monotonic dependencies. Therefore, in addition to these coefficients the author also applied a dcov test recently developed by Szekely (2007). This novel test, according to Szekely (2007), can be used for detecting non-monotonic correlations between variables. Error scores of the dcov test (error probability of rejecting the hypothesis of dependency between two variables) are shown in Table F.3. As shown in Tables F.2 and F.3, several of the inspected variables are significantly correlated and, moreover, in many cases one variable is correlated with a number of others. It was important to preserve such the detected correlations when creating agent populations, therefore multivariate probability distribution between the relevant variables were estimated by the author.

For the representation of dependencies in multivariate distribution an empirical copula was employed. N–dimensional copula (for every $n \geq 2$) is an n-variate distribution function on the d-dimensional unit cube $[0, 1]^n$, whose univariate marginals are uniformly distributed on the interval $[0, 1]$. Figure 3.2 gives an example of the empirical two-dimensional copula (depicted by the sunflower plot) for bivariate distribution of available land and household size of Kibinge DC member households. From this copula function the observed probabilities of various combinations of land and household size (represented by copula cells) can be derived (Table 3.2). The precision of the copula and the respective probabilities estimation depends on sample size: increasing the number of observations in the sample will increase the quality of the estimates obtained. From Table 3.2 it can be seen that, for example, the smallest 20% of households are unlikely to operate the largest land holdings, the probability to have the largest land holdings increases with the land size, and so on. With the help of Stata software, multidimensional copula were similarly estimated (not only for land and household size, but also for other household characteristics) from the empirical dataset, thus capturing the empirical joint distribution of variables. Then, as in the example, the author calculated probabilities corresponding to the cells of this multidimensional copula. Using the estimated cell probabilities the variable combinations (i.e. particular copula cells) were sampled.

Having sampled the combinations (cells) of variables, the values of variables from the corresponding univariate cumulative distributions were sampled. These univariate distributions, in turn, were also estimated from the empirical data. Univariate distributions within the copula were made continuous using linear interpolation. The example in Figure 3.3 shows the estimated cumulative distribution function of land segmented according to the bins of copula that reflect household size quintiles.

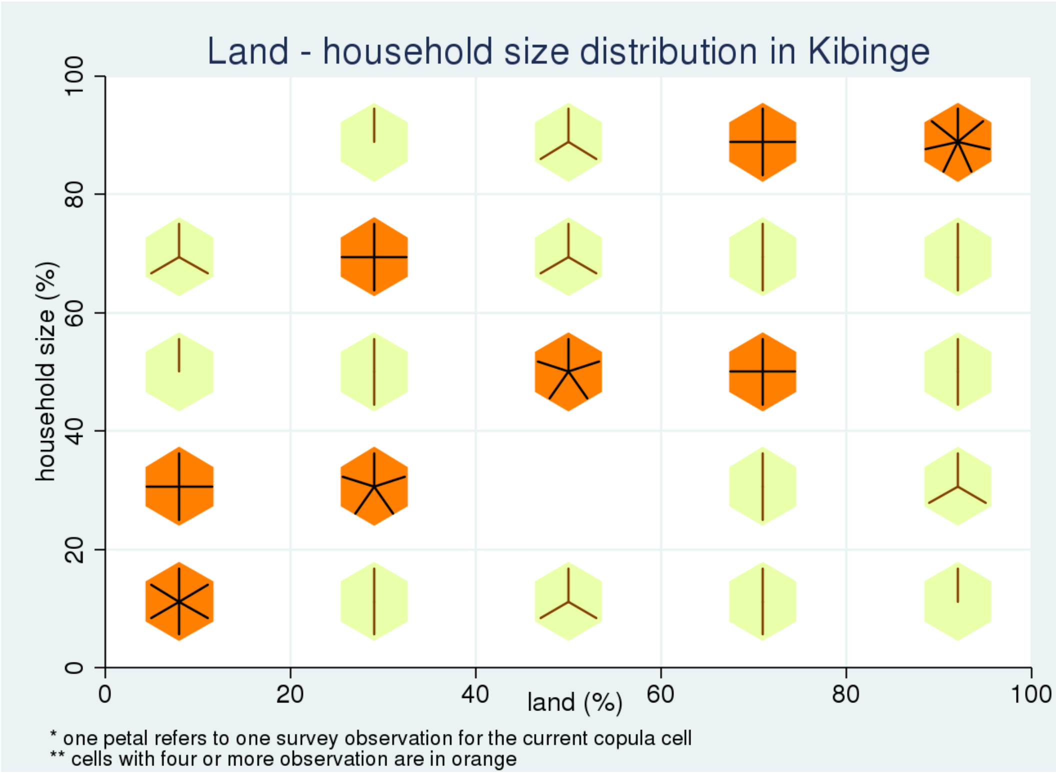
Table 3.2: Probabilities of copula cells. Example

Household size \ Land	0–20 %	20–40 %	40–60 %	60–80 %	80–100 %
80–100 %	0.0141	0.0423	0.0282	0.0282	0.0986
60–80 %	0.0282	0.0282	0.0563	0.0282	0.0563
40–60 %	0.0423	0.0000	0.0704	0.0423	0.0423
20–40 %	0.0282	0.0704	0.0282	0.0563	0.0141
0–20 %	0.0845	0.0563	0.0141	0.0423	0.0000

Source: Own estimation, based on IFPRI (2010)

From the estimated copula and cumulative distribution functions the necessary number of

Figure 3.2: Representation of joint distribution by copula. Example of land and household size

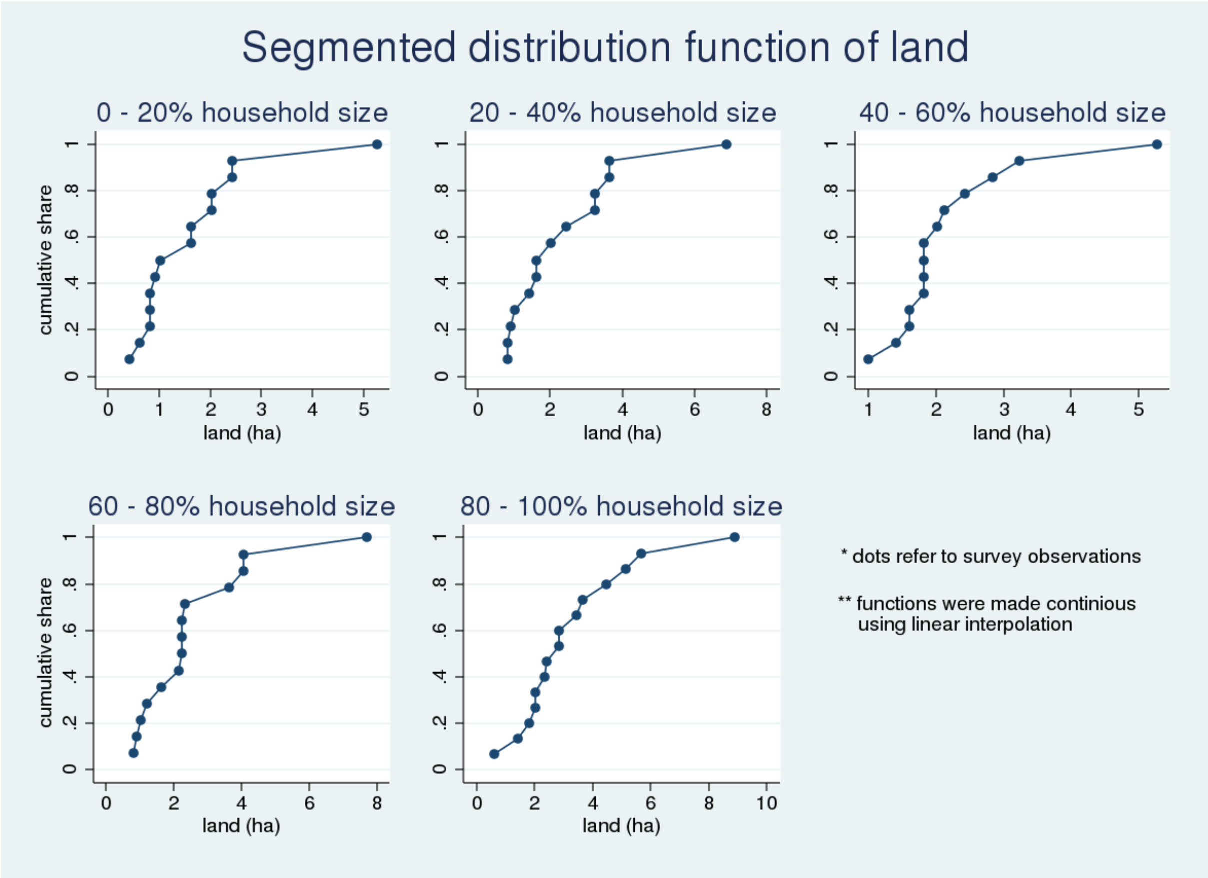


Source: Author based on IFPRI (2010)

population sets was randomly drawn using different random seeds. Table F.1 lists the variables whose values were drawn in the applied case of this research. After the pseudo-random draw, the values were transformed to MP-MAS input format. For example, size of coffee plantations was drawn as a share of total land (to ensure consistency with land sizes) and later transformed into pixels for the model input. The statistical representativity of populations generated for this research with the described method of application of empirical copula is characterized in Section 4.2.1.

The result of the population generation procedure defines the initial state of asset registry, which contains information on asset ownership of each model agent. The asset registry is updated after each simulation cycle according to the results of various MP-MAS modules (investments, permanent crops, livestock, demography, soil dynamics, market dynamics). Assets have a lifespan and MP-MAS handles the aging of assets. The lifespan is fixed for everything except the household members, for whom life is simulated by the demography model (see Section 3.8). The initial ages of household members were drawn from the empirical distribution (explained in Section 3.8), initial ages of other assets were drawn by MP-MAS software itself using uniform random.

Figure 3.3: Segmented distribution function of land. Example



Source: Author, based on IFPRI (2010)

3.3 Generating soil properties from geospatial data

Soil quality is an influential factor for on-farm decision making. Despite the fact that the IFPRI–IZA–UHOH research project did not record bio-physical characteristics of the farm plots, it was possible to include the soil quality factor in the MAS. Soil properties were modeled using econometric equations of Rhew et al. (2004), which estimated statistical relationships between soil properties and spatial terrain parameters, namely:

- Elevation ($ELEV$)
- Slope ($SLOP$)
- Topographic wetness index (TWI), which is a topographic proxy for soil moisture content, calculated as:

$$TWI = (ln(ACC + 0.001))/(tan(SLOP + 0.001)) \qquad (3.1)$$

  where ACC stands for flow accumulation – topographic variable that equals to the square of the upslope area for the current cell of the digital elevation model (DEM)
- Streampower index (SPI), a topographic proxy for water flows power:

$$SPI = ACC \times tan(SLOP) \tag{3.2}$$

The work of Rhew et al. (2004) suggests that these terrain parameters could be used as significant predictors of soil chemical properties in cases when only topographic data is available. Rhew et al. (2004) estimated their econometric equations (that are listed in Table 3.3) using the measurements obtained in the study sites in Mayuge District (until 2000 a part of Iganga District): villages of Magada and Buyemba. According to the GIS-based stratification by Ruecker et al. (2003), these villages and the study area of this research (Kibinge sub-county) (i) lie in the same development domain, (ii) have similar agro-climatic and socio-economic conditions, and (iii) have the same farming systems. Given the similarity of agro-ecological zones between the original study sites of Rhew et al. (2004) and Kibinge sub-county, it is assumed that the relationships estimated by Rhew et al. (2004) are likely to hold in the Kibinge setting as well, thus justifying the applicability of the predictive soil models from Table 3.3 in the context of this study. (More detailed characteristics of the common development domain can be found earlier in Table 1.7, where the villages of Rhew et al. (2004) research are still included to Iganga District.)

Table 3.3: Estimations of initial soil properties

Soil Property	Unit	Estimated relationship
Nitrogen (N)	%	$-1.22 + 0.039(ELEV)^{0.5} - 0.087(SLOP)^{0.5}$
Potassium (K)	mg/100 g of soil	$(0.748(ELEV)^{0.5} - 0.36log(SPI) - 21.17)^2$
Organic Matter (OM)	%	$(0.30(ELEV)^{0.5} - 0.79(SLOP)^{0.5} - 8.39)^2$
Acidity (pH)	pH	$6.47 - 1.32(SLOP)^{0.5}$
Calcium (Ca)	mg/100 g of soil	$-951.69 + 30.69(ELEV)^{0.5} - 104.69(SLOP)^{0.5}$
Sodium (Na)	%	$exp(1.90 - 5.73(TWI)^{-0.5})$
Sand	%	$536.32 - 13.7(ELEV)^{0.5} + 23.1(SLOP)^{0.5}$
Clay	%	$-394.19 + 12.2(ELEV)^{0.5} - 3.12log(SPI)$
Silt	%	$100 - (Sand + Clay)$
Phosphorous (P)	ppm	$(0.003(Ca) + 0.21log(Na) + 0.13(K)^{0.5} - 0.02(Clay) - 1.15)^2$

Source: Estimated by Rhew et al. (2004) for sites in Mayuge district of Uganda based on 30 meter grid size

The author of this study created the input for predictive soil models of Rhew et al. (2004) by analyzing the GPS measurements from the household part of the IFPRI (2010) survey and the DEM of CGIAR-CSI (2011). Using ArcGIS software the author estimated the descriptive variables of the soil models, namely $ELEV$, $SLOP$, SPI and TWI (see definitions above), for the survey households. These properties of the survey households were distributed among the full population of model households using the described copula-based method (see Section ssec:agents). Because for each household only one GPS measurement was done in IFPRI (2010), for the same land ownership, geographical properties were assumed to be homogeneous. Therefore, later soil property predictions turned out to be homogeneous within the land holding of one model agent as well.

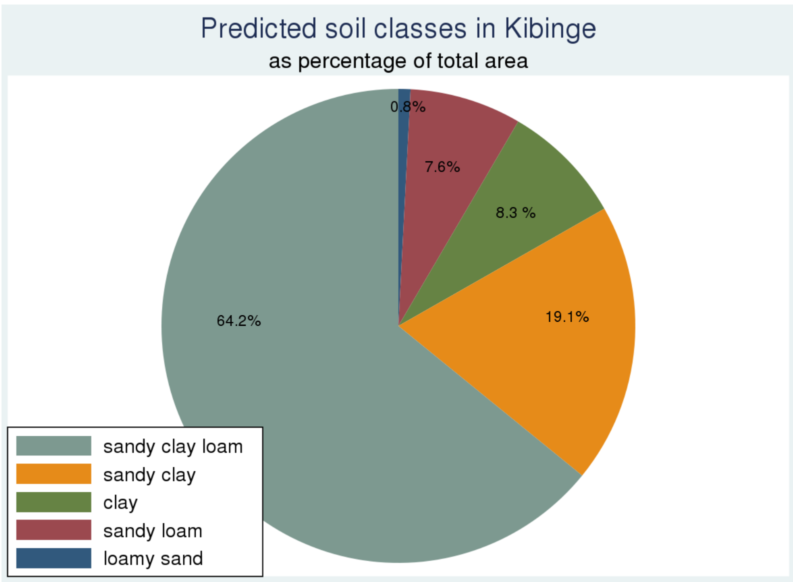
Soil chemical properties of the land of model agents were derived from the spatial variables ($ELEV$, $SLOP$, SPI and TWI) using equations from Table 3.3 based on 30 meter grid size. Table 3.4 summarizes geographical and predicted soil properties for households of Kibinge, for which precise geographical locations were recorded by GPS in the IFPRI (2010) project survey. Figure 3.4 shows the simulated distribution of soils of Kibinge households along soil texture classes (classified according to FAO (2006) guidelines). Sandy clay and sandy clay loam are expected to be the major soil classes in the research area.

Table 3.4: Predicted land characteristics of Kibinge households

Property	Unit	Mean	Median	Stdev
Elevation	masl	1251.1	1246.0	34.5
Slope	%	8.61	9.07	3.81
Nitrogen	%	0.135	0.132	0.020
Potassium	mg/100 g of soil	21.56	18.60	8.24
Phosphorous	ppm	1.349	1.395	0.276
Organic Matter	%	4.01	3.91	0.63
Acidity	pH	6.10	6.07	0.10
Calcium	mg/100 g of soil	104.1	101.5	16.3
Sodium	%	1.021	1.233	0.444
Sand	%	58.33	59.36	6.74
Clay	%	31.04	29.61	9.54
Silt	%	10.63	12.76	5.57

Source: Author, based on results of soil property prediction

Figure 3.4: Classification of soil texture



Source: Classified by author, based on results of soil property prediction
* classified according to FAO (2006) guidelines

3.4 Representation of farmer decision making

Household decision making is modeled in MP-MAS using the MP methodology, which tackles the problem of constrained optimization. The decision objective and constraints in MP-MAS Uganda are represented by a set of simultaneous linear equations and inequalities, where some of the decision variables can take only integer values. Therefore, the particular MP optimization technique is called mixed integer linear programming (MILP). The objective function of each agent is its expected household utility (U), which has to be maximized subject to a set of constraints, specified in the form of equations or inequalities:

$$\begin{cases} \max U(x) = \sum\limits_{i=1}^{n}(p_i x_i) \\ \sum\limits_{i=1}^{n}(a_i x_i) \leq 0 \\ \sum\limits_{i=1}^{n}(b_i x_i) = 0 \\ x_j \leq u_j \\ x_k \in \mathbb{Z} \\ x \geq 0 \\ x, a, b, p, u \in \mathbb{R}; \end{cases} \tag{3.3}$$

In the above equations/inequalities set x denotes the decision variables, which can take only non-negative values, p stands for numerical coefficients of an objective function, and a and b are specific constraint coefficients. Constraints could be represented in the form of equations and/or inequalities. Some of the variables (x_j) are subject to exogenous upper bounds (u) and some (x_k) can take only integer values. For solving such optimization problems MP-MAS employs the IBM Optimization Subroutine Library (OSL) that provides optimization algorithms based on the simplex and interior point methods. The solution to the problem contains values for x with which $U(x)$ takes the highest value possible to achieve without violation of specified constraints. The optimization problems in MP-MAS are formulated in a way that their results describe the individual decision-making that actually takes place in the real world (i.e. positive modeling), rather than prescribe the best use of available household resources (i.e. normative modeling). This is achieved by the incorporation of behavioral constraints and decision rules that define households' bound rational behavior (for more details see Schreinemachers & Berger (2006).

For the sake of convenience, optimization problems can be recorded in the form of a MILP-tableau. Table 3.5 gives the concise representation of the agent's optimization problem as implemented in the MP-MAS Uganda application. The full MILP of the MP-MAS Uganda application contains 2785 activities and 544 constraints. MILP integrates activities related to household investment, production, marketing and consumption behavior. Implemented constraints reflect household resource limitations, nutrient demand of household members, crop rotation requirements, livestock and poultry production requirements, credit obligations, and so on. MP-MAS makes the decision problem agent-specific by changing right- and left-hand side coefficients and fixing solutions for certain columns in the respective standard format of the tableau (concise form in Table 3.5). By solving the agent-specific MILP problems MP-MAS replicates the decision-making of the modeled farm households from the agent population.

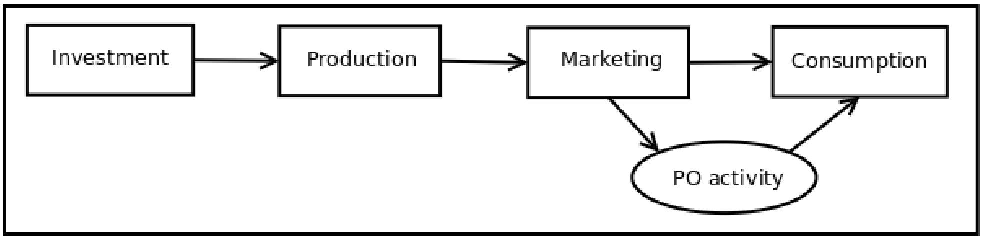
Table 3.5: Concise representation of MILP-tableau

	Sell output	Purchase production inputs	Purchase consumption products	Self-consumption	Credit	Hire labor	Make investments	Grow crops	Raise animals	Transfer activities	Budgeting	Sell future output		
Maximize	P	-P		P	-P	-P	-P	-P	-P			P		
Land							A			1			$=$	R
Labor						-1		A	A				$\leq$	R
Investments							-A	A	A				$\leq$	R
Input		-1						A	A				$\leq$	0
Output	1			1				-A	-A				$\leq$	0
Future output								-A	-A			1	$\leq$	0
Feed								-A	A				$\leq$	0
Manure								A	-A				$\leq$	0
Land balance								1	A	-A			$\leq$	0
Income	P	-P		P	-P	-P	-P	-P	-P		-1		$=$	0
Liquidity		P			-1	P	P	P	P				$\leq$	R
Consumption model			A	A							-A		$=$	0

*P – vector of market prices and costs; R – agent-specific right hand side values;
A – agent-specific technical coefficients;

In the original approach of Schreinemachers & Berger (2006), the decision making of farm agents in MP-MAS was originally split into three sequential steps: investment, production, and consumption. Such segmentation of decision-making is required to reflect the resource allocation and timing of activities (e.g. liquid assets that a farmer uses for long-term investments at the start of a cropping season cannot be used in production activities throughout the season). The steps are implemented by recursive solutions of agent MILP: each decision step involves optimization of a particular MILP and transferring certain parts of the solution vector to the MILP of the next step. Such recursive scheduling is a convenient alternative to the multi-period programming in positive modeling (see Berger (2001), Schreinemachers et al. (2007)). Each agent MILP is specified such that, when taking an investment decision, an agent already plans for production and consumption; and, when taking a production decision, an agent plans for consumption, respectively. For this research, the a marketing decision was incorporated as an additional step of agent decision-making in order to simulate household crop sales through RPOs. Figure 3.5 plots the sequence of household decisions, and Table 3.6 compares the respective four sequential stages of decision making. The implementation of household marketing decisions and its linkage with the model of RPOs is discussed later in Section 3.10.

Figure 3.5: Optimization sequence



Source: Author

Table 3.6: Stages of household decision-making in MP-MAS

Characteristic \ Stage	Investment	Production	Marketing	Consumption
Timing	beginning of the period	beginning of the period	end of the period	end of the period
Yields	expected in future	expected in current period	actual	actual
Resource supply	expected in future	expected in current period	actual	actual
Prices	expected in future	expected in current period	expected in current period	actual
Fixed decision variables	none	none	land and input use	land and input use, sales volumes

Source: Author

3.5 Production and investment alternatives

The universe of household production and investment alternatives represented in the decision model is a result of collaborative work of the author and MP-MAS development team (Woelcke 2000, Schreinemachers et al. 2007, Latynskiy & Berger 2012*a*). The collection and parameterization of alternatives was based on literature reviews, expert opinions, participatory research and analyses of empirical data. There are around 2,500 production and investment alternatives available for household agent choice in MP-MAS Uganda. This results in the nearly infinite number of linear combinations of agent choices of production and investment behavior and resource allocation. The implemented alternatives correspond to different farm enterprises: crop production, livestock farming, animal feed production, manure production, etc. This section provides an overview of the alternatives and explains their practical implementation.

3.5.1 Crop growth, production functions and alternatives

MP-MAS Uganda endogenously models crop yields based on the classical Mitscherlich equation describing yield responses to increases in limiting factors. Mitscherlich theory based on von Liebig's Law of the Minimum assumes yield to be bound by the maximum or potential yield (Y_{pot}). Constraining factors ($F_1 ... F_n$), whose availability are defined on [0;1] interval, limit the potential yield to the actual crop yield (Y_{act}):

$$Y_{act} = Y_{pot} \times F_1 \times ... \times F_n \tag{3.4}$$

From the above equation it can be seen that the maximum yield can only be reached, when all yield defining factors are abundant. Increase in availability of each factor has a positive impact on actual yield. This impact is moderated by the availabilities of all other factors. Theoretically, the Mitscherlich equation was assumed to apply the factors that limit plant growth, such as soil nutrients, water, temperature, light, pests, crop management, etc. These factors can be either natural (i.e. bio-physical) or human-controlled. In the case of MP-MAS Uganda, availabilities of natural factors are explicitly modeled with integrated Tropical Soil Productivity Calculator (TSPC) developed by Aune & Massave (1998) (see Section 3.6).

Human-controlled factors are represented in MP-MAS Uganda by the rate of labor application that is simulated, when solving agent-specific MILP problems. Agents can decide how much labor to apply, when growing different model crops. The rates of labor application coming from solutions of agent MILP are transferred by the MP-MAS code into the crop management factor of TSPC (MAN in Equation 3.7). Also, agents can control fertilizer application, which influences TSPC calculations (Section 3.6) as well. Other possible human-controlled factors such as spacing, quantity of planting material, as well as pest and disease treatments were assumed to be constant over the entire population. The yield effects of pests and diseases, as well as those of pesticide application, were explicitly included in the TSPC in the form of relative yield loss adjustments. These adjustments were roughly estimated based on the description of Ugandan agriculture compiled by Mukiibi (2001) and on the model input data of Schreinemachers (2006) (Table 3.11). The effects of other crop management factors that may be relevant are implicitly captured during the estimation of potential crop yields. The use of draft power is generally not practiced in the study area (as was reported during the field visits – see Chapter 2), because of the narrow tree spacing in the coffee/banana production system. Therefore, its application was not considered.

Yield response to labor input was implemented in agent MILP using piece-wise linear approximation of the estimated partial (yield-labor) Cobb-Douglas production function. The estimation of production functions for all model crops except coffee (estimation for which is explained in Section 3.5.2) was done by Schreinemachers et al. (2007) based on the IFPRI (2001) data assuming a Cobb-Douglas form of the production function. Three levels of labor use (minimal, medium and maximal) were made available for agent choice. The minimal level of labor application reflects the smallest amount of labor input required in order to receive any yield from the corresponding crop production alternative. At the maximal level the yield is unconstrained by labor. It is assumed that farmers always follow common fertilization practices (100 kg per ha) when applying mineral fertilizer. Hence, only one intensity level for each type of fertilization was implemented, given that manure is distributed uniformly across all plots. The fertilization types in the decision model are: (i) fertilization only with manure available on the farm, (ii) farm manure and nitrogen phosphorus potassium (NPK) fertilizer (NPK rating – 15–15–15), (iii) farm manure and calcium ammonium nitrate (CAN) fertilizer (NPK rating – 24–0–0). Table B.8 of the Appendix presents the MILP-implementation of crop management alternatives for a single crop. (Examples of implementations of other decision problems can also be found in the Appendix.) In total, nine different crop management practices per crop are available for agent choice. These combinations are further disaggregated by the five model soil classes to introduce different yield expectations according to soil quality.

Production alternatives of MP-MAS Uganda comprise ten arable crops. According to their MILP-implementation, these crops could be divided into four groups: seasonal, annual, aggregate and perennial. Model crops and their classifications are listed in Table 3.7. Physical characteristics, planting densities (TSPC parameters) and seed rates (MILP parameters) for model crops were collected by (Schreinemachers 2006) from agronomic literature.

Table 3.7: Model crops

Seasonal	Annual	Aggregate (seasonal)	Perennial
Beans	Cassava	Fruits	Coffee
Groundnut	Plantain	Vegetables	
Maize			
Sorghum			
Sweet potato			

Source: Author, based on MP-MAS input

The length of one modeling period of the farm decision model, as well as of other parts of MP-MAS Uganda is one calendar year. Since there are two distinct cropping periods in the study area, the modeling of production decisions required having separate production alternatives for each season. Practically, this was implemented in a way that for seasonal crops all growing activities from Table B.8 were further differentiated by seasons. Such pragmatic and simplified implementation was based on the assumption that a household takes a simultaneous production decision for both seasons at the start of the year, which also required differentiation of land and labor endowments by seasons via transfer activities in MILP (see Table B.2). (For all crops, except perennial ones, labor requirements were analogously disaggregated further on a two month basis.) Alternatively, two different season-specific decision and biophysical models could have been constructed.

A perennial crop is a crop that stays on a field for several years. Yield and input requirements of such crops vary during its lifespan. Therefore, perennial crops required a specific implementation in the model (explained in Section 3.5.2). Although cassava, plantains and fruits from the botany perspective are perennial crops, coffee is the only crop in the MP-MAS Uganda application that was implemented as perennial. Cassava and plantains were treated as annual, since they are typically harvested within the first year.

Potential yields of coffee, seasonal and annual crops were set to 90-percentile observed yields. The potential yield of coffee was estimated from the IFPRI (2010) project using data from the Masaka District of Uganda. Yields of seasonal and annual crops were estimated from UNPS (2010) national survey using the data for Central and Eastern regions of Uganda. The estimates of potential yields are provided in Table 3.8.

Table 3.8: Potential yield estimates

Crop	90% yield	unit	90% Confidence interval	
Beans	1,482.6	kg/ha/season	889.6	1,751.0
Cassava	5,987.6	kg/ha/year	5,135.6	9,094.1
Coffee	2,390.7	kg/ha/year	1,810.7	3,147.7
Groundnut	1,235.5	kg/ha/season	1,009.8	1,482.6
Maize	2,381.2	kg/ha/season	1,976.8	2,965.3
Plantain	9,266.5	kg/ha/year	7,346.9	13,839.7
Sorghum	1,408.5	kg/ha/season	988.4	2,325.0
Sweet potato	9,884.2	kg/ha/season	6,428.2	16,631.59

Source: Own estimations, based on UNPS (2010) and IFPRI (2010)

The farms in Uganda normally contain fruit and vegetable gardens located around the farmstead. In these gardens, households usually grow crops such as jack fruit, passion fruit, paw paw, dodo, cabbage, tomato, etc., for home consumption (IFPRI 2010). Because of the absence of experimental data, the cultivation of fruits and vegetables was implemented as an aggregate activity, attributed with median yields and median labor requirements (estimated by Schreinemachers et al. (2007) from IFPRI (2001)). Fruits and vegetables are typically grown on small areas and fertilized with kitchen waste (Schreinemachers 2006). Therefore, the cultivation of fruits and vegetables is not considered in TSPC calculations.

Crop rotation is a basic technique of soil management. Alternating crops that are grown in a single plot prevents disproportional depletion of soil nutrients and, therefore, improves soil fertility. These crop rotation considerations constrain farmers' choices of cropping patterns. A straight-forward MILP-technique of modeling crop rotation constraints is implementing them as a maximal share of total land that could be occupied by the crop (e.g. if beans are grown on the same plot only once in two consecutive seasons then the maximum land share allocated for bean growing activities is 0.5). Table 3.9 summarizes rotation constraints of the MP-MAS Uganda application.

Table 3.9: Crop rotation constraints

Crop	Bean	Cassava	Groundnut	Maize	Sorghum	Sweet potato
Max land share	0.393	0.256	0.181	0.531	0.125	0.236

Source: Calibrated values of Schreinemachers (2006)

Growing two or more crops in close proximity (i.e. intercropping) through optimization of nutrient efficiency, erosion protection and provision of shade may result in more efficient land use on the farm. As discussed earlier (Sections 1.3.3 and 2.5) for robusta coffee farmers in Uganda it is common to intercrop coffee with banana. Apart from coffee/banana intercropping, the following combinations of model crops are commonly observed to be mixed intercropped in the lake-shore production system in Uganda: (i) maize and beans, (ii) maize and cassava, (iii) maize and groundnut (Woelcke 2004). For these combinations, intercropping activities were allowed in MILP (yield premiums of these intercropping activities are provided in Schreinemachers (2006)).

3.5.2 Coffee growing and management

The production function for coffee with respect to labor input was estimated from IFPRI (2010) household survey. The production function was specified as Cobb-Douglas in logarithmic form:

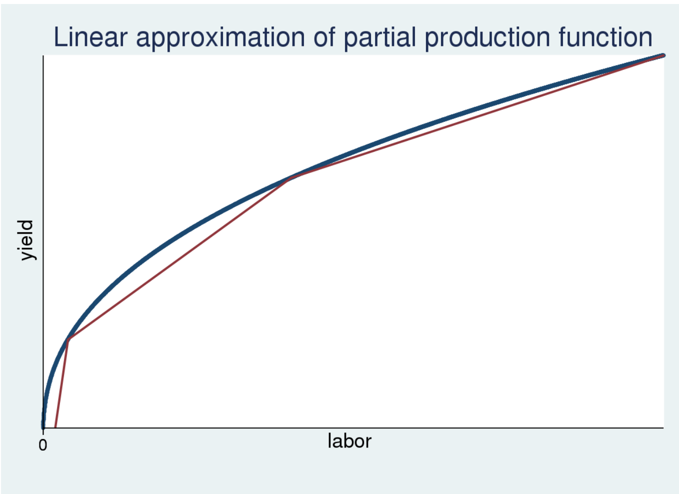
$$lnY = \beta_0 + \beta_1 lnLAB + \beta_2 ID + \beta_3 FD + \gamma_1 D_1 + ... + \gamma_n D_n \qquad (3.5)$$

where Y – yield per hectare of coffee plantation; LAB – labor use per hectare of coffee plantation; ID – dummy variable for intercropping of coffee with plantain; FD – dummy variable for application of inorganic fertilizers; $\gamma_1 D_1 + ... + \gamma_n D_n$ – vector of district dummies.

The estimation of fertilization intensity and intercropping ratios from IFPRI (2010) was problematic, since the survey captured data on the plot level, but not on the crop level. It is very common for Ugandan farmers to grow several crops on one plot (up to four different crops per agricultural season). The survey lacks data on land use shares of different crops, therefore, the application of mineral fertilizers and intercropping with plantains were included in the model in the form of dummy variables. The fertilization dummy reflects whether or not mineral fertilizers were applied on the coffee-containing plots during the preceding calendar year. The intercropping dummy reflects whether or not the coffee-containing plots also contained plantain plants. District dummies control for the differences in agro-ecological conditions. The labor application in person hours was calculated from IFPRI (2010) using average daily labor supply factors of Schreinemachers (2006).

Table 3.10 presents the estimated production function for robusta coffee. This function serves for modeling of the human-controlled labor factor of crop growth that enters the Mitscherlich yield equation (Equation 3.4) in MP-MAS Uganda. As seen in Table 3.10, labor use is the significant determinant of coffee yield. Mineral fertilization and intercropping with plantains turned out to be insignificant, most probably because of the previously mentioned inaccuracies of fertilizer and intercropping estimates. The district dummies that reflect the differences in agro-climatic conditions are significant, as well as the constant term. The estimated production function was implemented in MILP through its linear approximation (see Figure 3.6). Basing the calculation of labor use for coffee plantations on average daily labor supply resulted in an overestimation of the actual labor requirements of coffee. Therefore, in order to make the estimated production function fit the observed data better, Schreinemachers (2006) introduced a specific adjustment factor into TSPC for coffee. In the model set-up applied for this study, the average value of Schreinemachers (2006) specific LP calculations of this adjustment were used for single farm households.

Figure 3.6: Linear approximation of production function



Source: Author

A coffee plantation is a durable asset, therefore MP-MAS keeps information on its size and age in a household asset registry. In order to be able to grow coffee, an agent has to possess a coffee plantation. The soil class on which coffee was initially planted and the originally planned

Table 3.10: Production function for robusta coffee

Dependent variable = Ln(Coffee yield), kg per ha	coef	se
Ln(Labor use), hours per ha	0.420***	0.049
Inorganic fertilization	-0.069	0.131
Intercropping with plantain	-0.164	0.125
Masaka	-2.045**	0.857
Mpigi	-1.649*	0.900
Mityana	-1.952**	0.870
Mubende	-2.809***	0.868
Bushenyi	-2.046**	0.867
Kamuli	-2.263***	0.853
Wakiso	-1.818**	0.869
Constant	6.015***	0.893
F-test (10, 326)	11.01***	
R-squared	0.2524	
N obs	337	

Source: Own estimation from IFPRI (2010) survey
* implies a significance at 10%-level, ** – at 5%, *** – at 1%

management practice are also recorded in the registry. Input data of MP-MAS specify yields and labor requirements for different soil classes, management practices and ages of the plantation lifespan (42 years for coffee). The perennial crops module of MP-MAS inserts the respective coefficients into the agent periodical MILP according to the characteristics of their coffee plantations (age, soil, management practice). To ensure that an agent considers future returns of a perennial crop, the annuity of its expected returns is added to the objective function through an additional future selling activity containing expected future prices in the function coefficients row. This activity operates with the annuity of discounted expected future yields of the crop, which are inserted into agent MILP by MP-MAS. The expected future returns are excluded from the calculation of financial results of the modeling period (see simulation cycle in Figure 3.1), since they are accounted for in later modeling periods.

Different management practices and soil types on which coffee can be grown translate into 50 coffee growing activities in MILP. From year to year agents can switch the management practices of coffee plantations, changing the labor intensity and fertilization practices. The yield effect of the new management practice is immediate; the inter-annual yield impacts of different practices, however, are not considered. A perennial crop permanently occupies a land plot on which it is planted, therefore MP-MAS reserves land parcels under perennial crops for the duration of their lifespan. Therefore, switching between different soil classes is not allowed. There are 450 switching combinations (i.e. from practice x to practice y) in the model, each of them represented by a separate MILP activity.

Based on the insights from the fieldwork, that household agent MILP were implemented such that agents cannot cut their coffee trees, meaning that they are always maintained unitl the pre-defined end of their productive life. Therefore, coffee plantations in MILP require at least some minimal amount of labor input. This requirement was implemented through putting equality signs to the respective constraints. In case of labor scarcity, agents can always switch (via switching activities in MILP) to the specified lowest input management practice, that give minimal yields (see Figure 3.6).

The practice of intercropping coffee with plantains was modeled through a specific constraint. Since coffee plantations in the study area mostly also contain banana plants (IFPRI 2010), the respective MILP-constraint ensures that agents who grow coffee also allocate at least a certain proportion of their land to plantains. The plantain/coffee intercropping ratio in accordance with field observations was set equal to 1/5 (i.e. 20% of each ha of mixed plantation is occupied with plantains).

Table B.12 provides a tableau displaying MILP-implementation of coffee cultivation and management.

3.5.3 Livestock

There are four types of livestock and poultry species in MP-MAS Uganda: cattle, goats, chicken and pigs. Chicken and pig production were implemented following the stationary equilibrium approach of Hazell & Norton (1986), which means that the characteristics of the production were expressed in annual average terms. In terms of inputs, chicken and pig production require feed, labor and cash (e.g. for supplements, vaccination etc.), as well as the procurement of animals for raising and breeding. Chicken production provides two marketable products: chicken and eggs; pig production provides either pig weaners or finishers for sale. Additionally, animal production provides manure, which is an internal farm product used for fertilization (explained in Section 3.5.1). The maximum number of chicken and pigs that different households can manage at one time was derived from the IFPRI (2010) survey; this data translates into additional MILP constraints. Table B.9 shows the MILP-implementation of chicken production. From this tableau it can be seen that model agents have options to sell chickens or to keep them as laying hens. Laid eggs, in turn, could be consumed, sold or hatched. Therefore, agents can also decide whether to buy chicks or to raise them from eggs on the farm. Table B.10 displays the MILP-implementation of pig production. As this pig rearing example tableau shows, in agent MILP, production is divided into three stages: at the first stage piglets are raised to weaners; at the second stage weaners are either raised to finishers or sows; and at the third stage, breeding sows are maintained to produce piglets. Thus, agents may buy weaners and sows or raise them from their own piglets. Parameter values for chicken and pig production were estimated from the project survey (IFPRI 2010), national panel survey (UNPS 2010) and national livestock (UNLC 2008) and agricultural

(UCA 2009) censuses or taken from other MP-MAS models (Dang Viet 2012, Schreinemachers 2006) and literature (Kirunda et al. 2010, Zinunula 2009, Ssewannyana et al. 2008, NAADS 2005, Kyarisiima et al. 2004, Ishagi et al. 2003).

The rearing of cattle and goats (which may stay on a farm over several years) was modeled with a special livestock module of MP-MAS. The livestock module is similar to the perennial crops module in that livestock input requirements and output quantities have to be specified for each year of the livestock lifespan. The input data (lifespan, input requirements, liveweight, and amount of provided output products) vary according to the sex of livestock. Similar to pig and chicken production, raising cattle and goats also require feed, labor and cash inputs. Both male and female livestock provide meat and manure, while female livestock additionally provide milk and offspring. Therefore, the size of a livestock herd can be maintained or increased through the purchase of new livestock units (explained in Section 3.5.4) and the raising of own offspring. Meat is provided only when livestock is slaughtered (its amount equals the liveweight of a livestock unit and its offspring in a given period), while other products are provided constantly on the annual basis. The implementation of durable livestock in the MILP is shown in Table B.11 with the example of nanny-goats (a lifespan of two years is used in the example to simplify the representation). The multi-periodic implementation of livestock displayed in this table allows agents to sell livestock units before the end of their productive lifespan, at the beginning as well as at the end of the modeling period. Parameter values for production of cattle and goats were estimated from the IFPRI (2010) project survey and were calculated using the spreadsheets of (Schreinemachers 2006) updated with data from the literature (Lagu et al. 2012, FAO 2004, Nsubuga 1994).

3.5.4 Investments

From an economic point of view, an investment is a purchase of goods that are not consumed but used to generate future returns. Investment decisions differ from current production decisions in that they involve a longer planning horizon of a decision-maker, since investments generate returns for a period that is longer than one production cycle. In MP-MAS Uganda, investment goods are the ones that produce outputs for longer than one year. Hence, in MP-MAS Uganda there are two types of investment goods: (i) coffee plantations and (ii) durable livestock (cattle and goats). Each investment in MP-MAS is represented by an entry in the agent asset registry and a separate activity column in MILP. The asset registry contains information about the size and age of agents' durable assets. It is updated after every simulation period based on investment decisions taken by agents.

Optimization of household investment decisions is done by comparing expected future and annual returns of different resource use alternatives. When solving the investment stage of the decision process (Table 3.6), MP-MAS code calculates and inserts respective annuity cost and output coefficients to agent MILP. Table B.1 shows the MILP-implementation of investment problems for coffee. When making an investment plan, an agent also considers consumption preferences and requirements since consumption requirements are included in the investment MILP (see Table B.1). Therefore, the trade-off between future returns and current consumption is taken into account.

3.5.5 Risk, expected returns and consumption security

Risk management is an important aspect of farming. Because of market price volatility and uncertainty about natural conditions and crop yields, farmers have to make their investment and production decisions based on risk-return trade-offs. This issue is especially relevant in the case of subsistence-oriented agriculture in developing countries, where the household food and nutrition security is often at stake and farm livelihoods might be seriously endangered. For example, according to Hill (2006) 90% of the coffee farmers in Uganda were unable to satisfy their basic needs during the period of low coffee prices in 2000-2003. In another example, cassava is less attractive to farmers because it has a highly variable yield and is susceptible to pests and diseases (Mukiibi 2001). Regarding livestock, households have an additional incentive to keep goats, since they are more drought-resistant than cattle and, therefore, are a more secure income source (Ocaido et al. 2009). Hence, risk considerations are expected to be an influential factor for decision-making of agricultural households in rural Uganda as a whole and in the study area in particular. Farmers, when planning their enterprises, may consider not only the expected returns from their production activities, but also the expected variation of the returns.

MP-MAS Uganda adjusts agent decision-making given the risk considerations by the following mechanisms:

- Certainty equivalents: Adjust the expected returns of the current period. Table B.3 provides an example of implementation of certainty equivalents in agent MILP. A higher value of certainty equivalent (Eq) means a higher risk-associated discount for the expected return. These coefficients are only applied when modeling household investment and production choices. They are not considered during the marketing and consumption decisions, which are taken with actual results of production (see Table 3.6 for the comparison of decision stages). The values of certainty equivalents in MP-MAS Uganda were estimated during model calibration (see Section 4.1).
- Valuation coefficients of future returns: Adjust the expected returns of future periods (MILP implementation in Table B.3). Reflect farmer preferences assigned to future incomes with respect to current incomes. A higher value of the coefficient (V) would cause agents to allocate more resources to enterprises that generate income in the future (like livestock rearing), which would smooth the consumption over periods and reduce the risk of food insecurity. Also with these valuation coefficients agent attitudes towards future price and production risks may be tuned. Valuation coefficients of future returns were

also estimated during model calibration.

- Liquidity reserve factor: Models household preferences towards consumption security. This factor (R) defines the amount of liquid assets agents reserve (i.e. do not use for financing of their investment and production activities) to secure household consumption. The agent-specific amount of liquid assets (L_{res}) to be reserved is calculated by MP-MAS as:

$$L_{res} = R \times C_{min} \times HS \tag{3.6}$$

where C_{min} – minimal annual consumption requirement in ugx per gigajoule (estimation explained in Section 3.7.5); HS – household size in gigajoules.
Reservation of liquid assets for consumption is implemented in MP-MAS by reducing the corresponding right-hand side values of investment and production MILP of an agent by this amount (L_{res}). In the case of marketing and consumption MILP, full liquid assets are available. The R factor was assumed to be equal to 25% of the respective minimal annual consumption requirement of the model households, which translates to securing consumption for three months.

3.6 Simulating crop yields and soil dynamics with TSPC

Crop yields are one of the main parameters in any production-related agricultural model. Precision of yield estimates in MP-MAS Uganda defined its capabilities in modeling production decisions. For computation of crop yields and simulation of soil property dynamics MP-MAS Uganda used Tropical Soil Productivity Calculator (TSPC) of Aune & Massave (1998). It was specifically parameterized and calibrated for Ugandan agro-ecological conditions by its developer J. Aune within the work of Schreinemachers et al. (2007).

TSPC is a built-in module of MP-MAS. Theoretically, TSPC is based on Mitscherlich's relative yield theory. Therefore, it assumes yield to be limited by potential yield. Several constraining factors reduce the yield potential to calculate the actual crop yield. The yield function is specified as:

$$Y_{act} = Y_{pot} \times MAN \times NAV \times PAV \times KAV \times SOC \times pH \tag{3.7}$$

In this equation, Y_{act} stands for the actual crop yield and Y_{pot} for the potential crop yield, which is reduced by the six yield-determining factors defined on [0,1] interval:

- Crop management practice represented by the level of labor application (MAN)
- Available amount of nitrogen (NAV)
- Available amount of phosphorus (PAV)
- Available amount of potassium (KAV)

- Soil organic carbon (SOC)
- Level of acidity (pH)

Plot management practices influence soil fertility, which in turn determines future yields. Changes in crop yields over time influence farmers' decisions with regards to the choice of plot management practices. The integration of the TSPC equations with the farm-level production module in MP-MAS Uganda allows for the simulation of such a human-environment interaction cycle.

TSPC is a recursive model: it updates soil chemical properties based on the history of applied land use practices. TSPC calculations of soil property dynamics go through five mathematical phases (equations can be found in Schreinemachers (2006)):

1. Calculation of yield determining factors: The five natural determinants of crop yields that TSPC considers (NAV, PAV, KAV, SOC and pH) are computed from maps with plot chemical characteristics.
2. Calculation of crop and residue yields using Equation 3.7.
3. Explicit adjustment of crop yields. (Function adjustments for pest and disease effects, harvest and post-harvest and other losses are provided in Table 3.11.)
4. Calculation of soil property dynamics: Maps with chemical properties are updated to create the input for next the period yield calculations.
5. Evaluation of dynamics in balance equations: Plot level nutrient and acidity balances are calculated. Based on the outcome of these computations, land use processes are evaluated.

Table 3.11: Yield adjustments for negative effects

	Effect	
Crop	Magnitude	Adjustment to yield function, %
Bean	Medium	-30%
Cassava	Strong	-50%
Coffee	Small	-20%
Groundnut	Small	-20%
Maize	Medium	-30%
Plantain	Strong	-50%
Sorghum	Medium	-20%
Sweet potato	Strong	-50%

Source: Author's rough estimates, based on Mukiibi (2001) and Schreinemachers (2006)

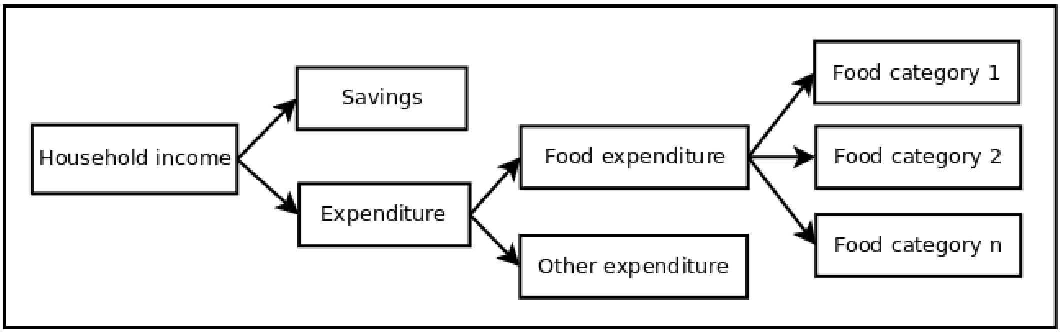
TSPC calculates yields based on solutions of agent production MILP, which are being solved with the expected yields, and inserts actual yields into marketing and consumption MILP (see

Figures 3.1 and 3.5 and Table 3.6 for details). Apart from grain yield, some plants also produce crop residues or stover yields, which comprise a certain percentage of the total crop yield and are used in MILP for livestock feeding (see Table B.11).

3.7 Consumption preferences

Considerations of food security and own consumption requirements have a certain influence in decision making of farmers in developing countries, where the agriculture is to a large extent subsistence-oriented. Therefore, modeling of household consumption received a particular focus in MP-MAS Uganda. Allocation of generated income for expenditures and savings is the last stage of agent decision making (see Table 3.6), and it is being considered during the earlier decision-making stages of investment, production and marketing. For modeling of household consumption, this study used the extended and adapted methodology of Schreinemachers et al. (2007), which in turn is based on theoretical concepts of Working (1943), Leser (1963), Deaton & Muelbauer (1980) and Sadoulet & De Janvry (1995). Savings and expenditures were defined by a stepwise budgeting process, represented in Figure 3.7. Through this decision process a household (based on the size of its income) splits the current income between savings, expenditures on different types of food, and other expenditures. Implementation of such income allocation in MP-MAS Uganda was done in accordance with the respective regression models estimated from UNPS (2010) and IFPRI (2010) surveys.

Figure 3.7: Concept of household budgeting



Source: Concept of Schreinemachers et al. (2007)

3.7.1 Savings

As follows from the budgeting concept (Figure 3.7) savings (S) is a function of income (I). Let us assume that the proportion of income that is saved increases with income. Therefore, considering the effects of household size (HS) and household location ($D_1 ... D_n$ – district dummies), the savings function can be specified as:

$$S = \beta_0 + \beta_1 I + \beta_2 HS + \gamma_1 D_1 + ... + \gamma_n D_n \tag{3.8}$$

This savings function was estimated from the IFPRI (2010) household data. Household savings were represented by a survey variable containing respondents' estimates of how much he or she was able to save in a "good month". Annual farm income was calculated and used as an income proxy. According to the IFPRI (2010) survey, a substantial share of households did not make any savings. This fact created a kurtosis in the distribution of the dependent variable S. Therefore, the model (Equation 3.8) was estimated only for households with non-zero savings. Table C.2 contains the regression output. From this table it can be seen that the squared term of farm income is close to zero. Therefore, it can be concluded that the savings function has a linear shape on the observed levels of income. Household size and most of the district dummies were insignificant.

Practical implementation of the savings function in agent MILP required it to be defined on all income levels. Hence, the regression model of savings as a function of farm income from Table C.2 was converted to the simple linear form with no constant term (Table C.3). A direct transition from monthly savings to annual savings was done, assuming households to have three "good months" in the calendar year. A distinction between saving and non-saving households was introduced by the estimation of a logit model from the same independent variables as the original savings function: I, HS, $D_1 ... D_n$. Results of the logit estimation are shown in Table C.1.

The logit model was used in MP-MAS Uganda for the assignment of propensity to make savings based on agent's income and household size. From the logit estimates, the agent-specific bounds for income, from which agents start to make savings, could be computed. In this dissertation, this bound is referred to as Ψ.) A dependent variable in the logit model is a probability in log-odds (P_{log}) of an agent to make any savings. Normal probability can be derived from it as:

$$P = 1/(1 + e^{P_{log}}) \tag{3.9}$$

By comparison of normal probability with uniform random number on (0;1) interval (R) non-saving agents could be identified. An agent makes savings if:

$$P \geq 1 - R \tag{3.10}$$

Substituting P with the right-hand side of Equation 3.9 results in the following condition of making savings:

$$P_{log} \geq -Ln(1/(1 - R) - 1) \tag{3.11}$$

Replacement of P_{log} by the regression equation of the logit model (see Table C.1 gives:

$$\beta_0 + \beta_1 I + \beta_2 HS + D \geq -Ln(1/(1 - R) - 1) \tag{3.12}$$

where $\beta_0, \beta_1, \beta_2$ – regression coefficients of the estimated logit model; D – corresponding regional dummy.

Finally, solving the inequality for income, provides an income bound for savings behavior. Assignment of agent-specific random numbers provides a distinction between saving and non-saving agents. An agent makes savings if:

$$I \geq (-Ln(1/(1-R)-1) - \beta_0 - \beta_2 HS - D)/\beta_0 \tag{3.13}$$

The term at the right-hand side of Inequality 3.13 is an income bound for savings behavior (Ψ). MILP-implementation of the savings component of budgeting process is explained in Table B.4. From the displayed tableau it can be seen that different income sizes and Ψ values of individual agents made the savings model agent-specific.

3.7.2 Food and non-food expenditure shares

Expenditure budget partitioning between food and non-food expenditures was represented by the Working-Leser model (Working 1943, Leser 1963). Unlike Schreinemachers et al. (2007), who used the modified version of the Working-Leser model, in this work an original form of the model was applied. The model defines a share of total household expenditure spent on food (η) as a function of total expenditure (E), household size (HS) and a vector of dummy variables ($D_1 ... D_n$). The function has a log functional form, which is called to reflect a decrease in the share of food expenditures with the rise of total expenditure budget:

$$\eta = \beta_0 + \beta_1 lnE + \beta_2 HS + \gamma_1 D_1 + ... + \gamma_n D_n \tag{3.14}$$

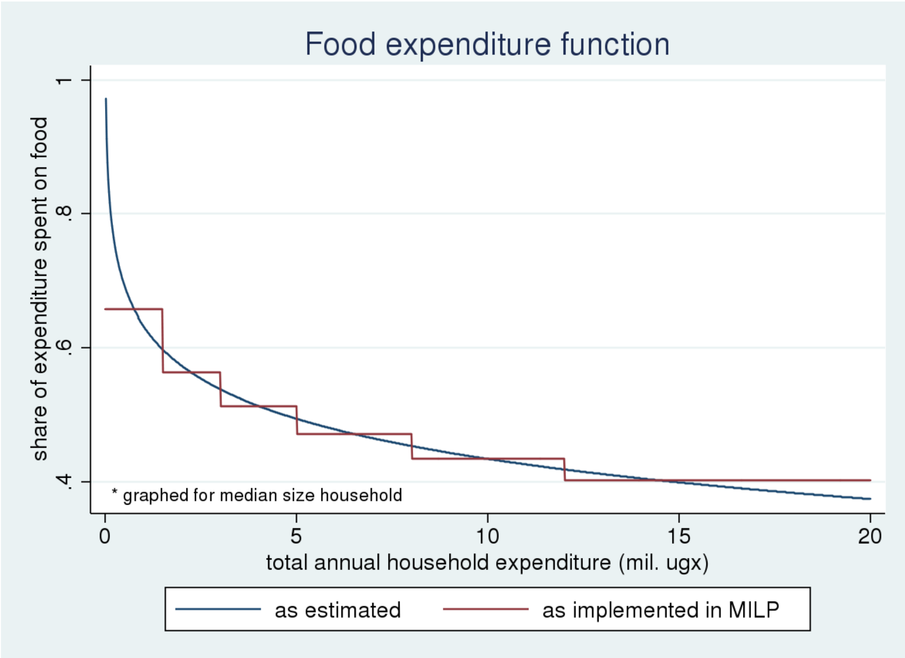
The regression model specified by Equation 3.14 was estimated for Uganda from the UNPS (2010) national survey. Table C.4 presents the regression estimates.

Transfer of the non-linear food expenditure partitioning function (Equation 3.14) to the MILP (which requires a linear set up) was done through division of the function to a number of linear segments according to the size of the expenditure budget. Figure 3.8 shows linear representation of the expenditure part ($\beta_1 lnE$) of the function (calculated for the average household size). Table B.13 demonstrates how the function was implemented in the agent MILP-tableau. MP-MAS makes the tableau agent-specific by inserting the respective household sizes of individual agents. MILP coefficients for the expenditure part of the function for linear segments (Υ) are calculated using average expenditure of this segment:

$$\Upsilon_n = \beta_1 ln((E_{n+1} - E_n)/2) \tag{3.15}$$

where E_n – segment lower bound (expressed in total expenditure); β_1 – expenditure regression coefficients of estimated Working-Leser model (Equation 3.14).

Figure 3.8: Food expenditure function



Source: Author (expenditure function estimated from UNPS (2010))

3.7.3 Food product categories

In the last stage of the budgeting process (Figure 3.7) a household decides on how many items to consume from different food categories. A food category is an aggregation of products according to their substitutability. Products within the same food category, therefore, are assumed to be perfect substitutes. For the MP-MAS Uganda application eight food categories were defined (listed in Table 3.12). Monetary values, energy and protein contents for units of different food categories were calculated as averages weighted by shares of particular products in the household consumption expenditure for the given food category (estimated from UNPS (2010)). For estimation of monetary values, price records (medians for rural agricultural households) of IFPRI (2010) for Masaka district, to which the study area belongs, were used. Energy and protein content of foods were taken from USDA (2011) database.

A household choice between food categories that a household makes can be explained by the application of an almost ideal demand system by Deaton & Muelbauer (1980), where expenditure shares spent on different food items depend on relative prices and on a measure of real income. For the empirical applications it is practical to use a linear approximate of the system (Alston & Chalfant 1993). There, shares of particular food categories (σ_i) in the household food expenditure (FE) are defined by k equations of the form:

$$\sigma_i = \beta_{0,i} + \beta_{1,i}(ln(FE/HS))/PI + \beta_2 HS + \varepsilon_{i,1} lnUV_1 + ... + \varepsilon_{i,k} lnUV_k + \gamma_1 D_1 + ... + \gamma_n D_n \tag{3.16}$$

Table 3.12: Aggregation of food categories

id	Food category	Main products	Mean budget share, %	Energy, GJ/kg	Protein, kg/kg	Mean unit value, .00 ugx/kg
1.	Plantains	plantain	15.95	0.00378	0.00963	5.00
2.	Tubers	sweet potato, cassava, irish potato	18.31	0.00445	0.01321	3.96
3.	Cereals	millet, sorghum, rice, maize	13.62	0.01418	0.08411	7.53
4.	Legumes and bakery	beans, groundnut, peas, sesame, bread	12.75	0.01565	0.22140	22.21
5.	Additives	sugar, salt, cooking oil, ghee	9.52	0.01863	0.00038	28.24
6.	Animal products	beef, chicken, mutton, pork, fish, milk, eggs, butter	15.06	0.00591	0.16295	28.95
7.	Fruits and vegetables	sweet banana, passion fruit, tomato, cabbage, onion, jackfruit, dodo	8.49	0.00160	0.01065	8.05
8.	Food luxuries	infant food, restaurant food, soda, juice, tea, coffee, beer, tobacco	6.30	0.00523	0.03302	29.27

Source: Own calculations from UNPS (2010) and IFPRI (2010); unit values are given in 2010 real prices; calculations of energy and protein contents are based on USDA (2011) data

where i – food category index; k – number of food categories; HS – household size in gigajoules; UV – unit value of food category; PI – Stone's geometric price index calculated as a product of unit values and category expenditure shares ($PI = \sum_1^k UV_k * \sigma_k$); $D_1 ... D_n$ – vector of dummy variables.

In order to be consistent with a theory of consumer behavior, the estimated regression coefficients of the regression models (Equation 3.16) have to satisfy the following conditions:

- Sum of shares of all categories equals to one:

$$\sum_1^i \beta_{0,i} = 1 \tag{3.17}$$

- Budget constraint:

$$\sum_1^k \varepsilon_{1,k} = \sum_1^k \varepsilon_{2,k} = ... = \sum_1^k \varepsilon_{i,k} = 0 \tag{3.18}$$

- Symmetry of the price coefficients:

$$\varepsilon_{i,k} = \varepsilon_{k,i} \tag{3.19}$$

Like the Working-Leser model of food expenditure, the demand system was estimated from the UNPS (2010) national survey. Prior to the model estimation the sample was corrected using the two-stage Heckmann procedure (Heckman 1979) for the cases when a household is not consuming products from particular food categories. Only the non-zero shares (σ_i) were considered in the estimation of the demand system. The estimation of the system (Equations 3.16 - 3.19) was done through application of seemingly unrelated regression of Zellner (1962). Tables C.5 - C.12 demonstrate the estimated linear approximation of the demand system.

From the demand system specified by Equations 3.16, income elasticities (ξ_d) for different food categories can be derived as:

$$\xi_d = 1 + \beta_{1,i}/\sigma_i + \sigma_i \tag{3.20}$$

Table 3.13 presents the income elasticities at average level of income as estimated from UNPS (2010). Categories 1 (plantains), 6 (animal products) and 8 (food luxuries) have income elasticities greater than one, which means that demand for the food from these categories rises more than proportionally with respect to income. It is an expected result the in case of animal products and food luxuries. Plantains are an important staple food in Uganda; the results of the elasticity calculation suggest that with rising income, households prefer it over the other staples (categories 2, 3 and 4).

Table 3.13: Income elasticities at average level of income

Food category id	1	2	3	4	5	6	7	8
Income elasticity	1.18	0.93	0.79	0.75	0.84	1.31	0.71	1.61

Source: Own estimations from UNPS (2010)

Compensated price elasticities for food categories could be derived from Equations 3.16 as:

$$\text{Own price elasticity:} \quad \xi_{k,k} = -1 + \varepsilon_{k,k}/\sigma_i + \sigma_i \tag{3.21}$$

$$\text{Cross price elasticity:} \quad \xi_{i,k} = \varepsilon_{i,k}/\sigma_i + \sigma_i \tag{3.22}$$

Tables 3.14 and 3.15 report price elasticities at average level of income as estimated from UNPS (2010). As expected, all own price elasticities have a negative sign (i.e. demand for all food categories falls with the increase in price for the categories). Most of the cross-price elasticities have a positive sign. That is also an expected result: demand for a given food category rises, when the price of the different food category increases.

The non-linear relationships of σ_i shares and household food expenditure were translated to agent MILP in a similar way as the food expenditure part – by division of the function to linear segments for different food expenditure levels. Table B.14 exhibits a MILP-representation of the demand system. Segment-specific food category expenditure coefficients ($\Omega_{n,i}$) were calculated using average segment food expenditure:

Table 3.14: Own price elasticities at average level of income

Food category id	1	2	3	4	5	6	7	8
Own price elasticity	-0.84	-0.63	-0.65	-0.61	-0.57	-0.60	-0.66	-0.46

Source: Own estimations from UNPS (2010)

Table 3.15: Cross price elasticities at average level of income

Food category id	1	2	3	4	5	6	7	8
1		0.19	0.23	0.13	0.02	0.11	0.04	0.10
2	0.17		0.14	-0.03	-0.02	0.15	0.05	0.00
3	0.24	0.19		0.06	0.08	0.07	-0.03	-0.11
4	0.16	0.08	0.07		0.05	0.13	0.11	0.08
5	0.12	0.12	0.12	0.09		0.14	0.05	0.01
6	0.12	0.19	0.05	0.10	0.07		0.06	-0.13
7	0.14	0.17	0.06	0.14	0.06	0.14		0.03
8	0.17	0.16	0.05	0.14	0.06	0.07	0.06	

Source: Own estimations from UNPS (2010)

$$\Omega_{n,i} = \beta_{1,i} * (ln((FE_{n+1} - FE_n)/2) - ln(HS) - ln(PS)) \tag{3.23}$$

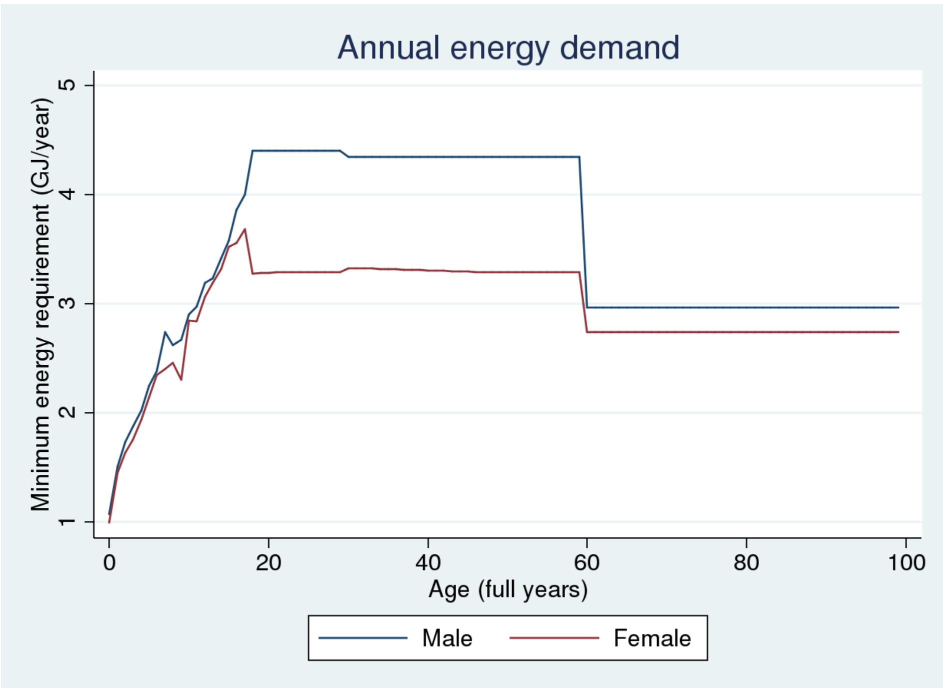
where FE_n – segment lower bound (expressed as total expenditure spent on food); $\beta_{1,i}$ – real per capita food expenditure regression coefficient from the estimated demand system (Equations 3.16–3.19).

Agent consumption of purchased food products was valued with mean unit values (see Table 3.12). Consumption of crops produced by household was valued using median market prices for rural agricultural households (estimated from IFPRI (2010)). In the case of crops grown in the study area exclusively for home consumption (sweet potato, cassava, groundnut, sorghum), median market prices reduced by a percentage defined during model calibration (see Section 4.1) were used. This reduction was incorporated, since the value of such crops for households is defined by the opportunity cost of their production. The values of home-grown fruits and vegetables, which were implemented in the model as aggregate crops (described in Section 3.5.1), were also subject to calibration.

3.7.4 Food consumption requirements

In the MP-MAS Uganda application, required food energy intake (energy demand) was used as a proxy for household requirements of food consumption. An agent's energy demand is quantified in MP-MAS as a sum of individual demands of household members, which vary based on their sex and age. Sex- and age-specific human minimum energy demands were calculated by Schreinemachers et al. (2007) based on the respective parameters of James & Schofield (1990), who estimated these demands from basal metabolic requirements and physical activity related requirements. Figure 3.9 displays the levels of minimal annual energy demands as they were set in MP-MAS Uganda. Agent minimum energy demand entered agent MILP as an additional constraint. Therefore, it was assumed that households have an absolute preference for satisfying their minimum energy demand, which is consistent with the basic motivation theory of (Maslow 1954). In other words, households at first try to meet their food needs and only then maximize their income. Table B.15 provides an example of MILP-implementation of household food consumption requirement. The high negative value attributed to the food energy deficit makes agents prefer current food consumption over future incomes until the point where food energy requirements of the agent are met. Based on the food items household agents choose to consume, MP-MAS Uganda also calculates food protein supply (implementation in Table B.15). Alternatively, one can also similarly include protein requirements as a constraint in agent MILP.

Figure 3.9: Annual energy demand



Source: Calculations of Schreinemachers et al. (2007) based on James & Schofield (1990)

Thus, the consumption part of agent MILP calculates the allocation of agent income between savings and food and non-food expenditure based on econometrically estimated models, and optimizes household food consumption in monetary terms. For different types of food, an agent decides whether it's beneficial to produce the food on their own farm or to purchase it on the market.

3.7.5 Cash flow and liquidity reserve

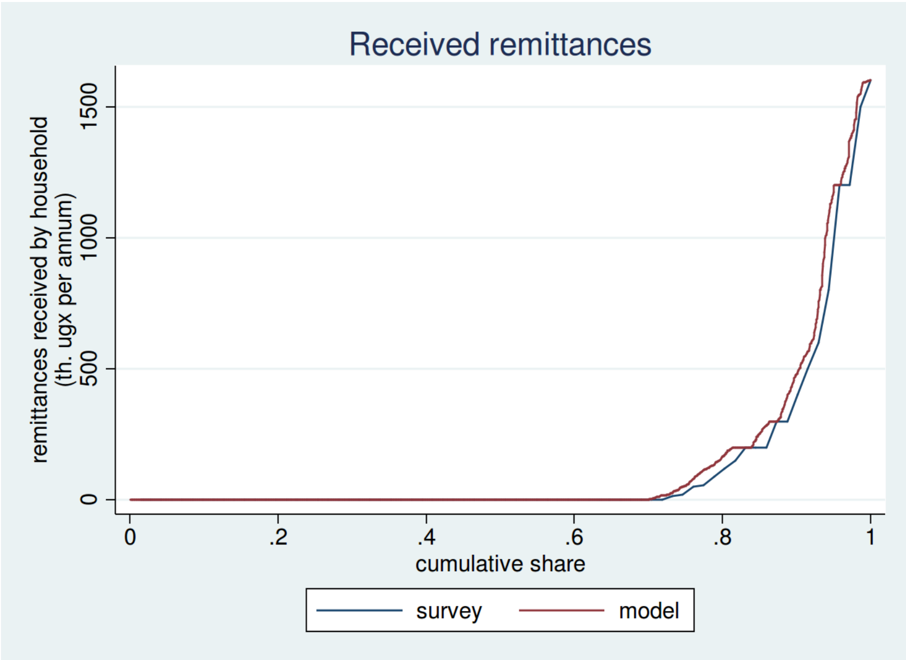
Liquidity constraint is an important factor that limits investment opportunities of smallholder farmers in developing countries and undermines the profitability of input applications (Dorward et al. 2004, Kydd & Dorward 2001). Lack of liquidity may also create a need to produce food for subsistence. Therefore, the liquidity aspect was included in the farm decision model of MP-MAS Uganda. It ensures that expenditures of model agents on production inputs and own consumption purposes do not exceed the amount of cash available at the period of time when these expenditures are made. The MILP-tableau from Table B.5 shows the implementation of cash flow and liquidity constraints in the MP-MAS Uganda application. In this implementation, current liquidity constraints of household agents are imposed for planting time and after harvest. The remaining cash at the end of the year is recorded in the solution of the specific MILP activity. MP-MAS code saves this value and uses it as a starting liquidity of the next period. The liquidity of the initial period was set to 150% of the estimated liquidity requirement (liquidity that is required to achieve the recorded production pattern) of IFPRI (2010) survey households.

For modeling agent preferences on consumption security, MP-MAS Uganda additionally has a parameter of a minimal annual consumption requirement, which defines the liquidity reserve of an agent (mechanism explained in Section 3.5.5). The value of this parameter was set to the 10th percentile of total household consumption expenditure per annum per household size expressed in gigajoules. The value was estimated from UNPS (2010) national survey, taking into account the expenditure of rural agricultural households in the Central Region of Uganda. In 2010 real terms, the minimum consumption requirement of model agents constitutes 109,929 ugx per gigajoule of household size per annum. In the MP-MAS Uganda application, agents would keep (if possible) 25% of this value for every gigajoule of their household size as their cash reserve, in order to secure their consumption in case of crop or market failures.

3.7.6 Remittances

Empirical evidence from various Sub-Saharan African countries (Davies et al. 2009, Mazzucato et al. 2008, Azam & Gubert 2006) shows that local and foreign remittances constitute an important source of household income. Remittances finance farm operations, provide additional investment capital and support household consumption, thus contributing to rural development as well as to alleviation of poverty and malnutrition. The IFPRI (2010) survey conducted in rural Uganda reported that 23.4% of all survey households and 28.2% of Kibinge households received remittances. Therefore, this important income inflow was introduced in the MP-MAS Uganda model. The amounts of received remittances in the model are agent-specific and constant throughout simulation periods. These amounts were distributed among model agents using the copula sampling approach (discussed in Section 3.2) jointly with other household characteristics as consist with the empirical data of the IFPRI (2010) survey. Figure 3.10 plots remittances received by Kibinge households as recorded in the IFPRI (2010) survey and implemented in MP-MAS Uganda. MILP-implementation of remittances is presented in Table B.6.

Figure 3.10: Received remittances



Source: Author, based on MP-MAS simulation results
* characteristics of survey population are estimated from IFPRI (2010)

3.8 Demography and population dynamics

Uganda has a rapidly growing population. The latest statistics of CIA (2012) estimated the annual population growth rate of Uganda at 3.58%, making it the third fastest growing country in the world. In the last ten years this indicator increased from 2.93% due to significant improvements in health and mortality indicators. Between 2001 and 2011, life expectancy at birth increased from 43.37 to 53.24 years, infant mortality decreased from 91.3 to 62.47 deaths per 1,000 births, and the death rate decreased from 17.97 to 11.71 per 1,000 persons (CIA 2012). Uganda's total fertility rate has remained high and now constitutes 6.69 children born per woman (the second highest in the world) (CIA 2012). Fast population growth, on one hand, provides an additional labor supply to the economy, but on the other hand, it results in increased demand for natural resources and population pressure on ecosystems. Therefore, long-term economic forecasting and modeling should consider the demographic factor.

The initial structure of the model population is defined by pseudo-random generation of model agents (see Section 3.2). In this procedure, the number of persons in each age-gender group is assigned for each model household. Later, the exact age of the household member within the age group is randomly assigned by the MP-MAS code. Age groups, not exact ages were used in copula sampling in order to keep the ages, which were not recorded due to the small size of the IFPRI (2010) survey sample, probable. Table 3.16 describes the age groups used in the copula sampling. (For male and female members the bounds are identical.) The bounds of age groups were defined from the IFPRI (2010) survey such that the number of persons in each group were equal, 99 full years was assumed to be the maximum possible age.

Table 3.16: Age group bounds

	Group											
	1	2	3	4	5	6	7	8	9	10	11	12
Lower bound, full years	0	5	7	11	13	15	17	19	23	33	46	59
Upper bound, full years	4	6	10	12	14	16	18	23	32	45	58	99

Source: Author, based on MP-MAS input

The demography model of MP-MAS Uganda simulates population dynamics by calculating annual new births and deaths for household agents given the age specific probabilities of mortality and giving birth. This calculation is done before the end of each modeling period (see Figure 3.1). After the probabilistic modeling of survived and newborn household members in a given simulation period is finished, MP-MAS updates the respective information on agent household composition in the asset registry. In this research, the probabilities for the demography model were estimated using several sources of data: UDHS (2007), World Bank (2012) and CIA (2012). UDHS (2007) country-wide survey contained information on fertility rates in Uganda aggregated by regions, urban/rural residence and certain age groups.

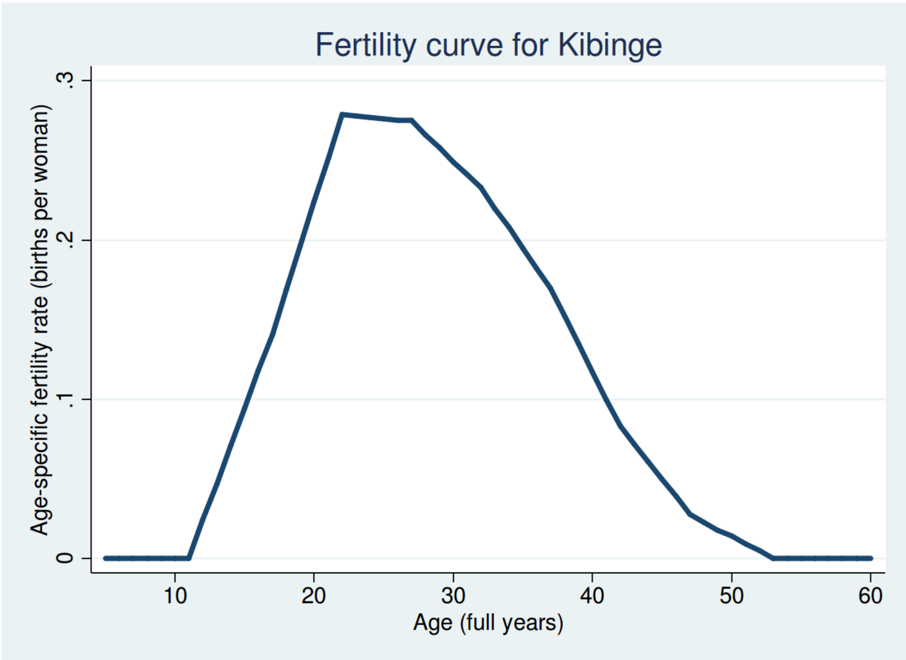
Table 3.17: Age-specific fertility rates in Kibinge sub-county, 2010

Mother's age at birth	Births per 1,000 women
15–19	141
20–24	279
25–29	275
30–34	233
35–39	170
40–44	83
45–49	28

Source: Own estimation, based on UDHS (2007) and CIA (2012)

Table 3.17 presents results of the author's calculations of birth rates from the UDHS (2007) survey for Kibinge sub-county (adjusted to 2010 according to CIA (2012) data on annual birth rates). For the calculation of age specific fertility rates for the study area, this data was linearly interpolated (in accordance with Feeney & Zaba (2001), for the estimation of the fertility curve

Figure 3.11: Demography model. Fertility curve



Source: Author, based on UDHS (2007) and CIA (2012) data

in Uganda the fertility was defined to be greater than zero on the age interval from 12 to 52 years). Figure 3.11 displays the respective age-specific fertility curve.

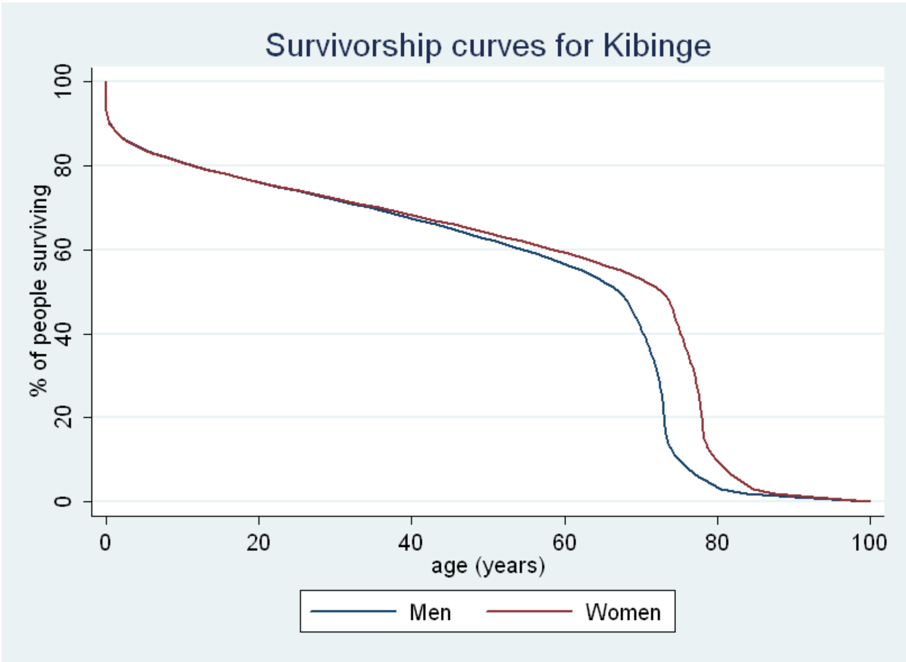
Table 3.18: Age-specific mortality rates in Kibinge sub-county, 2010

	Deaths per 1,000 persons	
Person's age at death	Women	Men
0	75.3	95.3
1–5	55.3	66.0
15–9	3.3	2.5
20–24	4.7	4.3
25–29	7.4	7.3
30–34	11.2	11.3
35–39	12.9	15.1
40–44	12.7	20.4
45–49	13.7	20.8

Source: Own estimation, based on UDHS (2007), CIA (2012) and World Bank (2012) data

UDHS (2007) survey also provided statistics on death rates in Uganda. Table 3.18 contains results of the author's calculations of mortality rates from this survey (adjusted to 2010 according to CIA (2012) data on annual death rates). For estimation of the age specific mortality rates the data was also linearly interpolated. Unfortunately, the UDHS (2007) survey, as shown in Table

Figure 3.12: Demography model. Survivorship curves



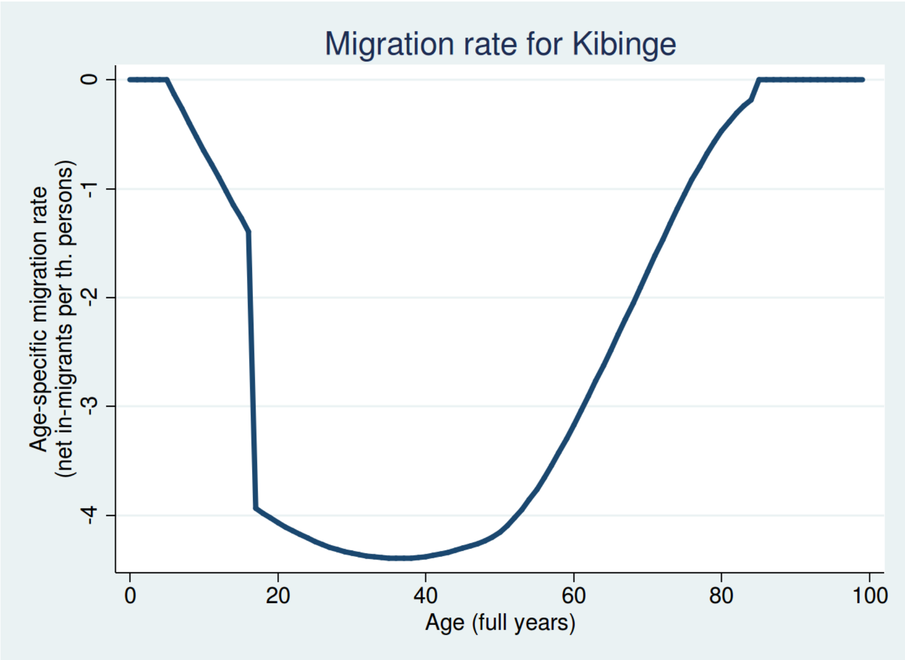
Source: Author, based on UDHS (2007), CIA (2012) and World Bank (2012) data

3.18, assesses only mortality information for the particular age segments and, therefore, does not provide the full picture of mortality during a person's lifetime. (Data on mortality after the 49th year was missing.) As one of the country demographic indicators, World Bank (2012) estimated the probability of a person to survive until the age of 65 (47.76 % and 45.19 % for women and men in Uganda, respectively); this data was used for further interpolation of the mortality rates. The mortality schedules for the remaining years (65 and older) were predicted by using Brass' relational model lifetable (Brass 1971). The resulted survivorship curves for the study area are shown in Figure 3.12.

The migration of labor out of rural areas is another important demographic factor to be considered. Dorosh & Thurlow (2009) simulated an average annual in-migration rate (number of net migrants as a share of total labor force) from 2005 to 2015 for the rural areas in the southern part of Uganda at the level of -0.24%. Since the empirical age-specific data on migration in Uganda was not available, it was drawn from the simulated value of Dorosh & Thurlow (2009) weighted by the model labor supply estimates and survivor proportions (assuming equality of migration rates by gender). Labor supply by age and gender was empirically estimated from IFPRI (2001) by Schreinemachers et al. (2007). Figure 3.13 presents baseline age-specific migration rates in MP-MAS Uganda, expressed as the probability of a person to take a migration decision in a given year.

Validation of the demography model is discussed in Section 4.2.6.

Figure 3.13: Demography model. Migration



Source: Author, based on UDHS (2007), CIA (2012) and World Bank (2012) data

3.9 Agent expectations

Table 3.6 shows that decision-making of model agents is based on expected values of market (prices, input costs) and natural (crop and stover yields) factors. MP-MAS Uganda models the development of agent expectations through different model periods, assuming that expectations of model agents are adaptive. Adaptive expectations imply that agent expectations about what will happen in the future are exclusively based on what has happened in the past. In this case, expected values (EV) of the current period are calculated from actual (AV) and expected values of the preceding period. Actual values of the preceding year are adjusted with the λ-share of the difference between expected and actual values of the preceding period:

$$EV_n = EV_{n-1} + \lambda \times (EV_{n-1} - AV_{n-1}) \tag{3.24}$$

Having λ-parameter equal to 1 makes agents to expect in the current period the actual value of the preceding period (naive expectations), λ equal to 0 implies constant expectations.

From the definition of adaptive expectations (Equation 3.24), it follows that the expectations of the starting period (initial expectations) have to be explicitly defined. Initial expectations on prices and costs in the MP-MAS Uganda application were set equal to the ones recorded by IFPRI (2010). Initial yield expectations for model crops, at first, were manually calculated in MS Excel using TSPC equations. These calculations were performed for each of the model soil classes separately. The transition from soil-specific to agent-specific (due to the uniqueness of agent soil properties) expectations is done by MP-MAS, which recursively updates the initial expectations during model spin-up periods that precede normal simulation periods. During spin-up periods, only the agent expectations are updated, while household physical and financial assets, soil properties and population demography remain constant. Yield expectations are formed by crop and by plot, i.e. for the same crop on the same plot, but grown with a different practice, an agent would expect the same trend in yield. Several spin-up periods were needed to form stable initial yield expectations, which are agent- and soil- specific. For the baseline scenario, λ parameter for yields was set to 1: agents expect yields of the preceding period. Market price expectations are formed by commodity and in the baseline scenario were constant to the initial prices (estimated from IFPRI (2010) (since the baseline scenario is performed with constant market prices). For expectations with regard to RPO payments, and for scenarios with changing prices, the lambda parameter of 0.5 was applied (if not stated otherwise).

3.10 Modeling coffee marketing with MP-MAS

Coffee marketing is the main focus of this research. Its modeling required a major extension of MP-MAS Uganda. Corresponding changes could be logically split into two parts: (i) additions to the household-level model and (ii) introduction of a new agent type. This section discusses the implementation of both.

3.10.1 Extending the household decision model

As the author revealed during his field visits to the RPOs of Kibinge sub-county (see Chapter 2), the choice of marketing channels for most of the RPO-members is limited to two options: (i) individual sales to local middlemen traders and (ii) collective sales through the RPO-channel. Hence, first of all, the selling activities for coffee in the household MILP were split to account for these channels. The irreversible decision over marketing channels was added to the sequence of household-decisions (see Figure 3.5 and Table 3.6). This decision is made at the end of the simulation period given the received yields, actual resource allocation, and contract and credit obligations. The prices in the case of RPO-channel, however, remain expected, since they are dependent on the quantity of produce sold through the RPO, which is uncertain for the household at the point of time when the decision is taken. (Derivation of RPO prices is explained in Section 3.10.2.)

As the interviewed farmers reported, the DC/ACE always offers a higher price to farmers than traders do. This was expected, given the lower per unit transaction costs, value addition done by the organization, and higher bargaining power of collective sales. However, during the field visits RPO-members reported selling up to 50–70% of their coffee produce to traders. Also, according to IFPRI (2010), only 52.1% of the coffee produced by RPO-members is sold through the RPO-channel, while the remaining 47.9% is marketed through local traders. These facts suggest that non-price incentives also have importance for farmers, as the profit margins with which traders operate are small (Dejene-Aredo et al. 2009). Therefore, we may expect non-price considerations to play an important role in defining farmers' marketing behavior. For modeling the choice between the coffee marketing channels, it is essential to understand these considerations. Hence, they are outlined below:

- **Informal money lending**: Because of a lack of formal credit institutions in rural areas, coffee farmers often take informal credits from local traders at the beginning of the season that have to be repaid with coffee at harvesting time (Latynskiy & Berger 2011).
- **Time preference**: Selling through RPOs involves a certain delay in payment (due to the coordination of the collection of individual produce, product transformation and banking operations), while when selling to a trader coffee growers are paid on the spot. Given the high rates of time preference of farmers in Sub-Saharan African countries (Holden et al. 1998), even small time delays may significantly discount the values of future payments, thus discouraging farmers from using the RPO-channel for their coffee.
- **Coping with emergency**: Unexpected needs for cash (because of funerals, illnesses, food shortages etc.) may set the time preferences to approaching infinity, in such circumstances selling through traders is an emergency coping strategy.
- **Cooperativeness, trust and social responsibility**: An RPO is a self-organized cooperative entity, hence, from the perspective of the theory of collective action, issues of individual attitudes, trust, reputation, member responsibility and commitment may apply (Ostrom 2004). Indeed, analysis of the results of public goods games conducted in Kibinge (see Latynskiy & Berger (2011)) suggested that the volumes of coffee that a member sells through their RPO was correlated with their game contributions (proxy for trust to other members and social responsibility).

The author, according to the insights gained from his fieldwork in Uganda, saw the first two incentives as prevailing factors influencing the choice of the sales channel. Therefore, they were both introduced to household agent MILP in MP-MAS Uganda. Their implementation is described in this section.

Informal money lending Village coffee traders also act in the study area as informal moneylenders providing short-term loans (Latynskiy & Berger 2011). Usually such loans are provided in the form of an informal futures contract. Debtors have to repay the loan with a part of their coffee harvest. Typically, the informal loans have no pre-arranged interest: the interest is rather hidden in the price margin the traders obtain. Interviewed farmers roughly estimated the individual credit limit up to which traders are willing to lend money as 50% of the value of the expected coffee harvest of the debtor, but usually not more than 100,000 ugx. This limit was introduced into the model. Table 3.19 contains the MILP-representation of informal money lending conditions.

Table 3.19: MILP-implementation of informal loans

	Grow coffee	Collect coffee	Sell coffee RPO	Sell coffee trader	Informal credit	Hire labor	Buy inputs		
Maximize			P_1	P_2		-C_1	-C_2		
Upper bound (for solution)					10^5				
Land	1							$\leq$	$Land$
Labor	L					-1		$\leq$	Lab
Capital					-1	C_1	C_2	$\leq$	$Cash$
Coffee plantation	1							$\leq$	Cof
Inputs	I						-1	$\leq$	0
Yield balance	-Y	1						$\leq$	0
Coffee output		-1	1	1				$\leq$	0
Credit repayment				-P_2	1			$\leq$	0
Credit limit		-$P_2 * Lim$			1			$\leq$	0

* P_i – expected market prices; C_i – production costs; S_i – household soil endowments;
$Land$, Lab, $Cash$ – household land, labor and capital endowments; Cof – coffee plantation size;
L – labor requirement; I – input requirement; Y – expected yield;
Lim – credit limit, expressed as a share of expected revenue from coffee sales;

Incorporation of individual time preferences Focus group discussions in Uganda facilitated by the IFPRI–IZA–UHOH project outlined delays in payment for the produce delivered by RPO-members as one of the main factors discouraging producers from selling through the organization (Dejene-Aredo et al. 2009). Hence, a block of questions related to the members' behavior in the case of payment delays was included in the project baseline survey (IFPRI 2010). First, a hypothetical situation was introduced to the interviewed farmers: "Imagine you are going to be given a gift worth 5,000 ugx. You will receive it either tomorrow or in one month. If you wait one month you will receive more." Then, the respondents were asked whether they would prefer to receive 5,250 ugx after one month or 5,000 ugx tomorrow. If the respondent refused to wait one month, then he or she was offered a better deal with 5,500 ugx of delayed payout. If this deal was also declined, then the offer was increased to 6,000 ugx. Finally, if the respondent declined this deal as well, he or she had to give the own value of payout, which he or she was willing to receive in order to wait for one month. Table 3.20 reflects the related responses of Kibinge farmers expressed as monthly rates of time preference.

Table 3.20 shows that in the study area the rates of time preference vary significantly from 0–5% to over 100% in monthly terms. Therefore, the author decided to introduce them into the model as an additional agent characteristic. The assignment of time preferences to agents was done by copula-based method (explained in Section 3.2, which assured the creation of a representative agent population in the model. (For households that had accepted one of the

Table 3.20: Time preferences of Kibinge households

Monthly rate of time preference	Frequency	Percent
0–5%	15	21.4
5–10%	7	10.0
10–20%	11	15.7
20–50%	5	7.1
50–100%	17	24.3
$>$ 100%	15	21.4

Source: Author from IFPRI (2010)

offered values, the discrete data on time preference was made continuous by linear interpolation prior to the assignment.)

The incorporation of time preferences into the household decision model means discounting the revenues of delayed sales (the incorporation of risk preferences can be undertaken analogously by discounting the revenues from risky activities). For this end, the calculation of an agent-specific penalty coefficient (Pen) from the agent's monthly rate of time preference (TP) was implemented in MP-MAS code:

$$Pen = 1 - 1/(1 + TP)^t \tag{3.25}$$

where t - time from delivery till payment in months.

This penalty coefficient was applied to discount (penalize) the revenues of the delayed activities in agent MILP (see Table 3.21).

Table 3.21: MILP-implementation of time and risk penalties

	Grow	Sell coffee		Sell future coffee		PO-sale penalty			
	coffee	RPO-channel	trader	RPO	trader	current	future		
Maximize		P_1	P_2	Pf_1	Pf_2	-P_1	-Pf_1		
Land	1							$\leq$	$Land$
Coffee plantation	1							$\leq$	Cof
Yield balance	-Y	1	1					$\leq$	0
Fut. yield balance	-Yf			1	1			$\leq$	0
Penalty		Pen				-1		$\leq$	0
Fut. penalty		1		Pen			-1	$\leq$	0

* P_i – expected market prices of this year; Pf_i – expected market price of future years;
$Land$ – household land endowment; Cof – size of coffee plantation; Y – expected yield of this year;
Yf – annuity of expected yields of the remaining years of the plantation;
Pen – agent-specific penalty coefficient;

3.10.2 Rural producer organization as a new agent type

Decision making of RPOs and other cooperative entities can also (as previously described household decisions) be represented in form of the optimization problem. Therefore, RPOs were introduced to the modeling framework as a specific agent type, in addition and different from farm household agents as in the original MP-MAS version of Berger (2001). The activity of this agent is also simulated by solving the respective MILP.

In the context of this case study, an agricultural RPO is a company and a business entity. Therefore its objective from the perspective of economic theory is profit (Π) maximization, which could be written as:

$$MAX: \quad \Pi = (P - VC) * Q - FC \tag{3.26}$$

where P – sales price; Q – quantity sold; VC – variable costs; FC – fixed costs.

Mathematically, the optimization problem of the RPO is similar to the one of the farm household agent (described by Equations 3.3), with the exception that RPOs maximize profit while households maximize utility. This problem can also be represented in the format of the MILP-tableau: Table 3.22 contains a simplified example of the MILP-formulation of the RPO optimization problem. Similar to MILP of household agents, the displayed MILP can be extended with various optimization constraints, such as RPO liquidity, transport and processing capacity, etc. The right most activity of the MILP-tableau from Table 3.22 calculates the profit of the RPO, i.e. the value of the objective function is also recorded as a solution of this activity. This extra calculation is done to simplify the implementation of RPO-household interactions (explained below) in MP-MAS source code. To allow for negative profits this activity was allowed to also have a negative solution.

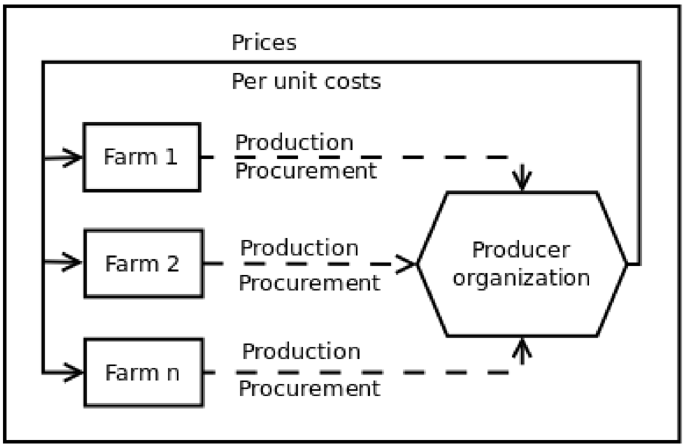
Table 3.22: MILP-formulation of RPO profit calculation

	Collect produce	Transport produce	Process produce	Fixed cost	Sell processed	Profit *		
Maximize	-C_1	-C_2	-C_3	-1	P			
Raw quantity	1						$\leq$	Q
Collected quantity	-(1-R_1)	1					$\leq$	0
Transported quantity		-(1-R_2)	1				$\leq$	0
Processed quantity			-(1-R_3)		1		$\leq$	0
Fixed costs				1			$=$	FC
Profit	-C_1	-C_2	-C_3	-1	P_1	-1	$=$	0

*solution of this activity is allowed to be negative;
C_i – variable costs per unit; P – market price of current year;
Q – available quantity; FC – fixed costs; R_i – weight reduction coefficients;

Since RPOs work with farm households in many ways (see Chapter 2), the RPO agent in the MP-MAS also interacts with farm household agents. Farm agents that are RPO members send their produce to the RPO agent, as well as their membership fees and inquiries for inputs, which serve as exogenous variables for the decision-making module of the RPO agent. The RPO agent in turn feeds back to its RPO member agents the sales prices and per unit costs, which then influence their decision-making. Figure 3.14 schematically displays the interaction process between the two agent types. In this way, RPO agents and farm household agents influence each other's behavior.

Figure 3.14: Interactions of farm agents and RPO agents in MP-MAS



Source: Author

Since RPOs (DC, ACE, etc.) are effectively non-profit organizations, the entire profit they make is transferred back to the producers. Hence, the payment for the delivered produce, or the farm-gate price that farmers receive (p), equals the profit margin of the RPO:

$$p = \Pi/Q \tag{3.27}$$

or

$$p = P - VC - FC/Q \tag{3.28}$$

From Equations 3.27 and 3.28 it can be seen that the price that household agents receive for products marketed through the RPO agent depends on the solution of the RPO agent optimization problem, which in turn depends on the total quantity of products sold through the RPO. RPO optimization enters the sequence of agent decision problems between the decisions on marketing and consumption (see Figure 3.5). MP-MAS calculates the total quantity of products delivered to the RPO (Q) from the marketing MILP of household agents and inserts this value to the right-hand side of the respective constraint in the RPO MILP (Table 3.22). After solving the RPO MILP, the price (p) is inserted into the consumption MILP of the household agents, thus implementing an interaction loop (see Figure 3.14). The described mechanism of interlinking the results of RPO and members' performance can be applied to various types of cooperative activities, for example certification or grading. Incorporation of several marketable products to the MILP of an RPO-agent could be done by disaggregating the profit calculation according to the enterprises. Table B.16 shows this with the example of basic and certified products. In this case, for the certified product the size of the per unit certification premium would be calculated by MP-MAS and transferred to MILP of household agents.

Following the discussed implementation, the MP-MAS Uganda application simulates the behavior and interactions of the Kibinge DC and its member households. The DC is represented by the separate agent of the RPO-type.

Cost structure of the producer organization The sustainability of marketing RPOs and their independence from external funding can only be achieved in the situation in which the RPO-generated total value added covers its fixed costs. From Equation 3.26 follows:

$$(P - VC) * Q \geq FC \tag{3.29}$$

An increase in the RPO sales quantity (Q) would reduce the fixed costs per unit sold – the so called *fixed cost degression effect* and, therefore increase the group's profits. That would result in the improvement of sustainability of the organization and its ability to absorb external risks (e.g. a fall in the selling price).

Modeling fixed cost degression with MP-MAS requires understanding of RPO cost structures. Business structures of Ugandan RPOs were captured by the project survey (IFPRI 2010). The broader understanding of the structure of the studied organization (in Kibinge DC) was achieved during the author's field work (see Chapter 2).

Fixed asset ownership According to IFPRI (2010), Kibinge DC does not own immovable property, processing machinery or vehicles, and possesses only a few assets that are quite low in value (motorcycle, computers, telephones, bicycles). This fact may explain the reluctance of the DC to make long-term investments, a recognized problem of RPOs and other cooperative firms in general (Chibanda et al. 2009, Nilsson 2001). It is caused by the limited planning horizons of RPO members (limited to the proximate duration of membership) and the administration (limited to the length of their elective terms). Issues of mutual mistrust and transparency may also hinder the willingness to invest in common property. Since the number and value of DC-owned fixed assets is small compared with the reported running costs, and their exact value was not provided in the IFPRI (2010) survey, the depreciation of these assets was not considered in the cost calculation.

Fixed costs Table 3.23 presents the calculation of annual fixed costs based on the data provided by the DC administration to IFPRI (2010). As the table suggests, management salaries form the major part of the fixed costs. The rental and storage costs were not reported by the administration:

these estimations were derived using the responses of other robusta DC from the IFPRI (2010) survey.

Table 3.23: Annual fixed costs (Kibinge DC)

Item	Cost, th. ugx
Management salaries	20,280
Rent	417
Storage	365
Electricity	1,200
Telephone	305
Member meetings	1,150
Total fixed costs *	23,717

Source: Own estimations from IFPRI (2010)
* not including depreciation

Variable costs The marketing costs of the Kibinge DC are considered in the price that the DC receives (IFPRI 2010, Latynskiy & Berger 2011): buyers gather the coffee from the DC storage, and transportation costs are deducted from the price directly. The DC operates with a fixed pool of buyers (all are exporters), therefore, currently there are no search costs involved. Buyers always pay on the spot, neither advancing nor delaying the payment (IFPRI 2010). Variable costs of milling (70 ugx per kg of FAQ coffee (Latynskiy & Berger 2011)) and delivery to the DC storage facility (17 ugx per kg of kiboko coffee) are considered in the price that is transferred to members.

The information in the above paragraphs was translated to the MILP-form (see Table 3.22 for the generalized example), and the Kibinge DC was included in the MP-MAS Uganda model as an RPO-agent (the estimated costs of the DC were later corrected for the relative model prediction error for members' delivery).

Chapter 4

Calibration and validation of the empirical model

Previous chapters showed that the MP-MAS Uganda application is a complex tool for empirical analysis. Like any model it simplifies reality to a certain extent. Its components (soil property and yield equations, production functions, consumption model, etc.) approximate observed relationships by describing them in terms of mathematical functions. These approximations lead to deviations of model prediction from the observed data (i.e. prediction errors). Also, estimations of MP-MAS Uganda components were mostly derived from household surveys, the data from which was often derived from farmers' self-assessments and recall values, which are likely to be inaccurate. Moreover, survey respondents often linked their responses to imprecise units (e.g. "a big bunch of plantains", "a large sack of maize"), interpretation and conversion to metric units was tricky and required certain assumptions. Parameterization of the crop growth and livestock modules substantially relied on aggregate data, expert rough estimates and assumptions (Chapter 3, Schreinemachers (2006)). The big sources of model uncertainty are farmers' valuation of home consumption, their expectations on prices and yields, and certainty equivalents. In order to compensate for the errors in model predictions caused by the discussed simplifications, uncertainties and data inaccuracy, the simulation model had to be calibrated. Calibration is a process that furnishes model behavior and prepares it for practical application. The calibration of agent decisions was done against the data of IFPRI (2010) survey, which contained the results of the production decisions of study area farmers.

Before the practical application, the model also has to go through a system of checks, test simulation runs and preliminary output analysis that ensure the model's consistency and assess its predictive and descriptive capabilities. In the literature this process is called *model validation*. A valid simulation model builds on two important aspects: (i) valid results and (ii) valid mechanisms and concepts with which the results were obtained. The respective validations are called (i) *operational* – for results and (ii) *conceptual* – for concepts. Validation is an important part of empirical analysis. At this stage the model's ability to replicate processes within the real world is estimated, model robustness is checked and prediction errors are recorded. Nevertheless, the recent survey of Heath et al. (2009) revealed that only 20.3% of ABM in economics developed between 1999 and 2008 were both conceptually and operationally validated, while 29.1% were not validated at all. Only 2.5% of ABM in economics incorporated statistical validation techniques (Heath et al. 2009).

The simulation model went through both conceptual and operational validation using statistical and qualitative methods. Assessment and discussion of model validity is done in Section 4.2. During the validation the author relied on statistical as well as qualitative methods.

4.1 Calibration process

Calibration is the last step in the process of model construction, which results in a functioning and valid model baseline. In the context of this work, calibration is the iterative process of varying uncertain parameters of the model within theoretically and/or arbitrary acceptable ranges until model results have a closest match with an observed data. As shown in Figure D.2 of the Appendix, in the case of MP-MAS Uganda, application calibration was associated with the large loop of data and file management, therefore, the time needed for the preparation and running of the model was an essential factor that influenced the choice of structure and logic of the whole calibration process. Of course, it only makes sense to engage into a cumbersome and time-consuming calibration process when a model is free from conceptual and implementation errors. Therefore, prior to calibration, multiple debugging loops (Figure D.2) were required to identify and correct such errors. Also, before engaging in calibration the author and other members of MP-MAS development team ensured conceptual validity of the simulation model. (This issue is discussed more thoroughly in Section 4.2.)

The MP-MAS Uganda application uses several components or sub-models, which are integrated sequentially (i.e. output of certain components serve as an input for others). Figure D.1 schematically displays the sub-models' integration within one modeling period (with no multi-period interactions).

Considering the sequence of the organization of model components, the calibration also had to be organized in a sequential way. This rationale led to a stepwise sequence of sub-models' calibration that had to be adhered to when calibrating the simulation model:

1. Estimation of soil properties
2. TSPC (yield simulation)
3. Random asset assignment
4. Consumption preferences
5. Household decision
6. TSPC (soil updates)

7. Livestock herd dynamics
8. Population dynamics

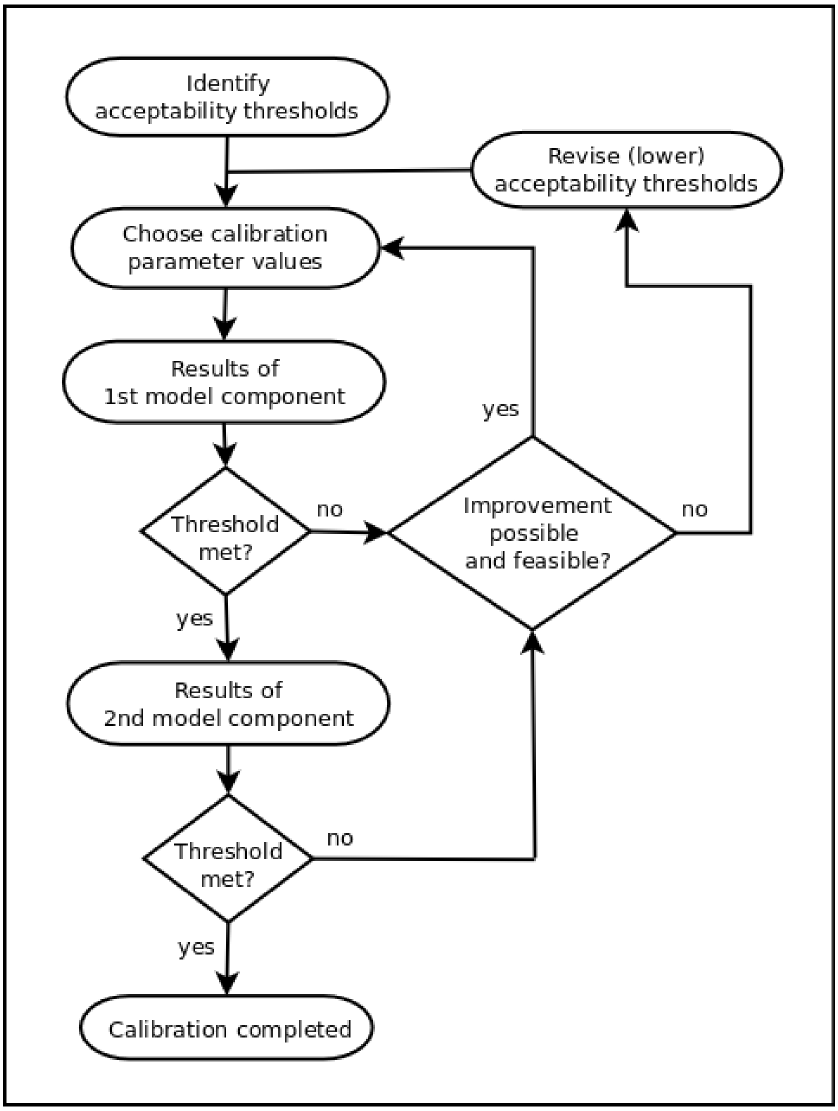
As described in Chapter 3, construction of the version of MP-MAS software that was used in this research was partially based on the earlier works of Schreinemachers (2006), Rhew et al. (2004) and Aune & Massave (1998). When their research efforts, data, time and resource limitations are taken into account, a number of "shortcuts" were taken while calibrating MP-MAS Uganda for this research case:

- Predictive soil property equations were estimated and validated by Rhew et al. (2004) for the similar area of Uganda. In the absence of new field measurements prediction of soil properties was done with equations as provided in Rhew et al. (2004). The applicability of equations for the study area is justified in Section 3.3.
- The equations of TSPC were specifically estimated and validated for tropical soils by Aune & Massave (1998). Furthermore, one of the TSPC creators, J. Aune, specifically calibrated TSPC for the agro-ecological conditions of Uganda for the research of Schreinemachers (2006). Therefore, the calibrated TSPC parameters for yield simulations and soil property updates were taken from Schreinemachers (2006) and Schreinemachers et al. (2007).
- A dynamic calibration of agent investment and disinvestment behavior in the MP-MAS Uganda application was not possible, since there were no panel datasets for the study area available. Hence, the calibration and validation were based on simulation results for a single simulation period. Therefore, the livestock model was calibrated so that observed household herd/flock sizes could be sustained with agent resources and current income and consumption incentives.

The equations describing household consumption preferences were empirically estimated from the project (IFPRI 2010) and national (UNPS 2010) surveys (see Section 3.7). It means that the parameters defining agent consumption preferences in the simulation (regression coefficients) already had the best fit (optimized for least squares) with the benchmarks (IFPRI (2010) and UNPS (2010)). Therefore, the list of sub-models subject to calibration could have been further reduced by this model component. The respective regression statistics (R-squared, test scores) served as a validity mark of consumption preference models.

The simulation model was subject to indirect calibration (according to Windrum et al. (2007) taxonomy). It means that during the calibration process micro-level calibration parameters were chosen so that the model was able to reproduce a set of empirically observed facts (benchmarks) at the macro-scale. For the calibration of the simulation model the author used different empirical benchmarks depending on the model part that was subject to calibration. These benchmarks are listed in Table D.1. Table D.2 reports the parameters that were used to calibrate the model components for the benchmarks. The parameters listed in Table D.2 could have taken only the values within the defined ranges of acceptability (e.g. long term prices for meat products may deviate by 25% from the estimates from IFPRI (2010) survey data). Choice of calibration parameters and their ranges defined model degrees of freedom. Calibration parameters do not include all model parameters, but only those whose estimations were likely to be imprecise. The definition of calibration parameters had to be done with caution (without giving too many degrees of freedom), since there was a danger of overfitting the model to the observed data, which may harm its performance out of sample (Fagiolo et al. 2007, Marks 2007).

Figure 4.1: Satisficing calibration strategy



Source: Author

Calibration experiments with random asset assignment against the IFPRI (2010) dataset were done in Stata software. For the calibration of other components, MS Excel spreadsheets and VBA-macro, Stata and MP-MAS software were used. In order to isolate the effects caused by the random asset assignment and for reasons of time efficiency, an alternative model population was constructed. This population included only the sample fraction of households from the study area that were covered by the IFPRI (2010) project survey (n=71), instead of using the full study population (n=1716). This ”small“ model, as well as single MILP of model agents, were used for preliminary calibration of other model components. With these tools, rough estimates of the calibration parameters were made. The model with full agent population was later applied to further fine-tune the calibration parameters estimated with the ”small“ model.

Conceptually, the process of calibration followed a satisficing (i.e. satisfying a set of sufficiency criteria) strategy. This strategy, as opposed optimization, which attempts to find a combination of calibration parameter values that would result in the highest model precision possible, aims for precision that would meet a certain subjective acceptability threshold. The satisficing calibration strategy is a pragmatic alternative to the optimizing calibration, taking into account the financial and temporal constraints of the research. Both factors put considerable costs on the time spent on calibration. Figure 4.1 contains the flowchart explaining the concept of satisficing calibration strategy on the example of model with two components that subject to calibration. When revising results of a model component, a model designer has to answer two questions: (i) whether results meet the chosen acceptability threshold and if not, (ii) whether it is possible to calibrate the model in an amount of time that allows the threshold to be met. Based on the answers to these questions, a model designer has to either continue calibrating the model for the current threshold or lower the threshold. Answering the second question requires an understanding of model behavior with respect to changes in calibration parameters. Such understanding may be obtained by experimenting with the model, analyzing and documenting its results. Certainly it makes sense to set very strict thresholds in the beginning and then gradually lower them as needed along the iterations of calibration process. In this research the results of the model calibration experiments were analyzed with respect to the imposed thresholds using various graphical and numerical statistical tools available in Stata and MS Excel software products. (Highlights from the final analysis of model validity are provided in Section 4.2.)

4.2 Assessment of model validity

Generally, there are five broader types of validity that economic simulation studies must take into account (Marks 2007, Richiardi et al. 2006, Stanislaw 1986). All together they contribute to the overall model validity. These five parts are the validities of:

1. Underlying theories
2. Model representation of the theories
3. Computer software used for simulation
4. Incorporated indicators relative to underlying unmeasured properties
5. Simulated results with respect to empirically occurring facts

With regard to the first of the listed validities, components of the MP-MAS Uganda application were based on well-established and recognized theoretical concepts (such as Cobb-Douglas theory of production). These theories are referenced in Chapter 3. The implementation of the theories in the modeling framework are reported in the Chapter 3, as well as in the Appendix. The mechanism of agent interaction was captured by participatory exercises with real RPO members (explained in Chapter 2), whom were considered to be the proper experts to consult about RPO.

The valid model representation of theories (second validity type) especially requires a proper documentation of the conceptual approach, model equations, algorithms and assumptions. During the construction of the simulation model, these were recorded in the form of pseudo-codes, numbered lists, flow charts, etc., in project reports, working documents, seminar presentations and comments in input files. Detailed documentation of model construction allowed the MP-MAS developers team to review, discuss and cross-check the conceptual models used in the MP-MAS Uganda application. The model implementations were presented to the student and academic audience during two regular modeling courses offered by Universitaet Hohenheim, "Modeling techniques" and "Land use economics seminar". At these courses the representations of theoretical concepts in MP-MAS were discussed and tested during course lectures and software training workshops.

Other MP-MAS county application also included several from the MP-MAS modules applied in this research, and, therefore, were also tested by their developers and users. Tables 4.1 and 4.2 compare country applications of MP-MAS modeling framework. MP-MAS framework was applied in several scientific projects in different parts of the world. The respective project reports went through critical evaluations of such organizations as CGIAR centers (MP-MAS applications for Chile, Ghana and Uganda) or DFG (MP-MAS applications for Thailand and Vietnam). Research using MP-MAS produced a number of peer-reviewed journal publications and conference contributions (listed at MP-MAS (2012)), which communicated modeling methodologies to a wider specialist community. Comments received from reviewers and readers were considered, and model implementations were revised when necessary. Thus, MP-MAS Uganda and other country applications of MP-MAS framework (that used common modules and concepts with MP-MAS Uganda) had a large exposure to the specialized audience: users, modelers, reviewers, project organizers, etc. This served as a face validation test (see Kluegl (2008), Garcia et al. (2007)) for the model: the model looked valid to the vested interest and expert parties.

Successful replications of model concepts and implementations done in the different MP-MAS country applications by different persons verified these concepts and implementations and demonstrated their robustness. Replications result in examinations and re-evaluations of the conceptual models, since replicators are motivated to understand the model and ensure its applicability for their use case. Hence, replications validate the original model (Wilensky & Rand 2007).

Given the aforesaid, it is anticipated that the first two parts of overall validity (namely validities of underlying theories and their model representations) are on the high level in the MP-MAS Uganda application.

Table 4.1: MP-MAS country applications

Model	Region	Focus	Project evaluators	Project period	References
Chile	Maule river basin	water pricing and diffusion of advanced irrigation technologies	IFPRI	2004–2009	Berger et al. (2007, 2010)
Germany	Swabian Jura	climate change impacts on agriculture	DFG	2009–2011	Berger et al. (2010), Troost et al. (2012)
Ghana	White Volta basin	transition from rainfed to irrigated agriculture	IFPRI	2004–2009	Birner et al. (2010), Wossen et al. (2010)
Thailand	Chiang Mai province	impact of advanced fruit tree technologies on agriculture	DFG, NRST	2006–2012	Schreinemachers et al. (2009, 2010)
Uganda 1	Iganga and Mayuge districts	impact of improved varieties and credit access on poverty and environmental sustainability	IFPRI	2001–2006	Schreinemachers & Berger (2006), Schreinemachers et al. (2007)
Uganda 2	Masaka district	organizations of agricultural producers	BMZ, IFPRI	2009–2012	this thesis, Latynskiy & Berger (2012*b*)
Vietnam	Son La province	diffusion of soil conservation techniques	DFG, MOST	2006–2012	Dang Viet (2012)

Source: Compiled based on MP-MAS (2012) and Schreinemachers & Berger (2011)

To ensure the third type of validity, the author constantly performed simulation runs for testing newly implemented model features and did structural "walkthroughs" revising the input and output of different modules of the model. MP optimization problems of model agents were tested to give feasible results. Infeasible problems were analyzed individually with special Excel macro written by the MP-MAS development team. Based on such analysis, the necessary changes to MILP structures were made and/or the settings of IBM OSL solver were adapted. During the test simulation experiments, the model behavior with respect to change in model parameters was tested. Cases with unexpected "strange" model results, which were the likely signals of an error, were investigated thoroughly. The MP-MAS development team is continuously revising the snippets of the software code based on feedback and error reports supplied by users of various MP-MAS country applications. Currently, the MP-MAS software contains several special test modes, which help to identify likely errors and support the debugging process. These features of MP-MAS were used to eliminate implementation errors, thus, increasing the overall validity

Table 4.2: Replications of MP-MAS components

Component	Model						
	Chile	Germany	Ghana	Thailand	Uganda 1	Uganda 2	Vietnam
Production and investment decisions	x	x	x	x	x	x	x
Three-stage consumption decisions			x		x	x	
Perennial crops	x			x	x	x	x
Durable livestock			x		x	x	x
TSPC					x	x	x
Population dynamics			x		x	x	x
Adaptive expectations	x	x	x	x	x	x	x

Source: Compiled based on MP-MAS (2012) and Schreinemachers & Berger (2011)

of the model.

The fourth type of validity has little relevance to the MP-MAS Uganda application, because the model operates with standard quantitative indicators and parameters, which do not require additional interpretation (as will be seen from the next chapter), such as per capita income, profit, etc. However, since the model is largely based on the data from national (UNPS 2010, UNLC 2008) and project (IFPRI 2010, 2001) surveys, the author has concerns about the validity of respondents' recall estimates (especially on prices, production and consumption).

Concerning the fifth validity type, currently, there is little or no consensus among modelers on whether and how agent-based economic models should be empirically validated (Fagiolo et al. 2007, Windrum et al. 2007, Midgley et al. 2007, Richiardi et al. 2006). Fagiolo et al. (2007) in their paper outline the main points of the ongoing discussion. Among them are:

- Role of empirical validation for acceptance or rejection of a model
- Choice of empirically observed facts that form a model benchmark
- Relationship of output traces of a simulation model to empirical facts and counterfactuals
- Alternative (to the reproduction of stylized facts) tests of empirical model validity

Due to the applied nature of this research and the need for its results to have practical relevance, the demand for empirical validation of the simulation model was clear. Therefore, the author agrees with Marks (2007), who stated that for a simulation model to be useful it must be able to exhibit some properties of the real-world system that it was modeled after. Ideally, the model outputs should be equivalent to the outputs produced by the real-world processes (i.e. model results are accurate and complete). However, this certainly does not imply that if both sets of outputs are not equivalent but intersecting, than the model is useless. Otherwise, we would have to conclude that all the models are useless. Since a model is a simplification of reality and is usually meant to be so, we may expect it to be wrong to some extent. The function of empirical validation here is to inform the researcher about model accuracy, completeness and differences that its outputs have with the respective outputs of the real-world processes.

Later in this section the output of the constructed simulation model is empirically validated. The validation was done in a way that is commonly practiced among the agent-based modelers (Windrum et al. 2007, Fagiolo et al. 2007): by comparing model outputs with stylized facts about the respective real-world system (agricultural system in the study area). Apart from that the validity of the model's initial conditions in relation to the observed properties of the real-world system are assessed and the model's reflection of real-world relationships, which were resembled in the model by econometric equations, are discussed. For the empirical validation, model components were run as standalone models and as MP-MAS Uganda as a whole. Various quantitative and graphical statistical methods were applied during this part of the validation.

4.2.1 Initial household characteristics

Since the IFPRI (2010) project survey covered only 4% of the study population, the full population for the simulation model had to be generated by data sampling and interpolation using multivariate distributions estimated from the project survey and described by the copula (the approach is explained in Section 3.2). Hence, in order to justify the approach and, therefore, the applicability of model results, it is important to assess the consistency of the generated model agents with the real-world population. The generation of statistically consistent model population was the target of methodological choice and calibration of implemented random asset assignment. For ensuring the robustness of the approach with respect to the random seed, a set of 50 generated populations was reviewed.

First of all, let us compare some common statistics (mean, median, standard deviation, percentiles) of survey and generated populations with respect to various household characteristics. Table 4.3 compares the amounts of land available to households. This variable was directly drawn from the empirical copula (see Table F.1). Table 4.3 shows that statistics of generated populations concerning land availability closely match statistics of reference population estimated from the IFPRI (2010) survey. Such a close match is a consequence of the fact that land variable was directly drawn from the reference population (e.g. without further transformation and/or aggregation). Slight deviations between populations are likely to be caused by data interpolation of values and imprecision of estimated copula that had to be employed because of the limited number of survey observations for the study area (n=71). The deviations between survey and generated populations are larger, but yet acceptable, in the case of characteristics related to household size (Table D.3). Since the number of household members were drawn by age-gender groups (see Section 4.2.6), totals of household members are aggregate characteristics. Therefore, the deviations related to drawn age-gender specific variables in this case multiply. Additionally, rounding to integers may increase the deviations. Therefore, larger deviations in the case of household sizes are observed in Table D.3, which compares populations statistics of household sizes expressed in persons, male adult equivalents and persons per hectare. However, as follows from Table D.3, deviations still remain relatively small, also in male adult equivalent expression that captures age-gender structure of households, and in per hectare expression that reflects the relation of household size to available land. Tables D.4 and D.5 show that statistics of generated populations closely match those of the reference population in cases of coffee plantations and livestock ownership as well.

Table 4.3: Household land availability

Characteristic	Populations	Mean	Median	Stdev	10%	25%	75%	90%
Available land, ha	survey	2.43	2.02	1.67	0.81	1.42	3.24	4.45
	generated	2.46	2.02	1.66	0.81	1.39	3.16	4.95

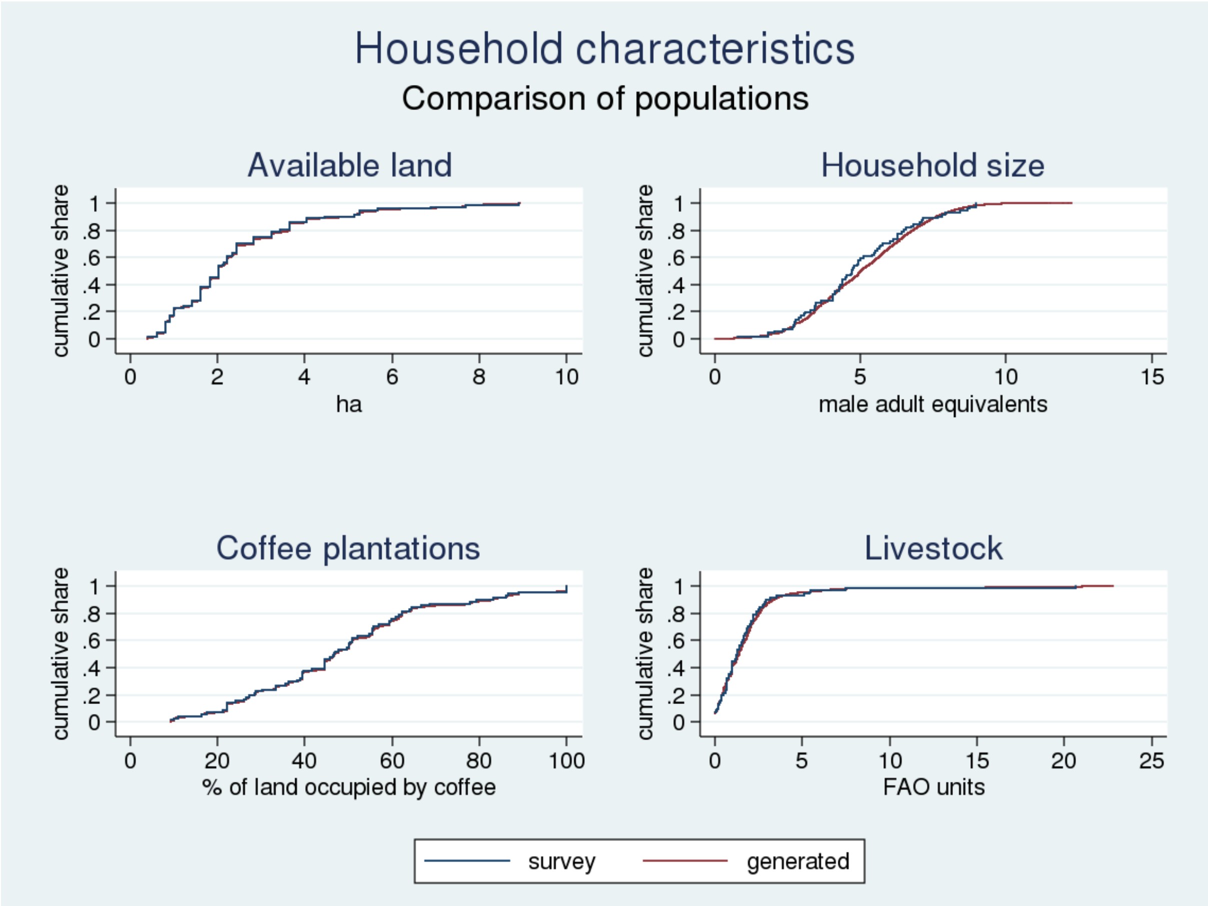
Source: Author, based on results of sampling from empirical copula
* characteristics of survey population are estimated from IFPRI (2010)
** generated populations are represented by average values over 50 populations drawn with different random seeds

Figure 4.2 graphically compares the distribution functions of household characteristics estimated for the survey and generated populations. The graphical comparison supports the previously derived statement of close replication of empirical univariate distribution functions in the model.

The consistency of bivariate relationships was checked by looking into correlations between variables in the survey and model populations. Figures D.3–D.6 of the Appendix display important correlations between household resource endowments. Figure D.3 displays relationships between area under coffee plantations and available land, Figure D.4 – number of persons resigning in household and available land, Figure D.5 – livestock stocking rates and available land and, finally, Figure D.6 plots area occupied by coffee plantations and household size expressed in male adult equivalents. Figures D.3–D.6 show that during the population generation the empirically estimated correlations were transferred to the model and heterogeneous, statistically consistent asset combinations at agent level were produced.

Tables and figures listed in this section support the applicability of the chosen method of generating model agents (described in the Section 3.2). Based on the performed numerical and graphical comparisons, it is concluded that the generated populations of model agents are good representations of the real population of the study area. Therefore, the later use of the populations generated by this method in simulation modeling is justified.

Figure 4.2: Distribution functions of household characteristics



Source: Author, based on results of sampling from empirical copula
* functions of survey population are estimated from IFPRI (2010)
** functions of generated populations are representing 50 populations drawn with different random seeds

4.2.2 Underlying econometric equations

Estimations of soil properties, crop yield responses with respect to labor use, and household consumption preferences for the MP-MAS Uganda model were econometrically derived from the empirical data. The determination coefficients of underlying regression equations can provide insights into the validity of the respective MP-MAS components, in which the obtained estimates were incorporated. Table 4.4 summarizes how well the econometric equations applied for parameterization of MP-MAS Uganda may explain the empirical facts, which is reflected by the R-squared coefficients of the corresponding regression equations. The significance tests (F-test or Wald Chi-squared test) performed on all listed regression equations showed their significance at 1%-confidence level. Therefore, despite the low value of R-squared in cases of some equations, it is better to apply these models for agent-specific predictions than to use sample means or expert estimates uniformly across the whole agent population. The production functions of other model crops were estimated from Schreinemachers (2006). The R-squared coefficients of the respective equations were not reported in this literature source. However, Schreinemachers (2006) provided results of Wald Chi-squared tests, showing that the relationships between actual yields and applied labor inputs are significant at 1% level for bean, cassava, groundnut, maize, plantains and sweet potato, and at 5% – for sorghum.

Table 4.4: Determination coefficients of underlying econometric models

MP-MAS component	Equation	Source	Dataset	R-squared	Adj. R-squared
Predictive soil properties	Acidity	Rhew et al. (2004)	Ruecker (2003)	–	0.11
	Potassium			–	0.21
	Calcium			–	0.32
	Organic Matter			-	0.07
	Phosphorus			–	0.07
	Sand			–	0.38
	Clay			–	0.43
Production functions of labor	Coffee	Author	IFPRI (2010)	0.2524	0.2295
Consumption preferences	Savings	Author	IFPRI (2010)	0.2929	0.2919
	Food expenditure		UNPS (2010)	0.2875	0.2856
	AIDS (plantain)		UNPS (2010)	0.2518	–
	AIDS (tubers)		UNPS (2010)	0.1340	–
	AIDS (cereals)		UNPS (2010)	0.0624	–
	AIDS (legumes and bakery)		UNPS (2010)	0.1449	–
	AIDS (additives)		UNPS (2010)	0.2318	–
	AIDS (animal products)		UNPS (2010)	0.1290	–
	AIDS (fruits and vegetables)		UNPS (2010)	0.0972	–

Source: Author's compilation

4.2.3 Crop production

Replication of household crop production by MP-MAS Uganda model was validated by comparing the output of the model baseline simulation runs with estimates from the IFPRI (2010) project survey. To minimize the effect of the initial allocation of livestock on crop production, model results from five simulation periods following the initialization were considered. Soil property updates and population dynamics were switched off. In doing the comparison, it had to be assumed that the production patterns of the study area as a whole would remain stable under constant bio-economic conditions (prices, soil fertility, market access, etc). Tables 4.5 and 4.6 compare estimated and simulated means of household production of selected crops. In order to estimate the robustness of the result with regard to the generated characteristics of agent populations and properties of their soils, as well as the random seed for model events, the baseline simulation was performed with different seeds and populations. Table 4.5 shows that the average RPO-member household from the study area produces 981 kg of green coffee per year. Such low levels of cash crop production create the need to join RPO for marketing. Plantains are the main staple crop in the area; the average household produces 3.4 tons of them annually.

Table 4.5: Average crop production (in 100 kg/year)

		Crop							
Population	Random seed	Bean	Cassava	Coffee	Ground-nut	Maize	Plantain	Sorghum	Sweet potato
Survey*	N/A	2.09	1.43	9.81	0.14	3.68	34.14	0.04	0.88
Model** 1	1	1.57	1.72	9.86	0.17	3.70	34.98	0.04	0.68
Model 2	2	1.54	1.39	9.81	0.15	3.65	34.75	0.04	0.74
Model 3	3	1.52	1.01	10.02	0.17	3.63	35.06	0.05	0.77
Model 4	4	1.57	1.28	9.77	0.15	3.67	35.72	0.04	0.78
Model 5	5	1.54	1.08	9.92	0.18	3.70	34.53	0.05	0.76
Model 6	6	1.48	0.95	9.70	0.16	3.54	35.09	0.04	0.80
Model 7	7	1.50	1.78	9.87	0.16	3.56	34.54	0.04	0.69
Model 8	8	1.51	1.72	9.61	0.16	3.57	35.17	0.03	0.71
Model 9	9	1.48	1.62	9.84	0.17	3.55	34.34	0.04	0.68
Model 10	10	1.54	1.23	9.86	0.16	3.67	33.63	0.04	0.74
Model Average		1.52	1.38	9.82	0.16	3.63	34.78	0.04	0.73
Stdev		0.031	0.316	0.114	0.007	0.064	0.566	0.004	0.044
CV		0.020	0.229	0.012	0.045	0.018	0.016	0.107	0.060

Source: Author, based on MP-MAS simulation results

* expected production of survey population is estimated from IFPRI (2010)

** model production is reported as annual means of 5 period simulation

Table 4.5 shows that the dispersion of results with respect to the random parameters of the model is low for the production of beans, coffee, maize and plantains, which are, according to IFPRI (2010), the most commonly grown crops in the study area. These crops are also the only marketable crops; the remaining crops are grown exclusively for home consumption. For these crops the coefficient of variation lies below 0.025. Other crops are produced in smaller quantities and constitute lower shares of land use, therefore, they are more sensitive to model randomness. Still, the coefficient of variation is quiet low for groundnut, sweet potato (for both it lies below 0.1) and sorghum (below 0.2). Low dispersion of results is not surprising, given the large number of agents (1716) in the model and their consistent generation (see Section 4.2.1). Cassava is more sensitive to the model input in the chosen parameter setting with coefficient of variation equal to 0.229. However, it is, as well as sorghum, an inferior crop, which has a low share in the farm output value (see Table 4.8). Therefore, the author generally concludes on the robustness of the simulated crop production on study area level with respect to random seed and initial agent population.

Table 4.6 provides the model prediction errors expressed by the absolute value percentage difference between the model results and the author's estimates from the survey. From this table it is evident that the model replicates the production of crops fairly accurate with the average errors laying below 27%. The goal that the author pursued throughout the model calibration process was a close representation of coffee production, since, considering the research focus, high precision in modeling coffee production is desirable. At the same time the errors for other crops have to be kept at an acceptable level whenever possible. As a result, simulated production volumes of maize and plantains lay on average within 2.5% from the survey benchmark values (Table 4.6), while coffee production deviates from the benchmark by only 0.88%. The maximum error for coffee from the 10 featured test simulations was recorded at 2.12% from the benchmark. Prediction errors for groundnut, sorghum, cassava and sweet potato lay within 20% of the benchmark on average; for beans – within 27%.

Table 4.6: Model prediction errors, absolute value percentage difference

		Crop							
Population	Random seed	Bean	Cassava	Coffee	Groundnut	Maize	Plantain	Sorghum	Sweet potato
1	1	24.91	20.45	0.51	18.66	0.62	2.45	10.68	22.45
2	2	26.20	2.86	0.07	8.99	0.62	1.80	16.12	15.31
3	3	27.20	29.34	2.12	17.54	1.27	2.70	25.27	12.32
4	4	24.88	10.28	0.47	8.08	0.07	4.64	18.28	10.47
5	5	26.21	24.82	1.05	23.83	0.57	1.13	36.00	12.65
6	6	29.08	33.76	1.16	10.39	3.80	2.77	15.66	8.94
7	7	28.16	24.00	0.56	13.30	3.21	1.17	14.92	21.00
8	8	27.47	20.24	2.08	10.54	2.85	3.03	9.94	19.21
9	9	28.92	13.20	0.29	19.00	3.41	0.58	18.96	22.61
10	10	26.28	14.44	0.49	15.66	0.07	1.48	3.11	15.57
Average error		26.93	19.34	0.88	14.60	1.65	2.17	16.90	16.05
Maximum error		29.08	33.76	2.12	23.83	3.80	4.64	36.00	22.61

Source: Author, based on MP-MAS simulation results

With regard to the simulated yields of coffee (Table 4.7), the model rather closely reproduces the mean yield (1,317.0 kg per ha per annum in the survey and 1,259.5 in the model). However, there is a higher variance in yields of the survey population (standard deviation of 1,153.5 kg per ha per annum) than in the model (645.4). The simulated distribution of the achieved coffee yields is close to the observed in some parts (10th, 25th, and 75th percentiles), while in other parts (the median, the 90th percentile) it deviates substantially. The high variance in observed survey yields is likely to be caused by such factors as individual plant management skills and pest and disease treatment. As follows from the yield simulation methodology of MP-MAS Uganda application (explained in Sections 3.5.1 and 3.6), only aggregate magnitudes of these factors were included, while in reality they are, of course, household specific. Therefore, the realized approximation of the yield response led to the lower variance in simulated yields compared to the observed ones. Nevertheless, the results displayed in Table 4.7 show that certain properties of the real yield distribution are preserved. Unfortunately, the absence of crop level data from the study area for other model crops in the IFPRI (2010) survey made the estimation of actual yields for these crops and, therefore, yield validation not possible. Hence, for these crops the author used only data on crop production volumes.

Table 4.7: Coffee yields

	Mean	Median	Stdev	10%	25%	75%	90%
Survey	1,317.0	953.7	1,153.5	326.3	583.8	1,621.6	2,918.9
Model	1,259.5	1,419.5	645.4	412.2	574.1	1,621.9	1,672.7

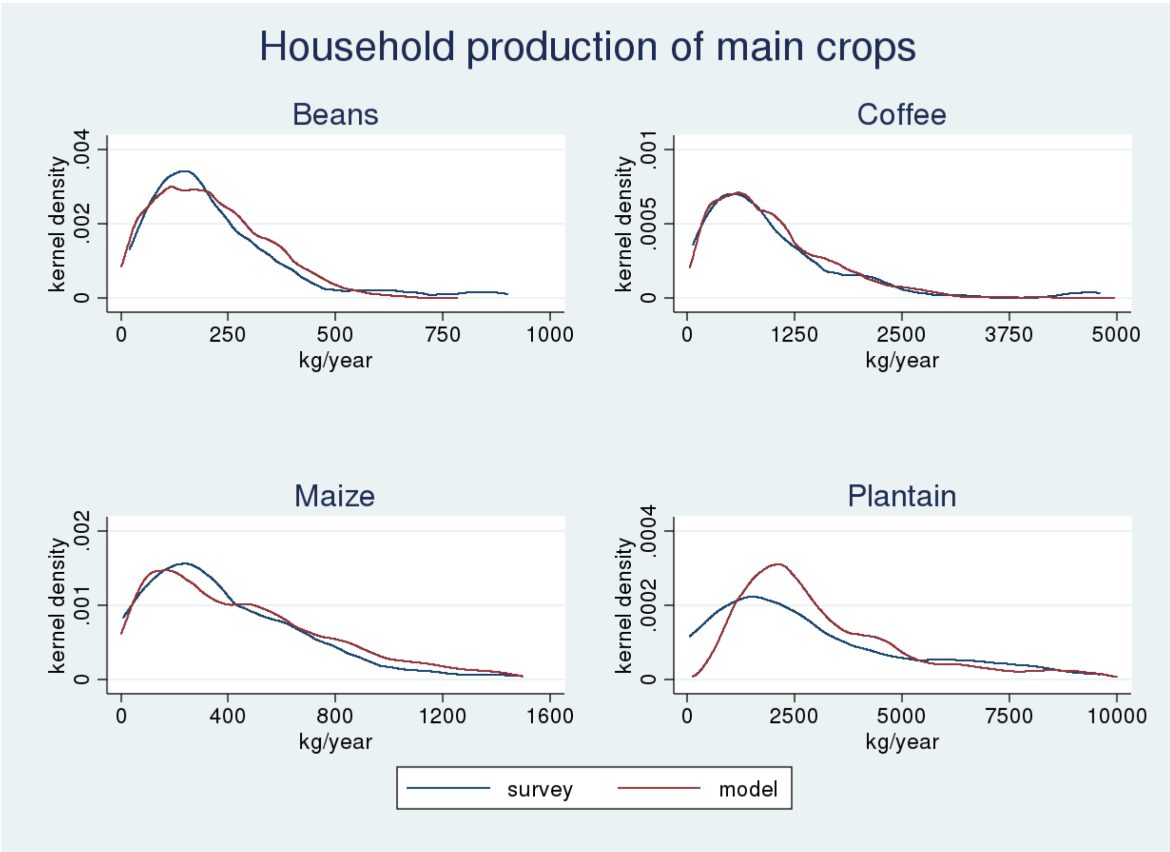
Source: Author, based on MP-MAS simulation results

* yields of survey population are estimated from IFPRI (2010)

** model yields are reported as annual means of 5 period simulation

Figure 4.3 compares the distributions of production volumes of individual households for crops that are most commonly grown by households in the study area according to IFPRI (2010): beans, coffee, maize and plantains. The model distributions on this figure are reported as aggregate distributions of ten test model runs conducted with different random population and seeds. As in the case of the study area total production, one can again observe a close match of the model results with the reference survey data for coffee. The rather small sample size of the IFPRI (2010) survey (71 households), which was used to create a benchmark for validation, might have caused higher deviations of model results from the benchmark values. Figure 4.3 shows that some parts of the simulated distributions differ from the survey distributions, although generally, especially for beans, coffee and maize, distributions have similar ranges and magnitudes. In the case of plantains, the model underestimates the number of smaller producers and overestimates the number of middle-size producers (Figure 4.3). Such errors in density functions may smooth out on the aggregate level, as in the cases of coffee, maize and plantains (see Table 4.6), whose aggregate production volumes are accurately represented with average prediction errors of only 0.88%, 1.65% and 2.17% respectively. The deviations of model results from the survey in the case of production of some crops (see Table 4.6 and Figure 4.3), which the author was unable to eradicate during calibration without compromising the model quality or assumptions on ranges of calibration parameters, may signal that the designed production module is missing additional production or marketing constraints. Conducting interactive modeling sessions with stakeholders from the study area (as done in Berger et al. (2010)) may provide insights into these constraints.

Figure 4.3: Crop production. Density functions



Source: Author, based on MP-MAS simulation results

* production volumes of survey population are estimated from IFPRI (2010)

** model production is reported as annual means of 5 period simulation

Even though the IFPRI (2010) project survey contained a limited amount of data that could be used for validation of the model results, the comparisons of the simulation results with the survey data showed that the model is capable of representing the coffee production in the study area (as follows from Figure 4.3, and Tables 4.6 and 4.7), which has an importance for the following analysis.

4.2.4 Livestock

Livestock was validated similarly to the crop production by comparison of the model output with author's estimates from the IFPRI (2010) survey, which served as a benchmark. For ruminant livestock units (cattle and goats) as indicators of production the amounts of livestock kept on the farm were compared, while for other livestock (chicken and pigs) amounts sold or used for own consumption were considered. Tables D.6 and D.7 compare estimated and simulated holdings of various livestock types by survey and model households. Model results are again reported based on ten test runs with the length of five periods performed with different random seeds and populations. The results of model initialization period were not considered: therefore, the effect of the initial allocation of livestock was minimized. Table D.6 reports that on average, study households throughout the year own 2.46 units of cattle and 2.32 goats, and produce 4.59 chickens and 0.79 pigs for sale and own consumption. During the field trip to the study area, it was observed that households typically own small numbers of diverse types of livestock.

As in the case of crop production, again one can see the low dispersion of model results and their consistency though different populations and random seeds (Table D.6). The model prediction errors (Table D.7) are rather small in the case of chicken (4.94% on average) and pig (5.66%) production. The errors are moderate in the case of cows and goats, 15.51% and 12.54% on average, respectively.

Figure D.7 compares simulated and observed distribution functions of farm livestock. As in the previous comparison, cattle and goats in this figure are expressed by the amounts of units kept on the farm, chicken and pigs – by the amounts of units sold or consumed. The distribution functions depict and locate inaccuracies of the model. These inaccuracies are likely the consequences of the fact that the parameterization of the livestock module was largely based on the aggregate country level data from external sources (see Section 3.5.3 and Schreinemachers (2006)). Conducting a specific livestock survey, expert interviews or discussions with livestock owners in the study area may improve the parameterization of the livestock module.

4.2.5 Goodness-of-fit and model efficiency

Goodness-of-fit statistics of a model and model efficiency coefficients are commonly established assessment measures of how well model results fit a set of empirical observations. The advantage of using these measures is that they aggregate different aspects of a model and provide unified model validity scores. In this research these measures were applied to validate the model results with respect to different aspects of the farm production system. The application of the measures required that the results of the different farm enterprises were expressed on the same scale. Therefore, they were standardized by multiplication with the monetary values of produce or livestock units observed in the study area (Table 4.8). These values were estimated from the IFPRI (2010) dataset; for ruminant livestock (cattle and goats), annuities were used. From Table 4.8 it may be concluded that the production of plantains and coffee are the most significant crop growing activities in the study area. (Therefore, the production system in the area is usually called “coffee/banana production system” (Ruecker et al. 2003).) Also, the calculations from this table suggest that cattle is by far the most valuable livestock asset.

For the calculation of goodness-of-fit, at first the standardized model results on crop pro-

Table 4.8: Standardization of results

Farm enterprise	Unit	Survey, units	Model, units	Unit value, th. ugx	Survey, th. ugx	Model, th. ugx
Bean	100 kg	2.09	1.52	100.0	208.5	152.4
Cassava		1.43	1.38	29.8	42.6	41.0
Coffee		9.81	9.82	105.5	1,035.4	1,036.6
Groundnut		0.14	0.16	96.0	13.7	15.6
Maize		3.68	3.63	50.0	183.9	181.3
Plantain		34.14	34.78	44.5	1,519.2	1,547.7
Sorghum		0.04	0.04	47.5	1.7	2.0
Sweet potato		0.88	0.73	28.0	24.5	20.6
Cattle	heads	2.46	2.08	119.1	293.5	248.0
Chicken		4.59	4.56	6.0	27.4	27.3
Goats		2.32	2.03	11.6	27.0	23.6
Pigs		0.79	0.83	39.2	30.9	32.6

Source: Author, based on IFPRI (2010) and MP-MAS simulation results

* unit values were estimated from IFPRI (2010)

** model results are reported as average over 10 test populations

duction were regressed on the respective estimates from the survey (standardized as well) using linear regression without an intercept. Again, the calculations were done using the results from model simulations performed with different initial conditions and random seeds. Table 4.9 provides the regression statistics. The regression slope coefficient can then be interpreted as a ratio of predicted results to observed ones, R-squared states for model explanatory potential (percent of the variation in the value of farm produce that can be explained by the model). The values of the slope coefficient range from 0.9850 to 1.0218, which signals that the mean values of farm output simulated by the model for the study area on average may be under-/over-estimated in comparison with the real data from the survey by 1.5-/2.2-%, respectively. The high value of R-squared statistics (0.9973 on average) suggests that the model predictions for particular farm products lie close to the fitted regression line. Both slope coefficient and R-squared statistics vary slightly with respect to the initial model population and random seed (as Table 4.9 suggests) and stay within the subjectively acceptable ranges for each of the ten test model runs. Figure 4.4 shows the derivation of the regression line for the average results and indicates point estimates for the different farm activities with relation to it.

For the evaluation of model efficiency, a Nash-Sutcliffe model efficiency coefficient (NSE) was calculated for all of the test model runs. The formula for calculating this coefficient is the following (Nash & Sutcliffe 1970):

$$NSE = 1 - \frac{\sum_{t=1}^{T}(Q_o^i - Q_s^i)^2}{\sum_{t=1}^{T}(Q_o^i - \overline{Q_o})^2} \tag{4.1}$$

where Q_o^i – observed value in i-case; Q_s^i – value simulated by a model for i-case; $\overline{Q_o}$ – mean over all observed values.

An efficiency $NSE = 1$ would then stand for a perfect match between simulated data and observed data. $NSE < 0$ would imply that an average over all observed values is a better predictor than a model. NSE efficiency coefficients for the MP-MAS Uganda application are reported in Table 4.9. It can be seen that for all of the test simulations the value of the coefficient is close to one.

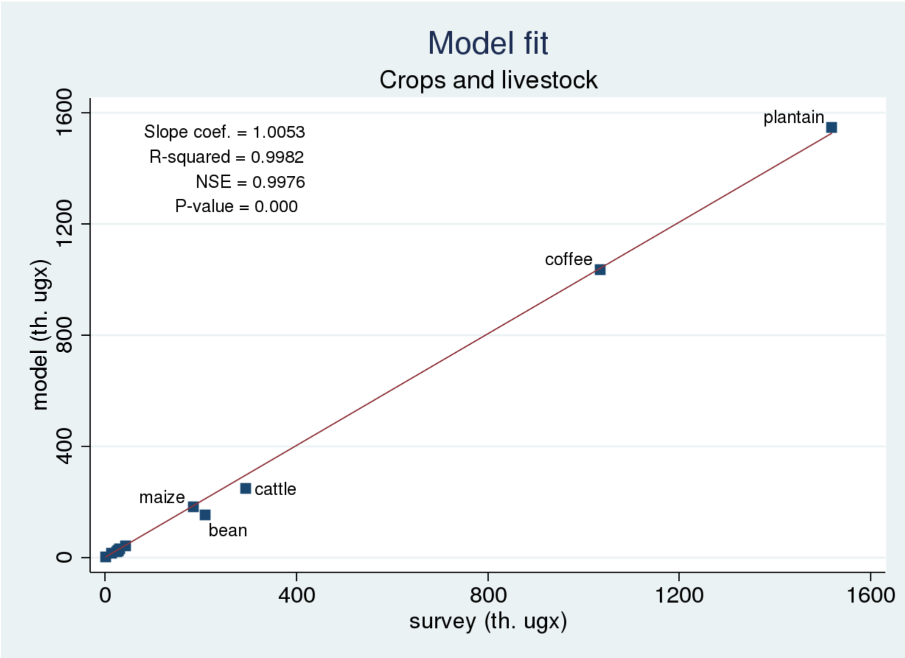
Table 4.9: Model fit and efficiency (by different populations and random seeds)

Model and seed	Slope coef.	R-squared	NSE
1	1.0111	0.9985	0.9977
2	1.0038	0.9982	0.9974
3	1.0169	0.9983	0.9972
4	1.0218	0.9978	0.9962
5	1.0042	0.9987	0.9981
6	1.0065	0.9978	0.9968
7	1.0015	0.9982	0.9975
8	1.0054	0.9976	0.9966
9	0.9972	0.9984	0.9978
10	0.9850	0.9987	0.9979
Average	1.0053	0.9982	0.9973
Best	1.0015	0.9987	0.9981
Worst	1.0218	0.9976	0.9962

Source: Author, based on MP-MAS simulation results
* p-value in all cases is lower than 0.000

Calculations reported in this section showed that the simulation model has a good fit and efficiency in terms of simulating outputs of crop and livestock production on the level of population averages. However, comparisons of distribution functions performed earlier in Sections 4.2.3 and 4.2.4) suggested that on the household level the accuracy of the model lowers in the case of some farm activities. Therefore, one may want to avoid using this model to make precise point predictions for particular farm households. This study is not intended to make such predictions, it is rather assessing directions and magnitudes of various treatments on the group of households, producing patterns and simulating processes for meso-level analysis (see Chapter 5). But, such aggregate-level analyses are done by taking into account the heterogeneity of individual farm households, captured by agent-based formulation of the MP-MAS Uganda model. The model agents reflect characteristics of the real-world households (see Sections 3.2, 3.3 and 4.2.1), and based on these characteristics the model mechanism (explained in Chapter 3) simulates household-specific responses to different treatments.

Figure 4.4: Model fit. Average results



Source: Author, based on MP-MAS simulation results
* model results are reported as average over 10 test populations

4.2.6 Population demography

Population pyramids for the study area were drawn from the empirical copula (see Section 3.8) estimated from IFPRI (2010) survey. Figure D.8 compares age pyramids of the survey and model populations. The model pyramid represented in this figure is the average pyramid of ten test populations. The limited number of observations for the study area in IFPRI (2010) survey did not allow for the making of a detailed (one year age resolution) estimation of the survey population pyramid. Hence, in the sampling procedure 12 equal age groups were used instead of exact ages. The exact ages within these groups were later randomly assigned. This allowed for the creation of a smooth population pyramid for the model from the rather ragged one of the survey. The survey pyramid (and the model pyramids resulting from it) has a constrictive shape that indicates lower numbers or percentages of younger people. It significantly differs from the country population pyramid provided in UDHS (2007), which has an expansive shape with a high proportion of youth. This pattern is a probable consequence of rural-urban migration processes that occurred in the study area or of the resettlement of household members (e.g. finding housing elsewhere).

For validation of the interpolated survivorship (Figure 3.12) and fertility (Figure3.11) curves their predictions on average life expectancy and total fertility rates, respectively, were compared with World Bank (2012) and UDHS (2007) data estimates for Uganda. Survivorship curves implemented in the MP-MAS Uganda application predict an average life expectancy of 54.28

years for women and 51.12 years for men, which is close to the corresponding estimates of World Bank (2012): 53.68 for women and 52.49 for men. The fertility curve gives a total fertility rate of 6.12 children per woman, which is in line with the 6.69 country average, given a relatively lower fertility rate in Central Uganda, as observed by UDHS (2007).

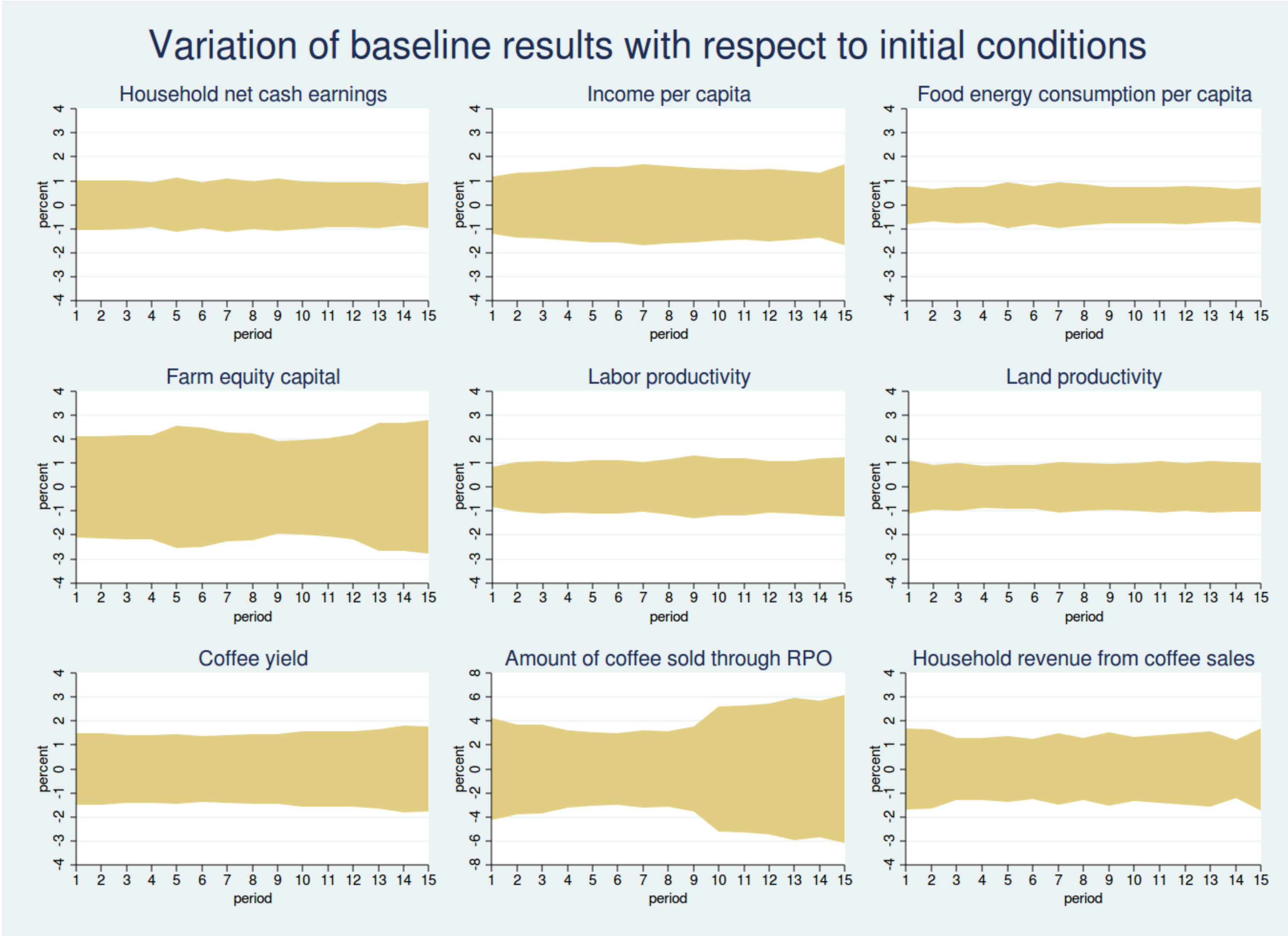
The generated population structure together with the interpolated survivorship and fertility curves define simulated population dynamics. The simulation model population produces an annual growth rate of 2.82% per annum. The current population growth rate for Uganda, according to World Bank (2012), is estimated at the 3.2% level; CIA (2012) estimated 3.576%. A growth rate that is lower than the country average is expected in the model, since the total fertility rates in the Central region, to which the study population belongs, are lower than in the county as a whole (5.6 – Central region and 6.7 – whole Uganda (UDHS 2007)) and the net migration rate is negative (see Figure 3.13).

4.2.7 Sensitivity of results to model initial conditions

The implemented approaches of generating model agents and soil properties (described in Sections 3.2 and 3.3) allowed for the creation of many statistically consistent agent populations. These alternative populations, as well as various model random seeds, were used to assess the sensitivity of model results with respect to initial conditions. Some attention was already dedicated to this issue in the preceding sections (4.2.3 - 4.2.5) of this chapter. This section supplements the previous analysis by estimating the results sensitivity on the extent of 15-period simulation run (a length that is later used in the applied model scenarios). The assessment was based on the results of 20 test runs conducted with different initial conditions. In these simulations all model components (including RPO-model, soil updates and population dynamics) were activated and all model parameters were as recorded in the IFPRI (2010) survey. This model set up is later referred to as the "baseline scenario".

Figure 4.5 summarizes the results of the model simulations on sensitivity. The figure displays the estimated variations in important model variables with respect to changes in initial conditions and random seed. A variation here is characterized by a standard deviation of a variable divided by an average value of that variable (relative standard deviation) over 20 test simulation runs. The variables themselves were taken as averages over all agents in one population. Figure 4.5 supports conclusions from previous sections on low dispersion of the model results depending on the initial model conditions and random seed. The simulated relative standard deviation for each of the selected variables lies within a +/- 7% interval. Moreover, the figure shows that the variations for most of the selected variables are almost constant over the model time, with the exception of amounts of coffee sold through the RPO, whose variation slightly increases in the later simulation periods. In general, the findings of this experiment prove the consistency and robustness of model results. However, the existence of the estimated variations and their magnitudes has to be considered when interpreting the results of the model simulations.

Figure 4.5: Variation of baseline results



Source: Author, based on MP-MAS simulation results

* variations are reported as relative standard deviations from meta-averages over 20 test simulations

Chapter 5

Simulation results

Previous chapters of this thesis discussed the design and development of the MP-MAS software application for modeling RPOs in agriculture. This chapter describes the scenarios for which the model was applied and analyzes the results of the respective simulation experiments. The choice and set up of the scenarios for analysis were driven by the research questions of this particular study (page 6), as well as by the objectives of the joint research project in which framework this research was done (Section 1.3.1). The scenario-based analysis resulted in the conduction of over 200 computer simulation experiments belonging to the following three sets:

1. System under current conditions (Section 5.1): The associated simulations meant to replicate in the model a situation that is close to what is currently occurring in reality. The results provide insight into what would likely happen in the study population over the next few years, assuming that present economic and demographic conditions and trends hold. Also within this set of simulation experiments the effects of RPO presence on study area households were isolated. Influences of soil degradation and population growth were assessed as well.
2. Sensitivity to external factors (Section 5.2): There are several external factors that are likely to influence the behavior of modeled households. Prices for coffee and staple crops, wages for seasonal labor, declines in crop yields (e.g. due to outbreaks of plant diseases) or yield increases (e.g. due to provision of quality planting material or adoption of good agricultural practices) are in the list of such factors. In order to capture household responses to possible external shocks (both negative and positive), the sensitivity analysis was performed.
3. RPO-level interventions (Section 5.3): With this set of experiments the author simulated the effects of potential development interventions at the RPO level. This was done in order to estimate likely impacts of the interventions on the study population. Recommendations for implementation of interventions can be derived from the results of this ex-ante impact assessment. Tested interventions include (i) shortening of delays in payments for

delivered coffee, (ii) organization of monetary motivation schemes for large sellers and (iii) engagement of an RPO in a certification program.

The listed experiments were intended not only to provide additional knowledge on the studied system, but also to assess and demonstrate the potential of application of MAS models (and MP-MAS framework in particular) for research on farm households and collective action organizations.

MP-MAS Uganda application is a simplified representation of the real-world agricultural system, hence certain characteristics, which are dynamic in the real-world, are static in the simulation model. It is worth noting that across all the simulation scenarios, land ownership and sizes of coffee plantations were fixed over the runtime. Agents could change their management practices (input and labor intensity, crop mixes of food crops) and replant coffee plantations, but could not expand or reduce the land ownership or parcels used for coffee growing. Consumption preferences of agents were assumed to remain constant.

All simulation runs were performed with the same initial population and random seed. In the case of all scenarios, the simulation model was run for 15 normal simulation periods preceded by three spin-up periods and one initialization period, during which agents formed their expectations and adjusted their liquidity reserves and initial livestock allocations. These four extra periods at the start of the simulations are "technical" and serve for the correct initialization of the model, therefore their results are not reported in this chapter.

As explained earlier (Section 1.3.4), the simulation model includes only the agents, whose real-world prototypes are current RPO members. Therefore, simulation results reflect only the behavior of current RPO members. Due to the absence of empirical data in the project survey (IFPRI 2010), the other coffee-producing households (non-members of RPOs) were not simulated. Hence, the membership in the RPO is fixed in the simulation model, i.e. the RPO agent may neither attract new members, nor lose existing members. Of course, in reality the membership is not fixed, but dynamic and certain factors and interventions might influence the dynamics of membership. These considerations have to be kept in mind, when extrapolating model results into the real-world situation.

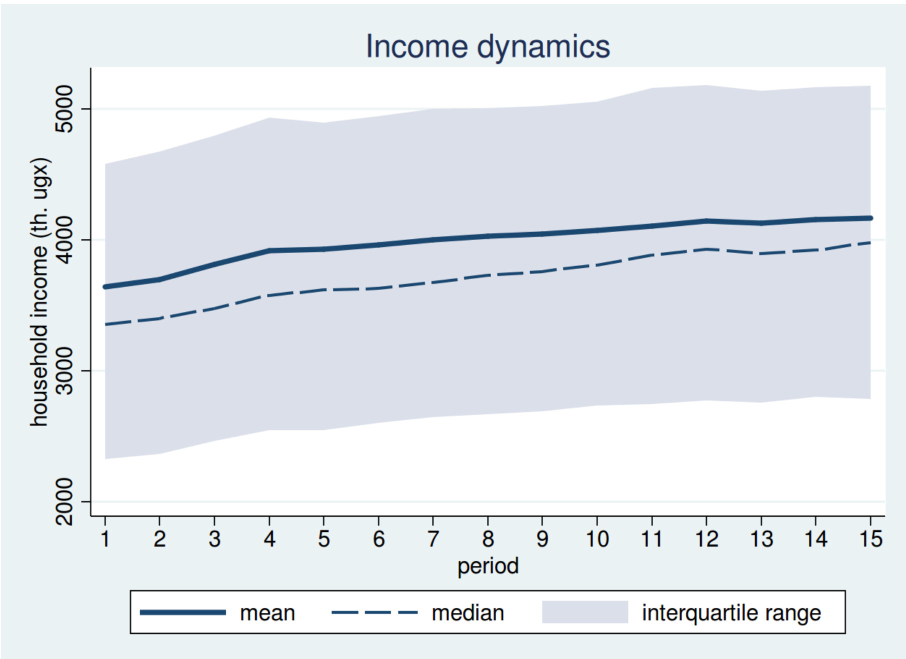
5.1 System properties under current conditions

In terms of model set-up, scenarios reviewed in this section were simulated with constant potential crop yields and constant purchasing and selling prices and production costs. These factors were set to observed levels of 2010. Scenario design assumed that the production alternatives remain constant over the runtime (the next 15 years after 2010), which means no innovations or technological changes were expected. Mortality and fertility rates remain as observed. The RPO agent (in scenarios where it is present) performs only its regular functions of collecting, processing and marketing of the coffee produced by farm agents.

This section aims to describe the baseline state and the dynamics of the simulated system. The analysis served as a benchmark to be used later in sensitivity tests and treatment assessments. Also, it was intended to give the reader an overview of the behavior of the implemented simulation model.

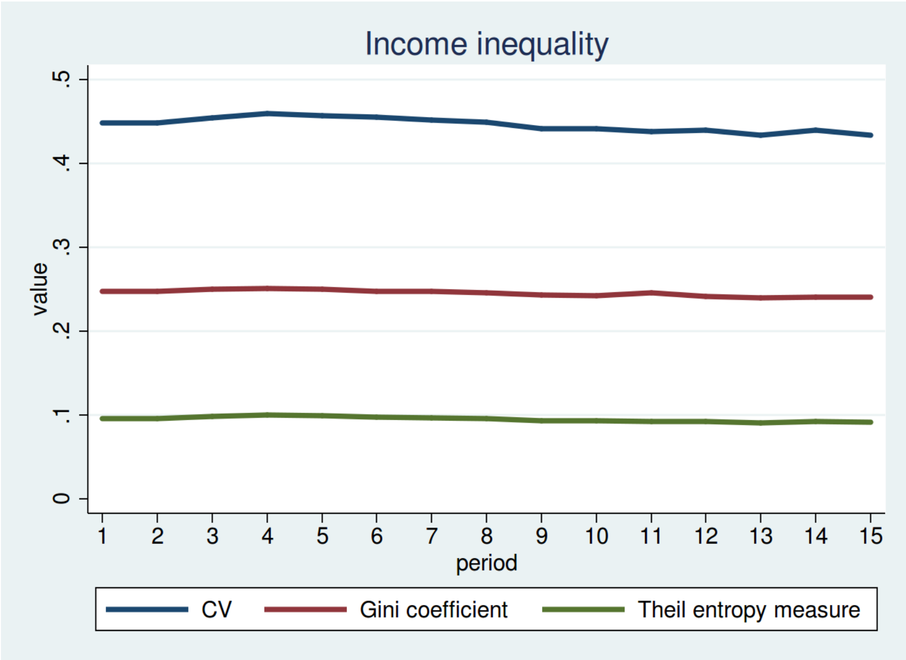
At first let us inspect the development of incomes of household agents depicted in Figure 5.1. As this figure suggests, the simulated household income rises over time. There are two reasons of this upward trend in the simulated household income: (i) recent high levels of producer prices for robusta coffee (see Figure 1.7) and (ii) an increase in agent labor supply due to the simulated rapid population growth and the aging of household members (many younger household members become available for farm work). The income effect of population dynamics is closer inspected in Section 5.1.2. The simulated income dynamics have a mean compound annual income growth rate of 0.9%. Figure 5.1 shows that the rate of growth is similar in the lowest and highest income terciles. When looking at the inequality measures (Figure 5.2), we see that income inequality between model agents is indeed relatively stable over time. The Gini coefficient of 0.25 indicates low income inequality. This is not surprising, since membership in the RPO implies a certain degree of similarity between members. Despite the growth in simulated household income, simulated income in per capita representation, due to the growing population, declines after the fourth period. Figure 5.3 shows the development of simulated household income per capita (adjusted according to the OECD adult equivalence scale).

Figure 5.1: Household income. Baseline scenario



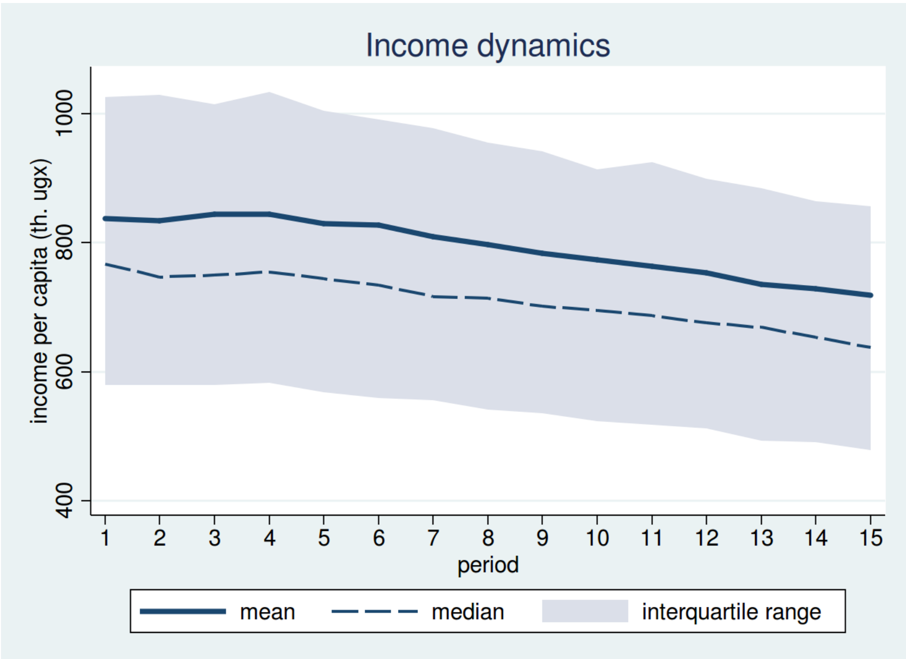
Source: Author, based on MP-MAS simulation results

Figure 5.2: Income inequality. Baseline scenario



Source: Author, based on MP-MAS simulation results

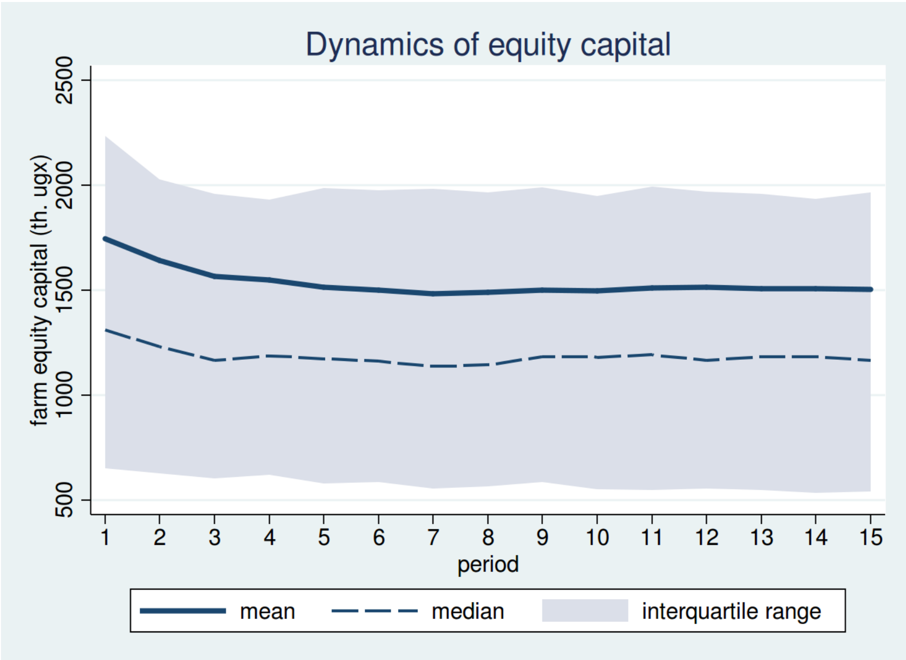
Figure 5.3: Per capita income. Baseline scenario



Source: Author, based on MP-MAS simulation results

As shown in Figure 5.4, agent equity capital remains stable over the long run. On the one hand, agents have to make regular withdrawals for their own consumption and, since capital investment opportunities are limited, not much equity capital is being accumulated. On the other hand, agent household capital is not declining, which means that agent production patterns and consumption levels are sustained over time. The livestock assets of model household agents increase (Figure 5.5); the herd sizes are growing. Because of the declining soil fertility (explained in Section 5.1.2), agents gradually increase livestock production and decrease crop production.

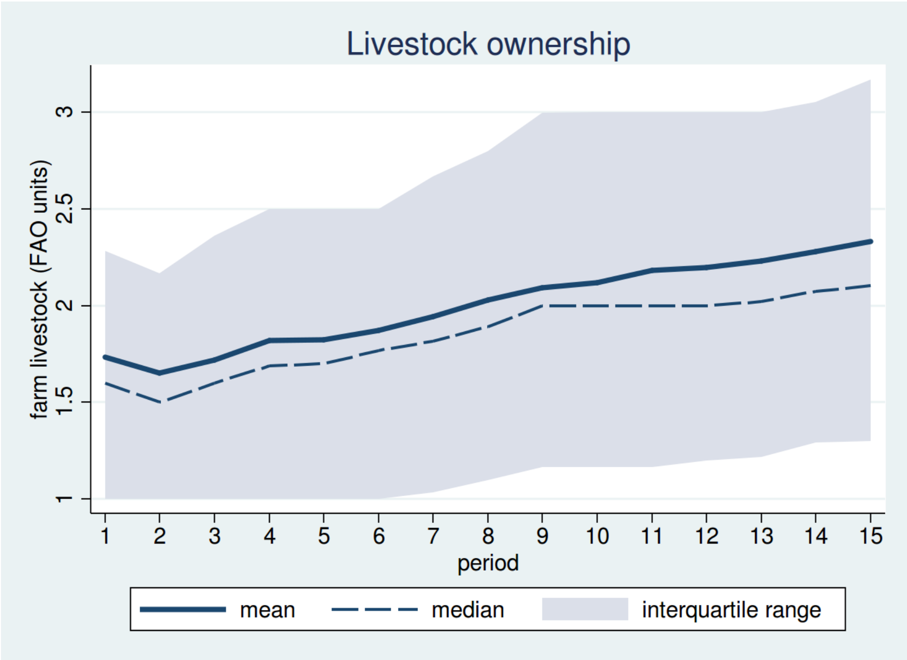
Figure 5.4: Farm equity capital. Baseline scenario



Source: Author, based on MP-MAS simulation results

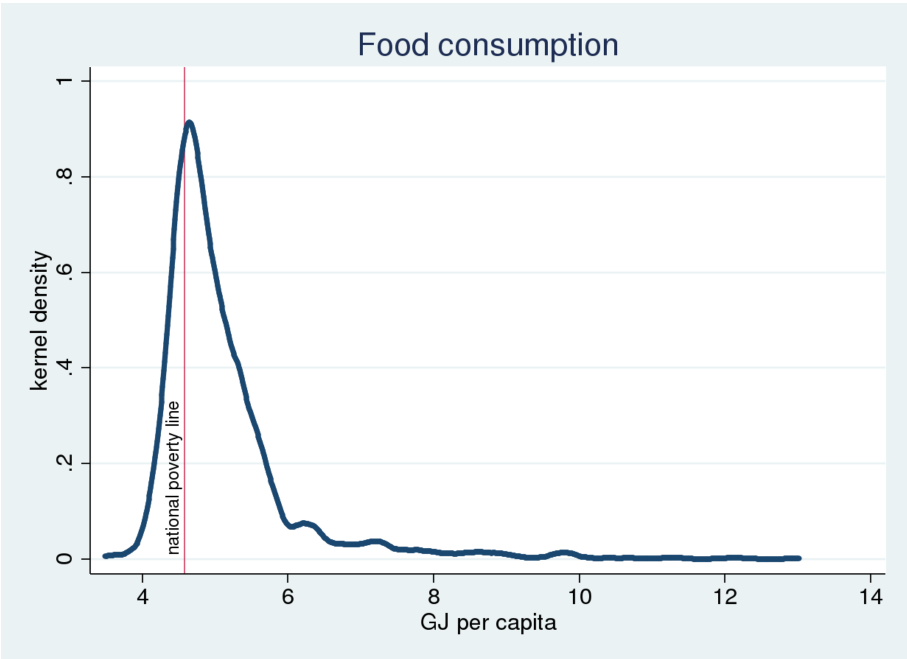
Agriculture in the study area is subsistence-oriented, i.e. part of the farm produce is not sold on the market, but used to cover household food requirements. The consumption module of MP-MAS Uganda application simulates this behavior (see Section 3.7). Figure 5.6 shows the simulated distribution of per capita food consumption (adjusted according to the OECD equivalence scale). This graph is plotted based on the agent-specific 15 period average food supplies. The daily food energy intake of 3000 food calories per adult equivalent per day is currently used in Uganda as a national poverty line (MFPED 2012). This poverty threshold can be transformed to 4.581 gigajoules per year. The threshold is plotted in Figure 5.6, showing that 25.1% of household agents from the model population lie below the national poverty line (left to the red line on the graph). The statistics of World Bank (2012) estimate the poverty headcount ratio for Uganda at the national poverty line at the level of 24.5%.

Figure 5.5: Livestock ownership. Baseline scenario



Source: Author, based on MP-MAS simulation results

Figure 5.6: Food consumption. Baseline scenario

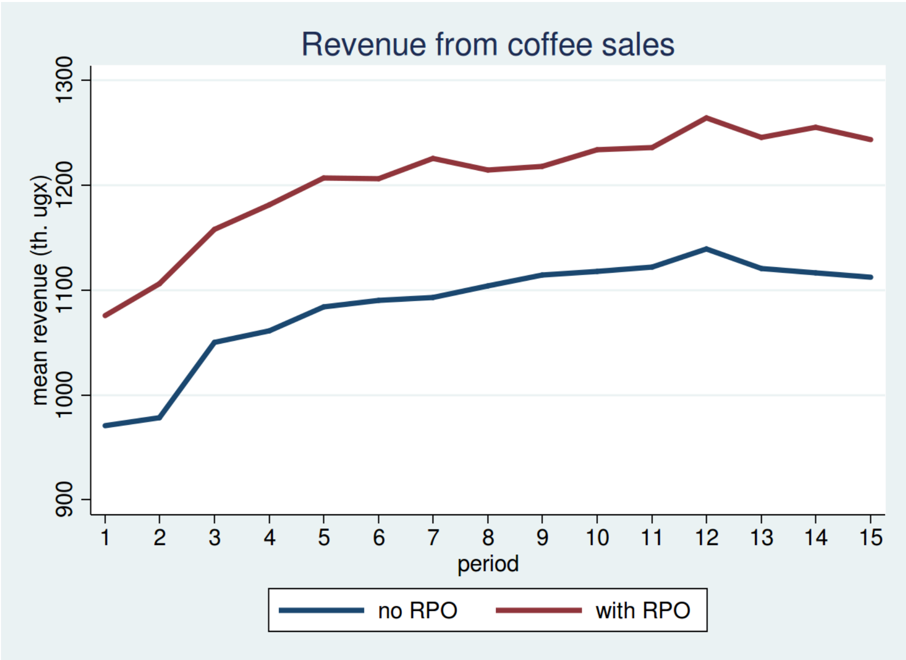


Source: Author, based on MP-MAS simulation results
* distribution of average period from 15 period simulation

5.1.1 Effect of RPO presence

In order to isolate the effect of the RPO presence, the baseline scenario from the section above was run without the RPO agent, i.e. in this case, farm agents can only sell coffee through middlemen. The results of both (with and without the RPO) simulations were compared. Figure 5.7 shows the impact of the RPO on agent revenue from coffee sales. The mean effect can then be calculated as a difference between the red and blue lines on the graph: on average, in the scenario with the RPO, sales revenues of farm agents are 11.0% higher than in the scenario without it.

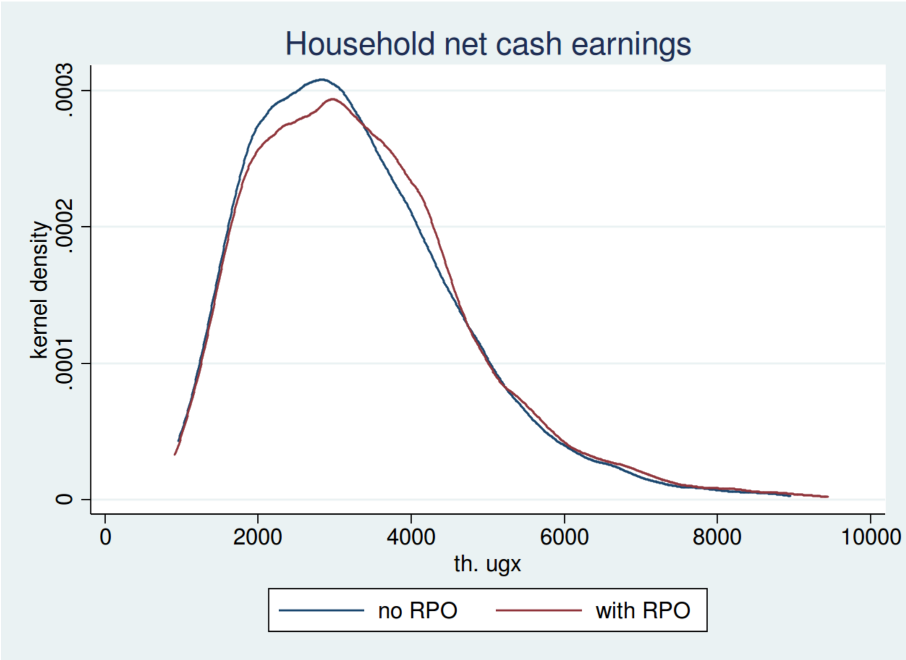
Figure 5.7: RPO impact. Sales revenue



Source: Author, based on MP-MAS simulation results

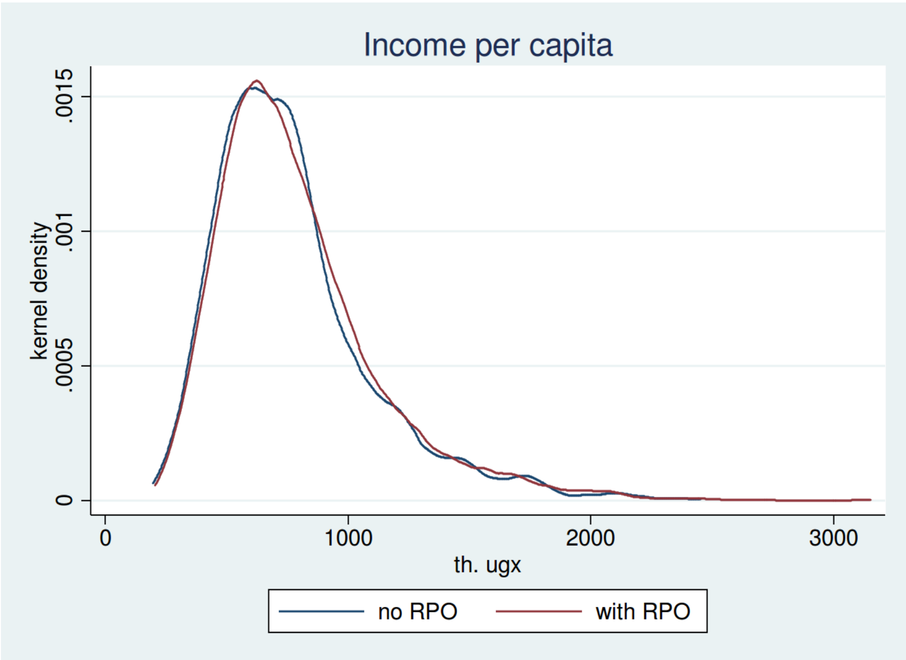
Coffee is an important cash crop for the study area households. It is grown almost exclusively for sale, while other crops are largely consumed on the farm. Consequently, coffee sales constitute one of the main sources of cash. Therefore, positive RPO impacts on agent sales revenue translates to higher cash earnings of household agents. Figure 5.8 compares simulated agent cash earnings in situations with and without the RPO agent. The figure provides a disaggregated picture by comparing distributions of cash earnings from respective scenarios. From the figure we can see a distinct increase in cash earnings for the large share of household agents cased by the RPO activity. We can also observe a positive impact of RPO in terms of simulated per capita incomes (Figure 5.9). The magnitude of the effect here is obviously smaller, since coffee production is one of several income-generating activities in the model. The effect is also noticeable in many parts of the distribution. Figure 5.10 compares dynamics of agent income under both scenarios. As shown in the graph, the RPO has a positive effect on income in every simulation period. Again, the difference between lines is calculated to assess the mean impact of the RPO: the income effect of RPO presence is simulated to constitute 2.8%.

Figure 5.8: RPO impact. Household cash earnings



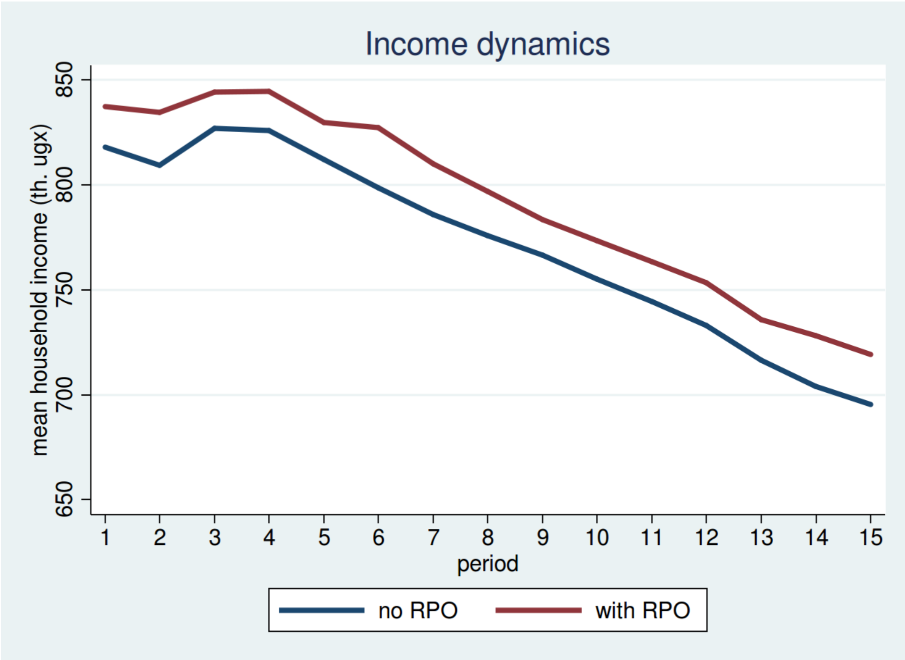
Source: Author, based on MP-MAS simulation results
* distributions of average period from 15 period simulations

Figure 5.9: RPO impact. Per capita income



Source: Author, based on MP-MAS simulation results
* distributions of average period from 15 period simulations

Figure 5.10: RPO impact. Income dynamics



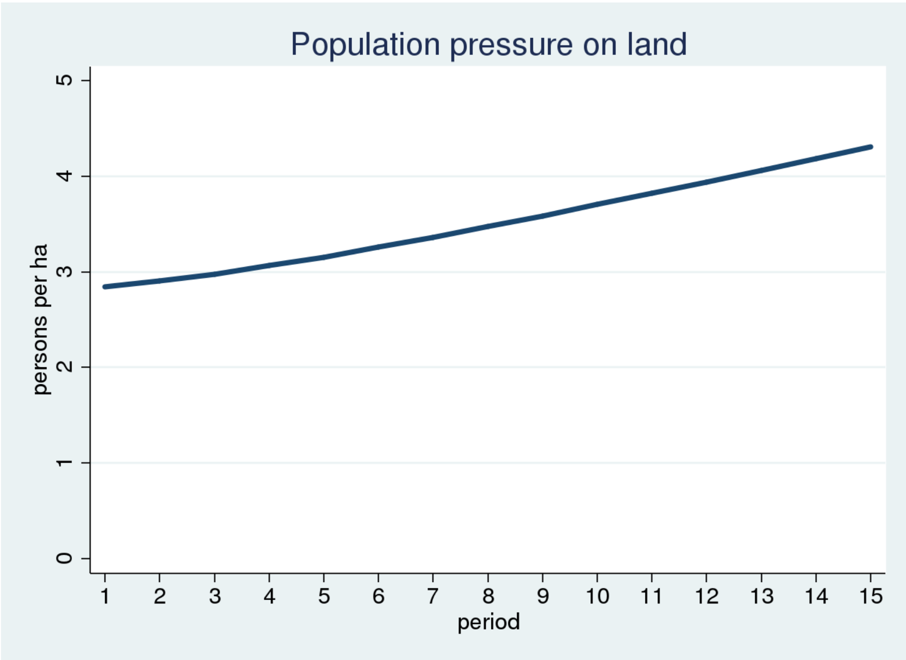
Source: Author, based on MP-MAS simulation results

5.1.2 Dynamic effects of soil degradation and population growth

Increasing population pressure on land is a typical characteristic of Sub-Saharan Africa. It is an important factor to be considered, therefore, it was implemented in the simulation model (implementation discussed in Section 3.8). Figure 5.11 displays simulated population pressure on arable land. The figure shows that current rates of population growth in Uganda are simulated to tremendously increase the population density in rural areas. For assessment of the effect of population growth, the results of the baseline scenario (with simulated population dynamics) were compared with the artificial hypothetical scenario, where the aging of household members was switched off, and fertility, mortality and migration rates were set equal to zero (i.e. no population dynamics). As Figure 5.12 demonstrates, the simulated population growth negatively influences agent per capita incomes in the long run. From Figure 5.12 we can see that on average, in the starting years, agents benefit from population dynamics because of an increase in farm labor availability. In later periods this effect is countervailed by population growth. Even with population dynamics switched off, agent mean per capita income experiences a slight decline in the later periods. This happens because (i) the benefits from high coffee prices are already fully realized and (ii) the decline in soil fertility also negatively influences agent incomes.

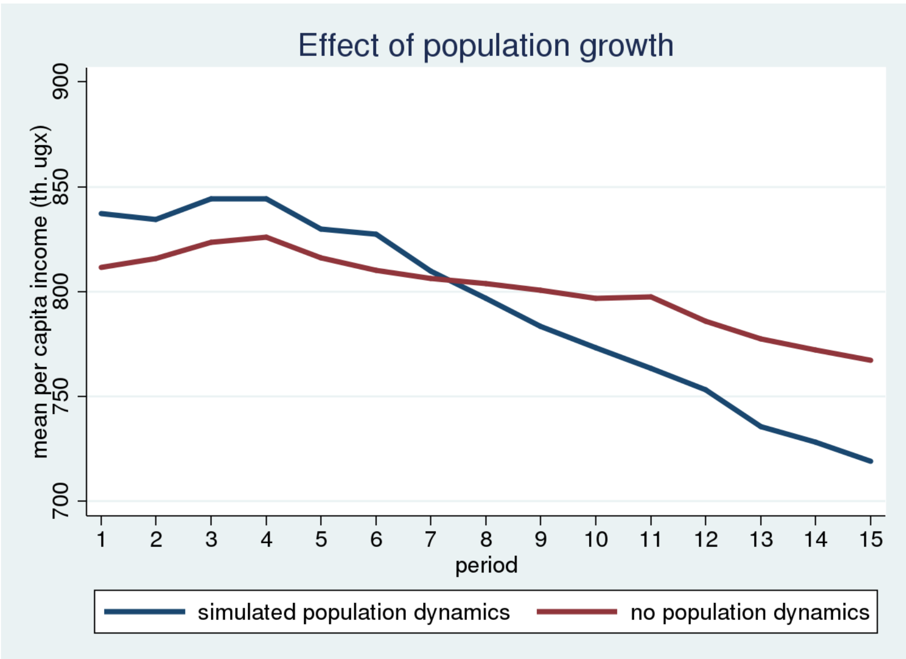
The integrated TSPC module (see Section 3.6) simulated a decline of soil fertility (reflected by negative nutrient balances) under agricultural practices chosen by model agents: as shown in Figure 5.13, simulated stocks of soil organic nitrogen gradually decline. Nutrient losses cause decreases in simulated crop yields and consequently, agent farm gross margins and incomes.

Figure 5.11: Population pressure on land



Source: Author, based on MP-MAS simulation results

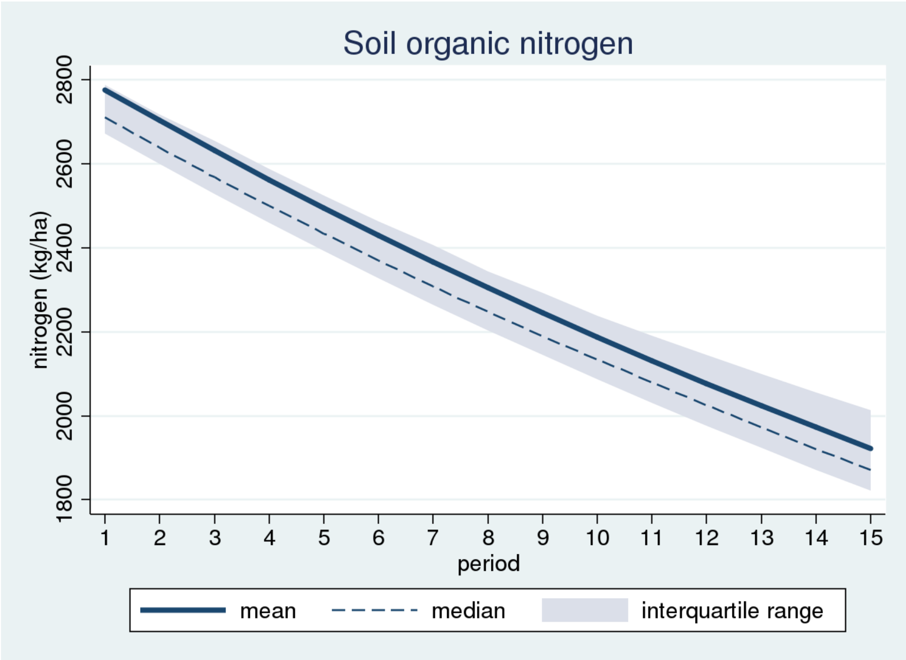
Figure 5.12: Effect of population growth. Income



Source: Author, based on MP-MAS simulation results

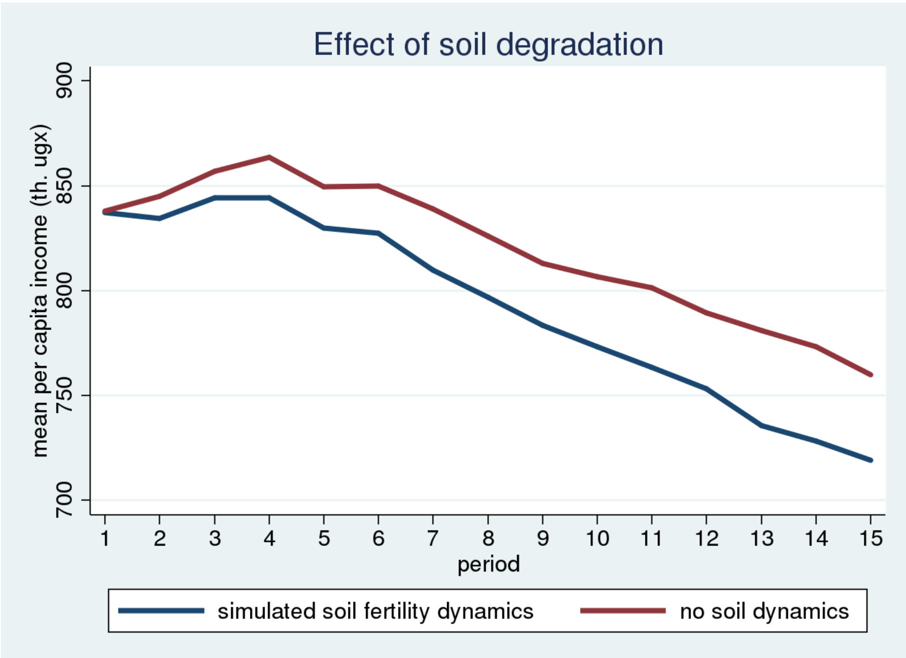
Figure 5.14 shows the simulated income gap substantiated by the soil degradation processes. At the period 15 the mean income gap constitutes 5.7% of the baseline average per capita income (in adult equivalent calculation).

Figure 5.13: Soil organic nitrogen



Source: Author, based on MP-MAS simulation results

Figure 5.14: Effect of soil degradation. Income



Source: Author, based on MP-MAS simulation results

5.2 Sensitivity analysis

In order to capture agent responses to possible external shocks, a sensitivity analysis was performed. The first part of this section reports on the sensitivity of simulated household incomes and poverty counts, as well as RPO profits with regard to changes in external factors that are likely to be influential (e.g. market prices, production costs etc.). It was tested by running the model using different levels of such external factors and comparing the respective simulation outcomes. The second part of the section assesses the impact that the variability of coffee prices may have on farm households and RPOs. This impact was captured through the comparison of simulation runs performed (i) with prices that are constant to the historical average and (ii) with prices subject to historical variability.

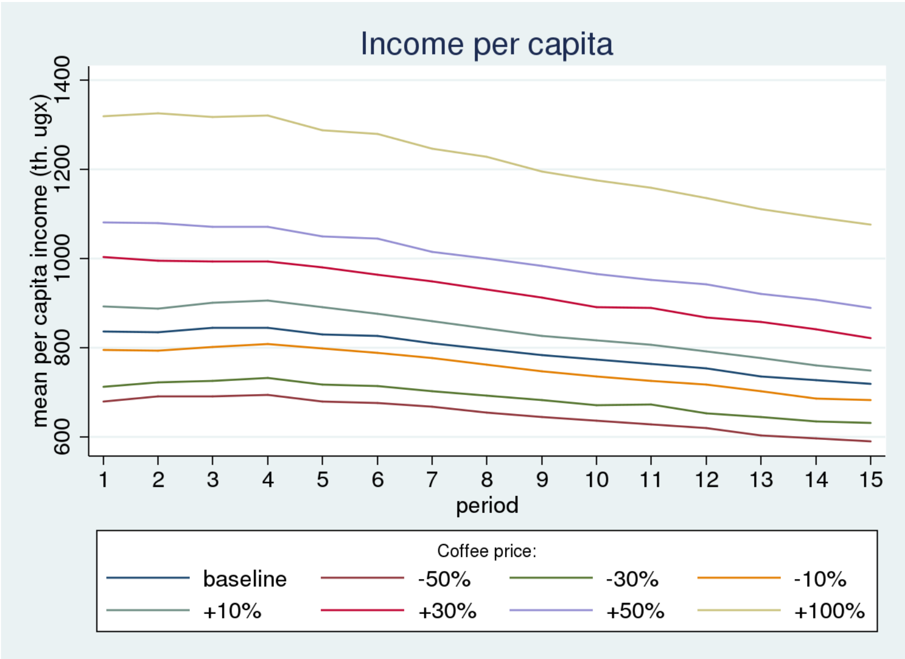
5.2.1 Sensitivity to changes in external factors

For this experiment, a number of factors were integrated into the Excel dataset that contains parameters of the simulation model. All these factors are multipliers that change values of one or several model input variables. In the baseline all factors are equal to one. For the sensitivity analysis, eight levels of every factor were tested ceteris paribus: 0.5, 0.7, 0.9, 1, 1.1, 1.3, 1.5 and 2. During the simulation run, the tested factor is kept constant at the initially chosen level. (E.g. price factor of 0.5 would imply that all prices in all model periods are lowered by 50% in comparison to baseline.) In total, six factors were incorporated in the analysis:

1. Coffee prices
2. Food prices (include cultivated crops, livestock and livestock products and food purchased on the market)
3. Input prices (planting material for coffee, seeds and fertilizers)
4. Wages of seasonal labor
5. Coffee yields (no effect on price assumed)
6. Yields of food crops (also with no price effect)

Let us start with the analysis of sensitivity with respect to coffee prices. Figure 5.15 displays the results of the simulation experiments that simulated income sensitivity related to coffee price reduction or increase. The results show that with the reduction of coffee prices by 50% of the 2010 level, agent incomes in per capita expression reduce by 17.4% on average. Since households want to secure their food consumption, they diversify farm enterprises and their income is never fully dependent on coffee production. Diversification of income sources through the cultivation of other crops (plantains, maize, beans etc.) and livestock rearing, as well as remittances from family members help to smooth the negative effects of price shocks. A 50% increase in coffee prices from the baseline resulted in a rise in mean per capita income by 27.1%. The relative effect from coffee price increase of 50% is higher than from the coffee price decline of 50%: 27.1%>17.4%. This is because higher sales revenues caused by producer price increases provide additional cash earnings for farm agents. In current conditions of the modeled system this leads to the relaxation of agent cash constraints, which opens more investment and production opportunities that in turn result in additional income improvement.

Figure 5.15: Coffee prices and income

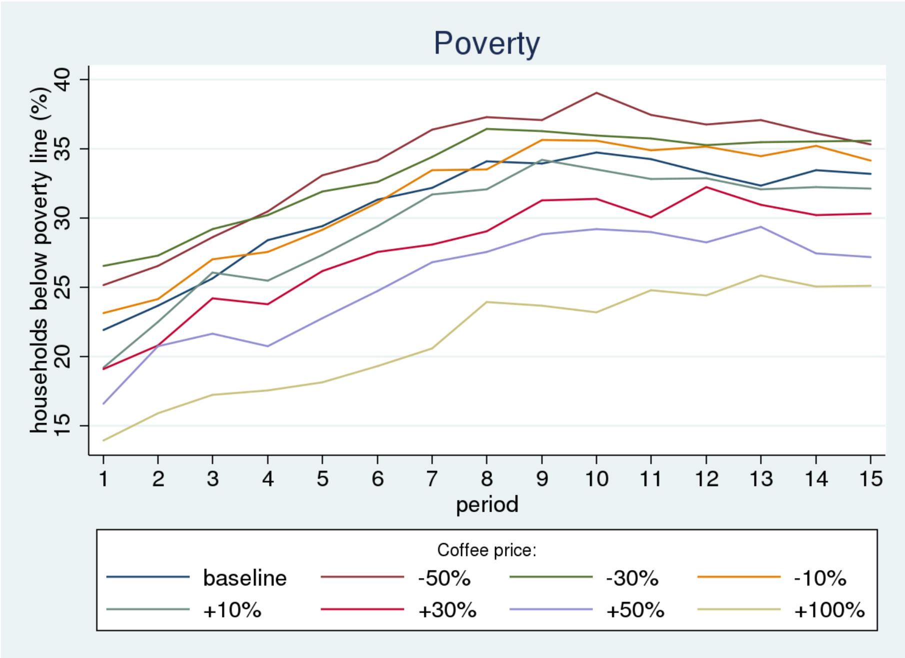


Source: Author, based on MP-MAS simulation results

Coffee is an important income source and a food security provider. The decline of coffee prices increases simulated poverty gaps and pushes more agents under the poverty line (Figure 5.16). For example, in the scenario with 50% lower coffee prices on average over 15 periods 33.2% of agents from modeled population are below the poverty line, while in the baseline scenario this indicator equals 30.8%. In the scenario with 50% higher coffee prices, the percentage of agents below the poverty line decreases to 25.4% on average.

In order to characterize the impact that coffee price changes create at the RPO level, let us look at the development of RPO profit under different price scenarios. Figure 5.17 displays simulated RPO profits at different coffee prices. According to the formulated definition of RPO profit (see Section 3.10.2), the profit reported on the graph accounts only for fixed and variable costs of the organization (does not include individual costs of coffee growing). This profit is distributed among the agents and forms the simulated producer prices received when selling through the RPO-channel. Figure 5.17 shows that in simulation with the general long-run level of coffee prices equal to 50% of the baseline, the RPO is unprofitable (i.e. it is outcompeted by local middlemen). Because of increasing returns to scale and strong producer incentives,

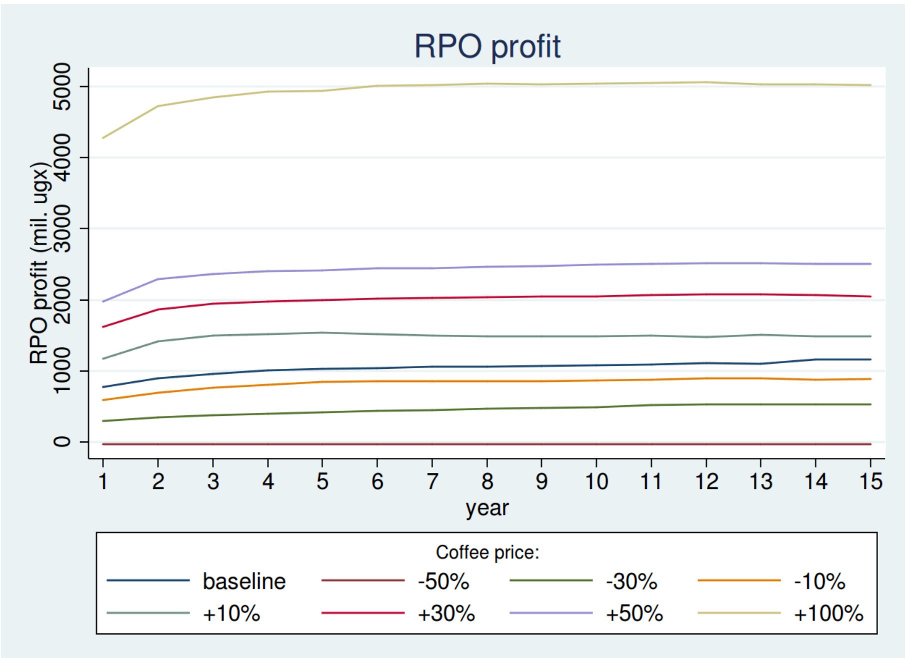
Figure 5.16: Coffee prices and poverty



Source: Author, based on MP-MAS simulation results

simulated RPO profit rises at a higher rate than the coffee prices (Figure 5.17). For example, a 50% increase in coffee prices lead to an increase in simulated RPO profit of 135.7% on average.

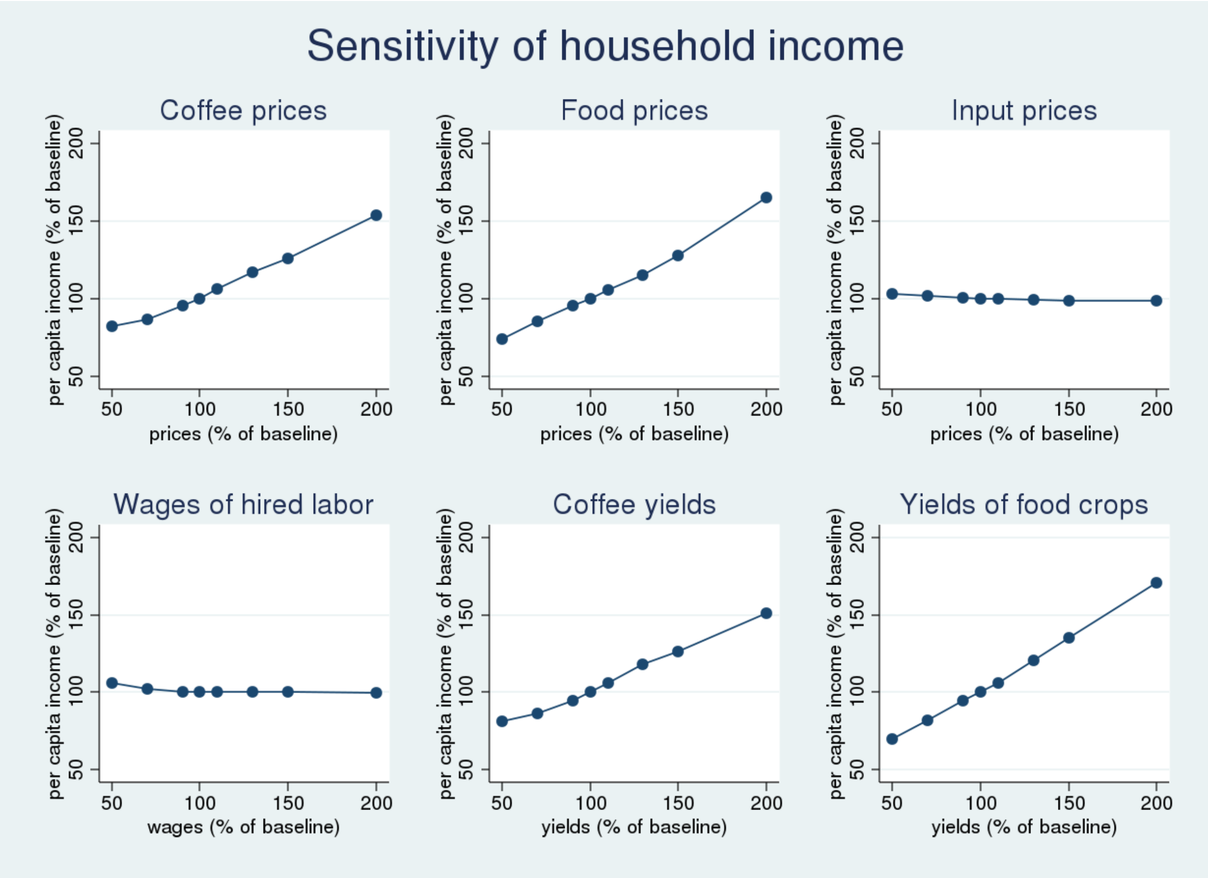
Figure 5.17: Coffee prices and RPO profit



Source: Author, based on MP-MAS simulation results

Similar to coffee prices, five other factors listed above were tested and their impacts analyzed. Figures 5.18–5.20 provide a summary and cross-comparison of sensitivities of simulated agent incomes (Figure 5.18), poverty estimates (Figure 5.19) and RPO profit (Figure 5.20) with respect to the selected factors. These figures plot simulated changes in the model result indicators against relative changes in the selected external factors implemented in the model input data. Each dot on the graphs of Figures 5.18–5.20 represents a result of a particular simulation run (dots connected by linear interpolation). Graphs report simulated effects as relative changes in population means.

Figure 5.18: Sensitivity analysis. Income

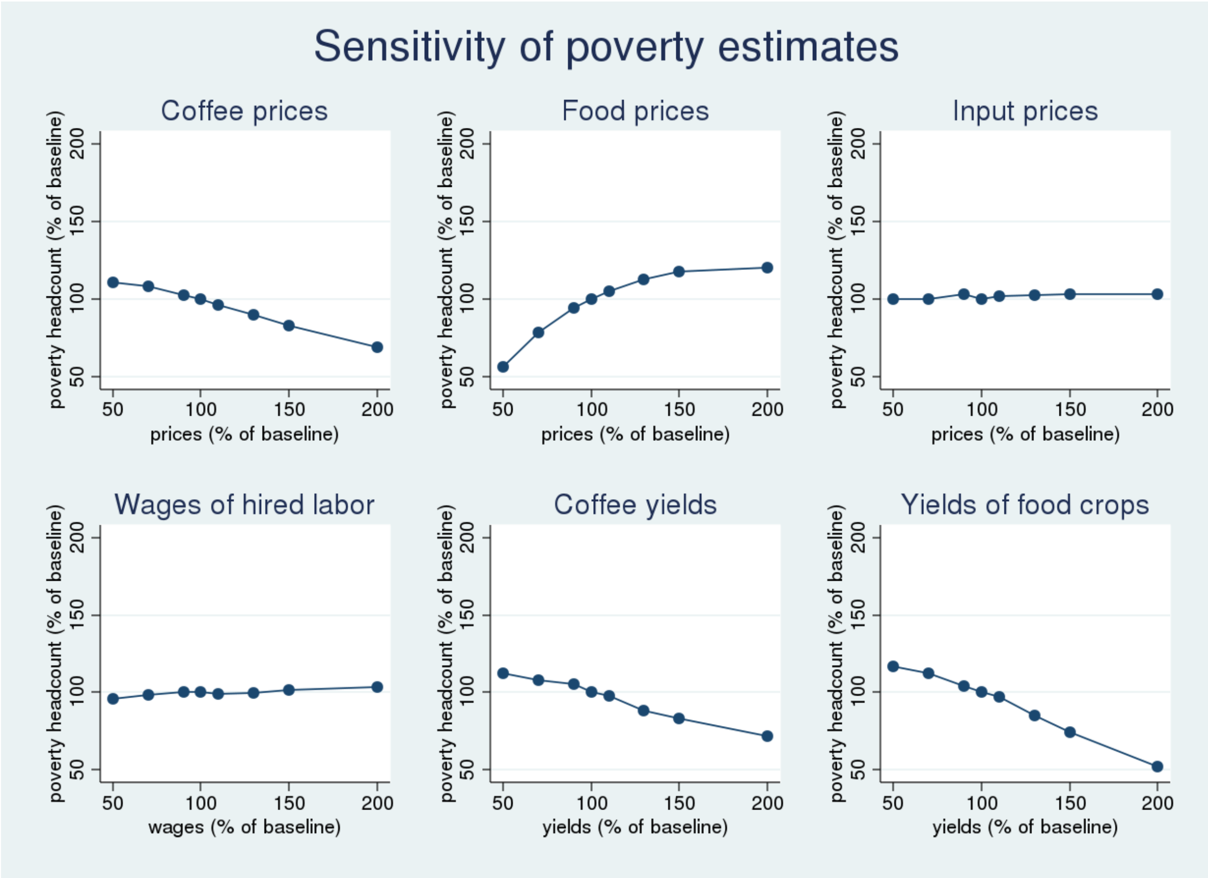


Source: Author, based on MP-MAS simulation results
* results reported as mean effects from 15 period simulation runs

As expected, simulated agent income statistics are positively correlated with coffee prices and coffee yields (Figure 5.18). Yields of food crops and food prices are also positively correlated with agent income, since model households also produce food crops in addition to coffee, such as plantains (with which coffee is intercropped).

As shown in Figure 5.18, income is almost immune to changes in prices of production inputs and seasonal labor wages: only a slight income decline is simulated, when either of these two factors increase. Agents are not dependent on external production inputs: traditional planting material is cheap and in many cases is produced on the farm, mineral fertilizers are rarely used.

Figure 5.19: Sensitivity analysis. Poverty estimates



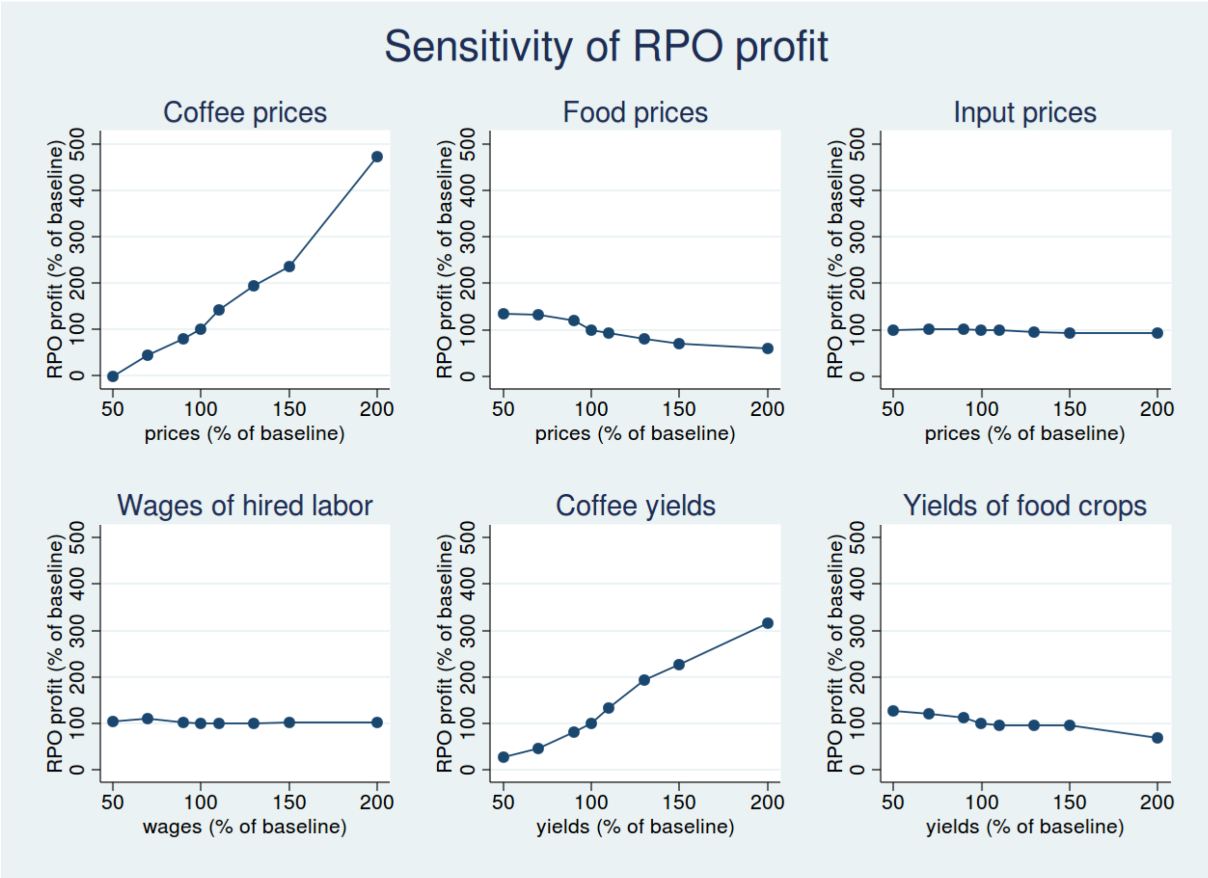
Source: Author, based on MP-MAS simulation results

* results reported as mean effects from 15 period simulation runs

Also, mostly own labor is involved in farming activities. Other indicators (Figures 5.19 and 5.20) also show low sensitivity to input prices and wages of seasonal labor.

Higher coffee and food crop yields and higher coffee prices were simulated to have a positive impact on poverty in the study area: increases in these factors led to considerable declines in poverty headcounts (Figure 5.19). Declines in these factors led to the aggravation of the poverty situation. Predicting the poverty and food price relationship prior to the simulation was not straightforward. Since households are not only sellers, but also buyers of food products, it was not clear without performing simulation experiments, how their welfare would be affected by an increase in food market prices. In this case, both household incomes and food expenditures would rise. The question that was addressed with the model was whether the related increase in income (Figure 5.18) is sufficient to cover the increase in food expenditure. Aggregate results on simulated poverty statistics (top middle graph from Figure 5.19) show an increase in poverty with increase in food prices. However, these statistics cannot provide a definite answer, since the benefits of net food producers can compensate for the losses of net food consumers. The agent-based nature of the model allows looking further to the household level of aggregation. As an

Figure 5.20: Sensitivity analysis. RPO profit



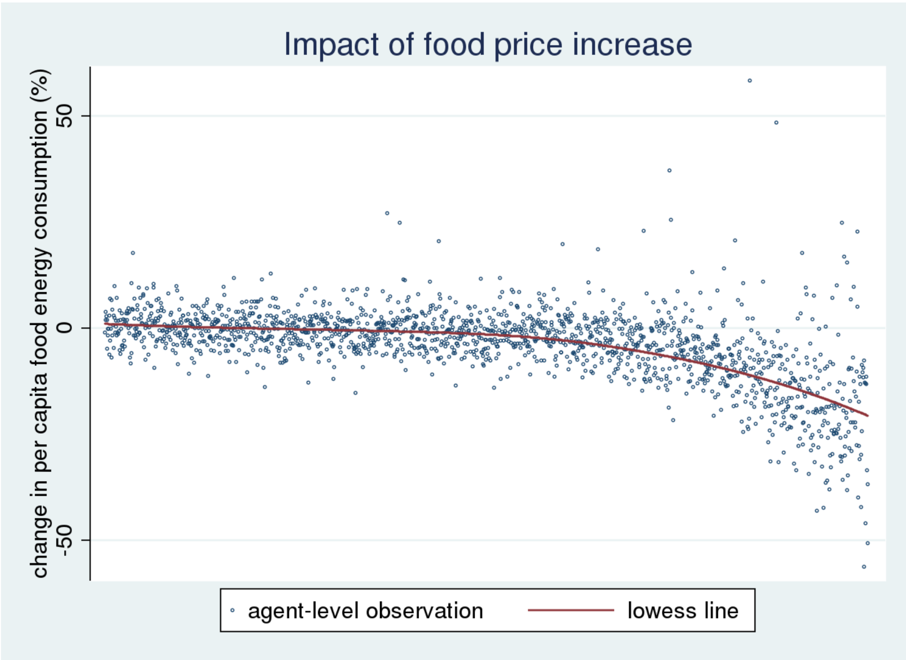
Source: Author, based on MP-MAS simulation results

* results reported as mean effects from 15 period simulation runs

example, Figure 5.21 assesses agent-level impacts of 50% food price increase on household food energy consumption. From this figure it can be seen that large numbers of agents are sensitive to food prices, but the direction of influence can be both positive and negative. The fitted lowess line shows that in terms of per capita food consumption wealthier agents in general suffer more from the food price increase than the poorer.

After inspecting the simulated changes in RPO profit (Figure 5.20) it may be concluded that the simulated size of the profit is highly dependent on coffee prices and coffee yields realized by RPO members. Moreover, as it was discussed before, at a certain level of coffee prices RPO agent become unprofitable. Also, simulation results show that food prices have a strong influence on RPO profit (top middle graph from Figure 5.20). For example, according to model results, the doubling of food prices causes a 32.3% decrease in simulated RPO profit. Such sensitivity of RPO profit with respect to food prices is a reason for the reallocation of agent resources to the production of food crops. With the increase in food price, both net food selling and buying agents focus more on food production, because (i) the selling of food crops become more profitable and (ii) a larger share of agent food requirements must be satisfied by own consumption, since food

Figure 5.21: Impact of food price increase (disaggregated)



Source: Author, based on MP-MAS simulation results

* average result of 15 simulation periods

** agents ranked in ascending order according to income in baseline scenario

purchases become more expensive. Changes in yields of food crops have an effect on simulated RPO profit as well (bottom right graph from Figure 5.20). The direction of the effect is the same as in the case of food prices, but the magnitude is noticeably lower, since the prices of crops bought for consumption are not affected by yields.

Results reported in this section show that agent incomes and poverty statuses are highly dependent on the market prices for coffee. The effectiveness of the RPO agent is largely defined by these prices as well. The analysis showed that in certain price scenarios the RPO agent appears to be unprofitable. Also, agent welfare is highly sensitive with respect to increases in crop yields. Higher coffee yields also translate to higher profits achieved by the RPO agent.

5.2.2 Impact of price variability

As discussed in Section 1.3.3, the price for robusta coffee historically is subject to high variability. Based on the ICO (2013) data on producer prices in Uganda, it can be calculated that in the recent past the nation-wide average price of Ugandan robusta paid to growers varied from 1.96 usd per kg in 1995 to 0.33 usd in 2001 and then back to 1.53 usd in 2008 (prices given in 2010 real terms). Some basic statistics on the price variability can be found in Table 5.1. (In the variability analysis, only prices as far back as1995 were used as before that time there was a different coffee marketing system in Uganda and a period of transition.) The previous section showed how sensitive model households and RPO agents are to long-term changes in coffee price, this section in turn aims to elicit the impact of interannual price variability around the long-term average.

Table 5.1: Variability of producer prices for robusta coffee (1995–2010)

	Mean	Median	Max	Min	Stdev	Iqr	Cv
Price, usd/kg	1.07	1.16	1.96	0.33	0.44	0.65	0.41
First difference effect, usd/kg	-0.05	0.11	0.32	-0.76	0.32	0.44	-5.98

Source: Own calculations from ICO (2013) data
* in 2010 real terms

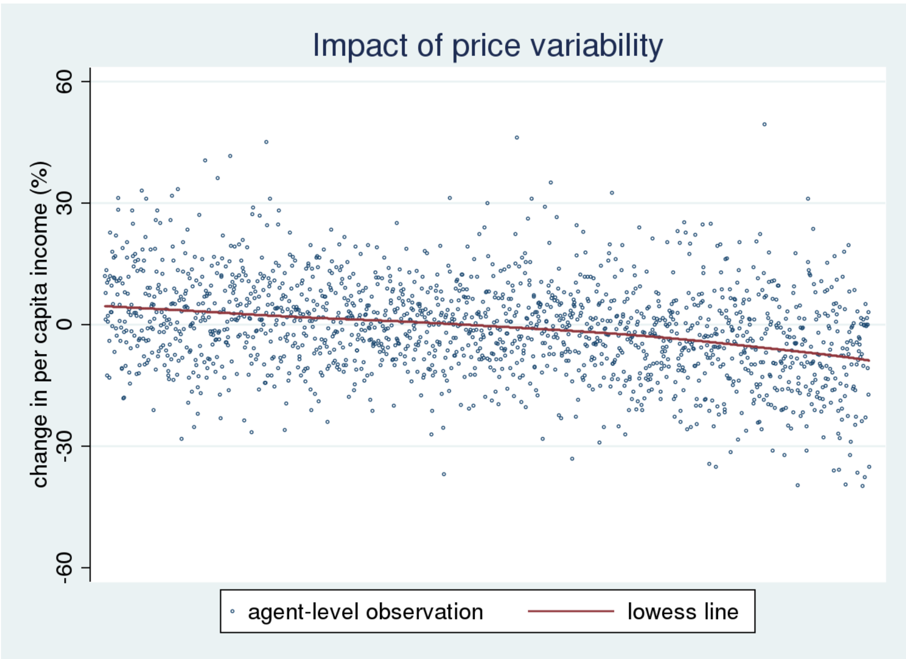
The analysis was undertaken by comparison of results from model simulations performed with (i) variable coffee prices and (ii) prices constant to long-term average. The set up of the experiments required the construction of a price pattern for model input that were consistent with the historically observed variability and price levels in the study area. This issue was resolved by the author as follows:

1. Uganda average nominal producer prices for robusta coffee (reported by ICO (2013) in usd on the annual basis) were converted to real terms of 2010 using U.S. producer price index.
2. Real term prices were normalized by the price of 2010, expressing prices of all years as a share of 2010 price.
3. Study area prices of 2010 (RPO price for FAQ coffee and middlemen price for green coffee) were multiplied with the shares obtained in the previous step, thus providing price projections for the study area for years 1995–2009.
4. Dataset with yearly study area prices for the period 1996–2010 was used to generate the necessary 15 year price patterns for the model input. Generation was done by random resampling with replacement of 1996–2010 prices. Required number of 15-year price patterns was drawn this way.
5. Prices for the run with a constant long-term average price were calculated by taking the averages of the generated price variability patterns.

In order to minimize the effect of random resampling of prices, ”with variability” simulation runs were performed using ten different generated price patterns. Then the results of these ten runs and an additional run with prices constant to long term average (”no variability”) were considered in the analysis.

Figure 5.22 assesses the impact of price variability from the perspective of agent income. The figure plots the relative change in per capita income that every household agent experienced, when facing coffee price variability, in comparison with the situation with constant prices. (For the "with variability" scenario, agent-specific averages over ten conducted runs were taken.) The fitted lowess line shows that in general the effect of price variability is moderate. On average, the variability results in a 2.34% decline in agent income. However, the effect of variability varies across the agents. The aggregate effect of variability is positive for agents with lower incomes, because their benefits in periods with high prices overcompensate the losses in periods with low ones. Periods of high prices open for them additional production and investment opportunities by relaxing the liquidity constraint. For middle income agents, the aggregate effect is almost neutral. Agents do not have a perfect forecast on market prices at the start of the simulation period, when production and investment decisions are taken. Agents make these decision according to their price expectations, which are formed based on agents' past experiences (this mechanism is explained in Section 3.9). Therefore, unlike the case with constant prices, in the situation "with variability" (because of inaccurate expectations) agent decisions may become suboptimal. Suboptimal agent resource allocations that arise with price variability especially harm high income agents: fitted lowess line shows a negative change in simulated income for this group of agents in the aggregate.

Figure 5.22: Impact of price variability (disaggregated)



Source: Author, based on MP-MAS simulation results

* average result of 15 simulation periods

** agents ranked in ascending order according to income in baseline scenario

The variability in coffee prices and, therefore, household incomes may have an effect on the poverty structure. Potentially, a larger share of the population may fall below the poverty line in years when prices are low, thus becoming more vulnerable. The author reviewed the results of MP-MAS simulation to investigate whether the described effect takes place in the model results. Table 5.2 compares poverty estimates obtained from simulation runs with ”constant prices” (no variability) and ”historical variability”. (Again, for ”historical variability” scenario agent-specific averages over multiple runs were taken.) First of all, the table shows that the model simulates high incidences of poverty in the agent population: only 25.04% of agents never experience poverty over the course of simulation even in the scenario with constant coffee prices. The large share of agents (70.87% in ”constant prices” scenario) are near the national poverty line and appear below it in 1–12 out of 15 simulation periods. Only a small portion of agents (4.09% in ”constant prices” scenario) are almost constantly (in 13–15 out of 15 simulation periods) located below the poverty line. With regard to the impact of variability, it can be seen that 0.88% fewer agents appear to never be poor. Agents mostly transit to the next category of poor in 1–3 simulation periods, where the share of agents rises by 1.11%. So, generally speaking, in terms of poverty structure, price variability shifts more agents under the poverty line. But, as the values from Table 5.2 reveal, in general, the simulated magnitude of the variability effect on poverty structure is small. Also, in ‘ the ‘historical variability” scenario, fewer agents appear to be poor in 10–12 and 13–15 simulation periods (15.48% compared to 17.04% in constant price scenario). So the poorest of the poor actually benefit from the variability (Figure 5.22 also supports this conclusion).

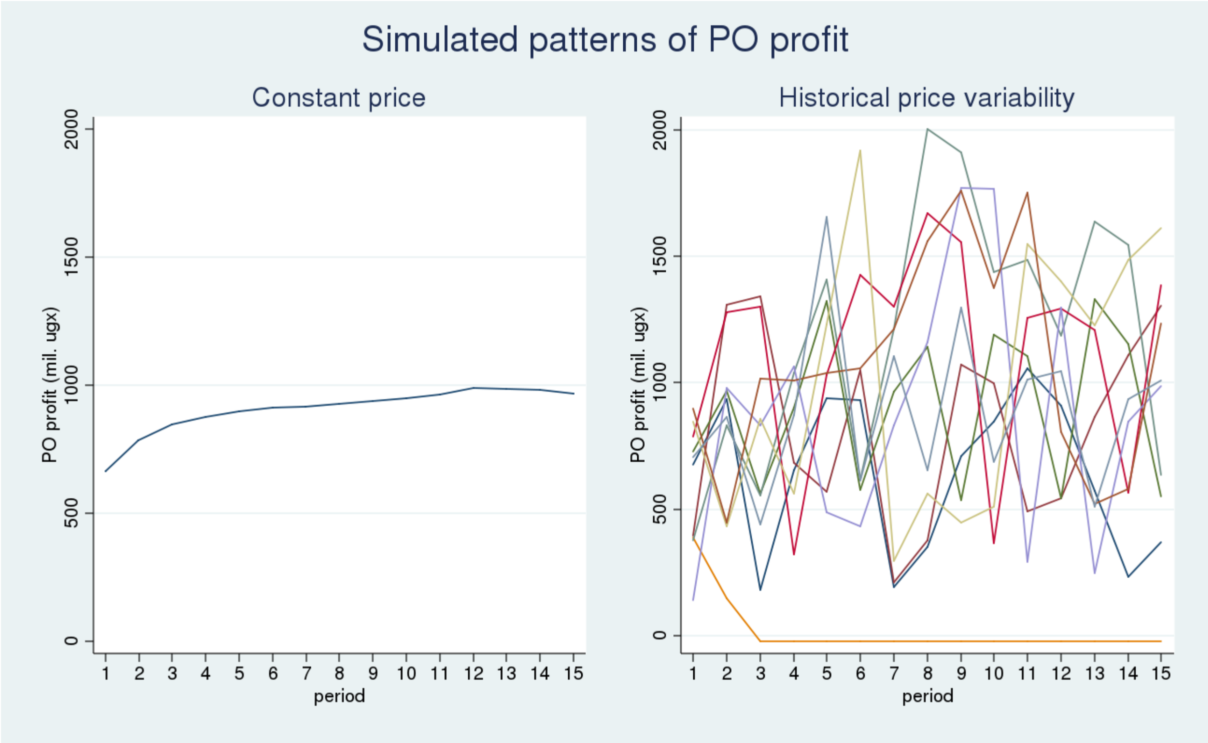
Table 5.2: Impact of price variability. Poverty structure

Periods under	Constant prices		Historical variability	
national poverty line	% of hh agents	cumulative %	% of hh agents	cumulative %
0	25.04	25.04	24.16	24.16
1–3	20.6	45.64	21.71	45.87
4–6	19.39	65.03	20.25	66.12
7–9	17.92	82.95	18.4	84.52
10–12	12.96	95.91	11.94	96.46
13–15	4.09	100	3.54	100

Source: Author, based on MP-MAS simulation results

As the previous section revealed, the simulated size of the RPO profit is highly sensitive to changes in market prices for coffee (see Figures 5.17 and 5.20). Therefore, interannual price fluctuations are expected to cause fluctuations in RPO profit. The simulated dynamics of the RPO profit under generated patterns of ”historical price variability” were compared with its dynamics when facing ”constant price” (see Figure 5.23). The left graph from Figure 5.23 shows that under a constant price level, the development of the RPO profit is smooth. The situation with smooth dynamics of the RPO profit changes when prices vary between years (right graph from Figure 5.23): the simulated profit varies strongly. Interestingly, one of the resampled price trajectories causes a decline in profit, from which after a certain point the RPO agent cannot recover (orange line on the graph) and consequently collapses. The collapse happens since the household agents, after experiencing a certain period of low prices, divert from intensive coffee production and, therefore, do not deliver amounts of coffee to the RPO agent that are sufficient for it to achieve the break-even sales volume.

Figure 5.23: Impact of price variability. RPO profit



Source: Author, based on MP-MAS simulation results

Agents' coffee production and their sales to the RPO are pretty much determined by the formation of their expectations about the future price (mechanism explained in Section 3.9). As Figure E.1 in the Appendix shows, higher values of lambda-parameter for price expectations (i.e. faster updates of agent expectations) lead to a greater number of cases with unsustainable RPOs. The simulated likelihood of RPO failure during the next 15 years under historical price variability in the setting with lambda equal to 0.3 constitutes 0 out of 10 cases, with lambda equal to 0.5 constitutes 1 out of 10, and with lambda equal to 0.7 constitutes 4 out of 10. In other words, the faster the agents adjust their behaviors according to the recently observed prices, the more problematic it is for the RPO to achieve sustainability.

This section revealed that the historically recorded variability in coffee prices is simulated to have impacts on model household and RPO agents. Impacts on simulated incomes of household agents are diverse and can be both positive and negative. The poverty situation is negatively affected by price fluctuations. In general, aggregate impacts in terms of agent incomes and poverty are small. A much larger impact of price variability is simulated at the RPO level. Simulation results show that price variability creates a hazard for the sustainability of the RPO agent. Results show that not only the long-term levels of prices matter, but also the short- and mid-term dynamics.

5.3 Assessing the impacts of RPO-level interventions

By RPO-level interventions the author means the possible changes and improvements in RPO functions that are likely to provide additional benefits to members of RPOs. Simulation experiments with the MP-MAS Uganda model were conducted in order to assess (ex-ante) the impacts of such interventions. The selection of interventions for testing with MP-MAS was done based on the results of focus group meetings with RPO-members organized by the IFPRI–IZA–UHOH project (Dejene-Aredo et al. 2009) and discussions with coffee farmers and key informants conducted by the author (this methodology is explained in the Section 2.1).

Similar to the simulation scenarios in Section 5.1, scenarios reviewed in this section were also run with constant (to the observed levels of 2010) potential yields, market prices and production costs. This isolated intervention effects from changes in the natural and market factors. All system dynamics, i.e. periodic changes in soil properties, population structure, livestock assets, available liquidity and agent expectations were activated in the model.

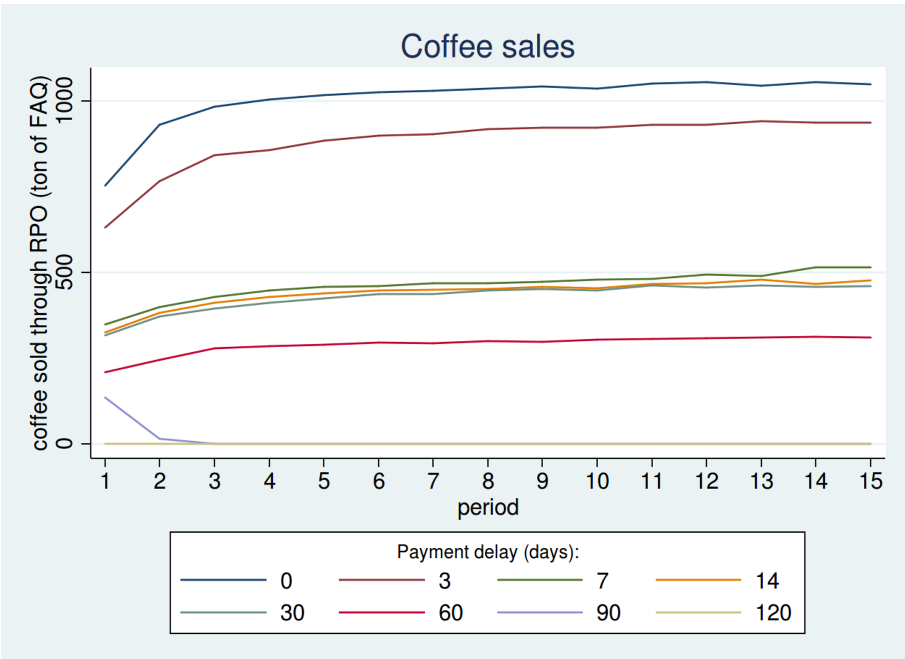
5.3.1 Shortening delays in payments for delivered coffee

Focus group visits of the IFPRI–IZA–UHOH project (Dejene-Aredo et al. 2009) and the author's interviews with key informants (Chapter 2, Latynskiy & Berger (2011)) indicated the importance of timely payments for the production of farmers from the RPO-side. Selling through the RPO-channel implies a certain delay in payment (due to the coordination of collection of individual produce, product transformation and financial operations), while when selling to middlemen coffee growers are paid on the spot. Given the high rates of time preference of farmers in Sub-Saharan African countries (Holden et al. 1998), even small time delays may significantly discount the values of future payments, thus discouraging farmers from using the RPO-channel for sales of their coffee. Shortening the time that farmers have to wait in order to receive their payments from the RPO, may therefore increase their willingness to market their produce through the RPO, increase the RPO turnover and, finally, cause the RPO to benefit from fixed cost degression. This would result in higher producer prices that the RPO could pass on to its member farmers and a higher share of coffee produced in the study area to be sold for these better prices.

As shown earlier in Table 3.20, rates of time preferences with regard to payments for the delivered coffee are expectedly high in the study area. Hence, the simulation model was used to assess the sensitivity of coffee sales volumes and possible delays associated with selling through the RPO-channel. With specific simulation experiments, the author tested the hypothesis that shortening payment delays would have a positive impact on the sales volumes of Kibinge DC and assessed the impacts of this intervention at the household level.

Simulation results suggest that the quantity of coffee sold through the RPO-channel varies significantly depending on the length of the payment delay (see Figure 5.24). The effect is especially prominent when agents are paid on the spot (payment delay equals zero). For example, by paying on the spot, the RPO agent could increase its turnover more than twice, when compared to the situation of baseline seven days delay. As it can also be seen from Figure 5.24, payment delays of four months and longer discourage all RPO member agents from selling through the organization and, therefore, cause the RPO agent to be unable to cover their fixed costs (staff wages, electricity bills, etc.). The follow-up insight is derived from Figure 5.24: shorter payment delays through higher turnover improve the efficiency (cost to sales revenue) ratio of the RPO agent. An increased efficiency ratio certainly implies increased sustainability of the RPO. The amounts of coffee sold through the RPO agent (shown in Figure 5.24) are gradually increasing over time. The growth in RPO profit happens because agents intensify their coffee production and sell more coffee through the RPO. The production intensification is caused by several drivers: (i) an increase in labor availability due to population dynamics (explained earlier in Section 5.1.2), (ii) an increase in livestock keeping (Figure 5.5) provides additional products for own consumption, therefore agents can concentrate more on producing cash crops, (iii) more coffee sold through the RPO results in better selling prices for the agents , which is a further incentive for the intensification of production.

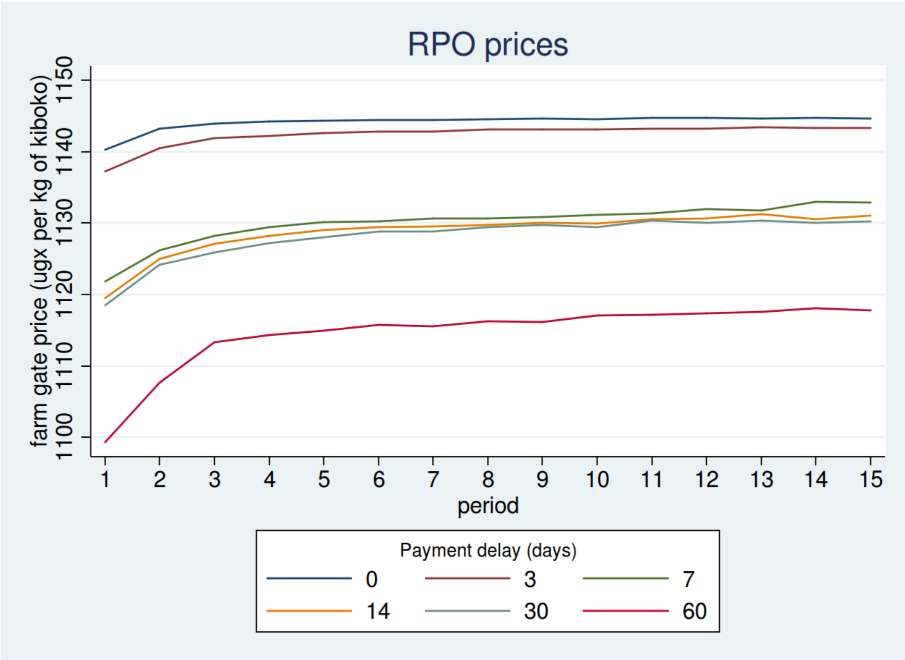
Figure 5.24: Payment delays. Sales of RPO agent



Source: Author, based on MP-MAS simulation results

As Figure 5.25 shows, shortening payment delays translates into an increase in the selling price of RPO member agents. The price effect is relatively small, however, compared with the quantity effect (Figure 5.24). In all cases depicted in Figure 5.25 the RPO agent is able to offer better prices than middlemen traders (the middlemen price is equal to 1000 ugx per kg of kiboko in all scenarios). Therefore, larger quantities being sold through the RPO agent at these better RPO prices together with the price effect from Figure 5.25 condition an increase in the average agent revenue of coffee sales (see Figure 5.26).

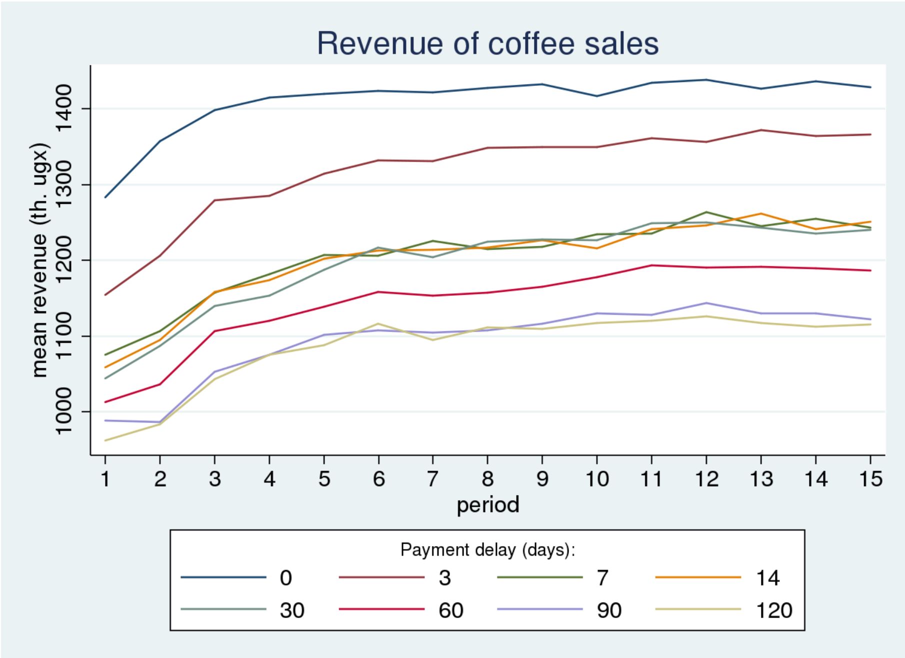
Figure 5.25: Payment delays. RPO prices



Source: Author, based on MP-MAS simulation results

So far, we assessed the effect of the intervention at the levels of the RPO and an average household agent. But the particular strength of MP-MAS is that it is capable of disentangling the effects of interventions at the level of individual household agents. Figure 5.27 demonstrates a disaggregated effect of shortening payment delays on agent sales revenue. The Figure shows simulated changes in revenues from coffee sales of model household agents in the situation, if payment delays observed in IFPRI (2010) were eliminated. One may be surprised by the existence of points lying below 0% grid-line on this graph, but due to the way in which household decision making is implemented in MP-MAS (explained in Section 3.4), an intervention may cause agents to change their whole production and consumption patterns. Therefore, some agents may actually decide to produce less coffee when facing an intervention. (For example, higher revenue in the earlier periods of simulation may allow agents to buy a cow, for which they will then allocate labor previously used for coffee.) In addition, minor agent-level random events (e.g. definition of sexes of newborn livestock offspring) that cannot be controlled explicitly cause variations in agent trajectories. The fitted lowess line suggests that, in general, the impact

Figure 5.26: Payment delays. Sales revenue



Source: Author, based on MP-MAS simulation results

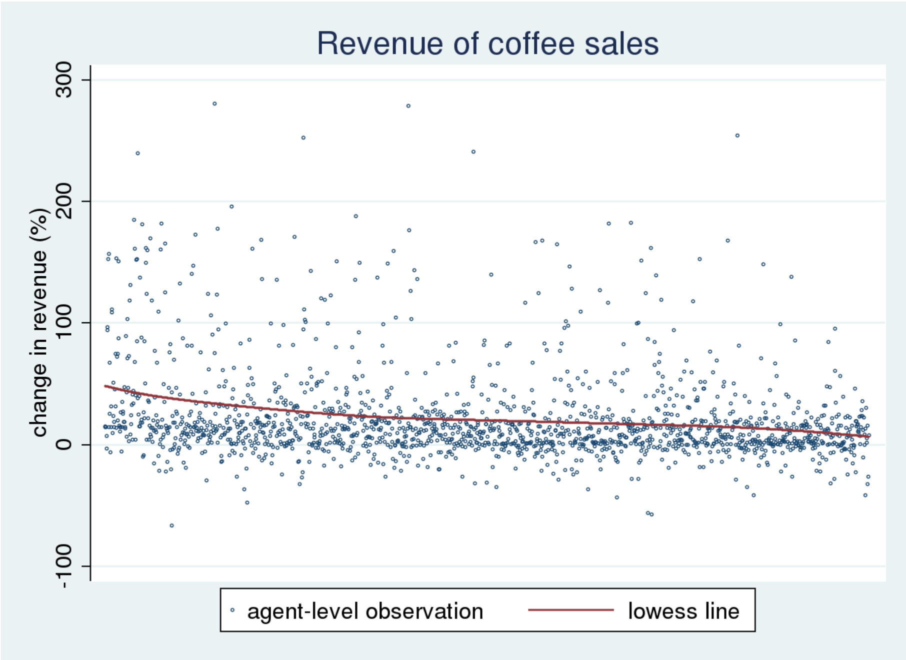
on agent revenue is positive and its magnitude is higher for agents who are smaller sellers. A positive impact on sales revenue results in higher cash earnings of household agents. Figure 5.28 compares simulated agent cash earnings in situations with current delays and with payments organized on the spot.

Since the sale of coffee is one of the main income sources for households and model agents in the study area , a positive income effect is also expected. Indeed, MP-MAS simulates an increase in mean per capita income by 32,975 ugx or 4.25% (on average over 15 periods) caused by the introduction of payment on the spot (Figure 5.29).

The high sensitivity to payment delays in MP-MAS can be attributed to both the high time preferences of farm agents (see Table 3.20), and the small margins of local traders (Dejene-Aredo et al. 2009, IFPRI 2010) (the prices these traders offer are highly competitive). The simulation results are also in line with expert opinions gathered by the author during his research in Uganda: several experts pointed out the importance of the provision of on the spot payment for the successful performance of RPOs (Chapter 2, Latynskiy & Berger (2011)).

Simulation results reported in this section so far show that shortening the delays of payments to RPO members is beneficial for the RPO agent as well as for the household agents. Table 5.3 reports the results of cost efficiency analysis of implementing the development intervention associated with the provision of on-spot payments for the members of the RPO. The analysis was done based on the output of the simulation model. Simulated change in household income was considered as benefit. As implementation cost the estimated cost of provision of the simulated

Figure 5.27: Payment delays. Sales revenue (disaggregated)

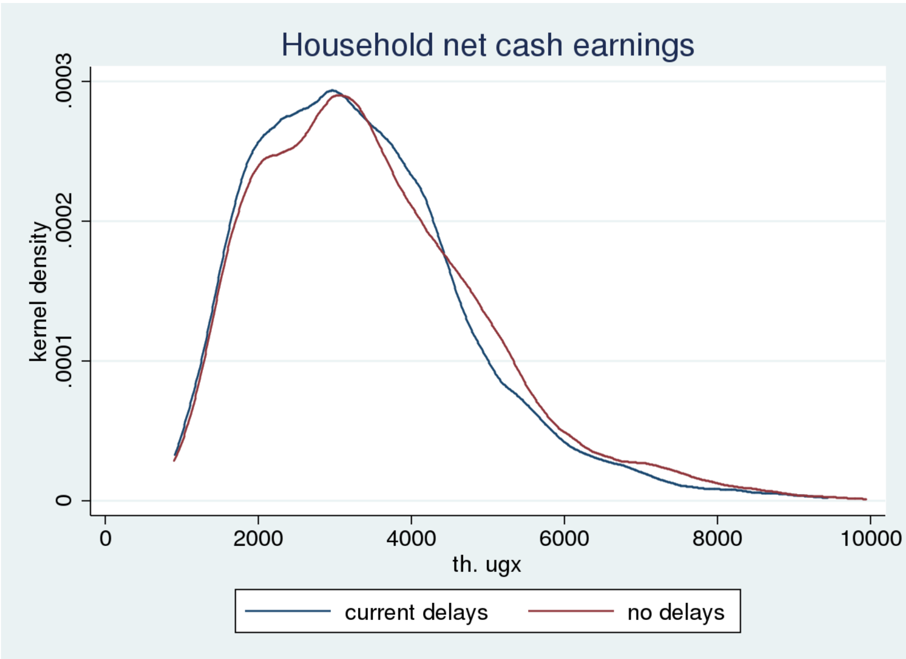


Source: Author, based on MP-MAS simulation results

* average result of 15 simulation periods

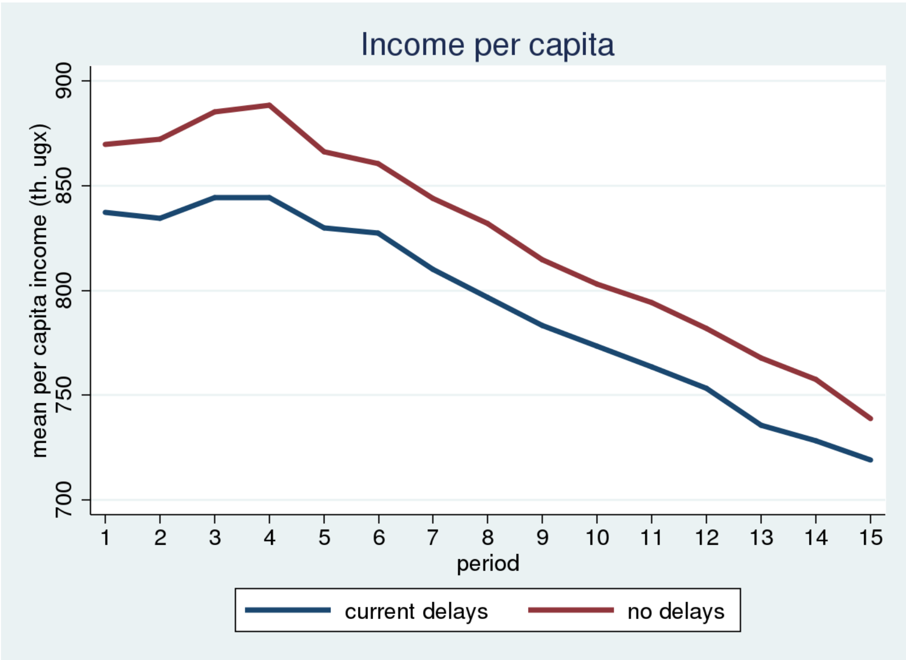
** agents ranked in ascending order according to revenue in baseline scenario

Figure 5.28: Payment delays. Household cash earnings



Source: Author, based on MP-MAS simulation results

Figure 5.29: Payment delays. Per capita income



Source: Author, based on MP-MAS simulation results

working capital requirement was taken. The calculation was done using the real market interest rate for borrowed capital provided in World Bank (2012): 11.48% percent. The working capital requirement was simulated based on the Kibinge DC sales schedule recorded in IFPRI (2010) and assuming a coverage ratio of RPO liabilities to members equal to 1.5. As key indicators of efficiency, Table 5.3 provides equivalent annual net benefit (EANB), benefit-cost ratio (BCR) and economic rate of return (ERR). In addition, the table quantifies previously displayed intervention effects in terms of household income and revenue as well as RPO turnover and profit.

Table 5.3: On-spot payments. Results of cost efficiency analysis

EANB, mil. ugx	BCR	ERR, %	Δ* Household income, %	Δ Household revenue, %	Δ RPO turnover, %	Δ RPO profit, %
174.86	2.54	29.21	4.25	17.20	119.13	121.88

Source: Author, based on MP-MAS simulation results
* relative difference with baseline

5.3.2 Producer motivation schemes

In order to encourage farmers to sell more output through the RPO-channel and, therefore, exploit fixed cost degression and increase the efficiency ratio of the organization, the administration of Kibinge DC considered experimenting with various monetary motivation schemes for its members (Chapter 2, Latynskiy & Berger (2011)). Two mechanisms of implementation of such schemes were considered: (i) a one-time bonus and (ii) a proportional premium. The one-time bonus is paid once an RPO-member sells more than a certain quantity (Q) of coffee through the RPO during a given time period, while the proportional premium is paid for every kg above Q. MP-MAS Uganda application has been used as a tool for the analysis of possible motivation effects and especially to answer the question of how far the various schemes might encourage farmers to deliver their coffee harvest to the RPO. MP-MAS results may inform the design of motivation schemes from different perspectives, for example RPO turnover, RPO budgeting, and member sales revenues. The implementation of motivation payments in MILPs of model household and RPO agents are presented in the Appendix in Tables B.7 and B.16, respectively.

In this section, the example of applying MP-MAS for the analysis of motivation schemes is provided. This is done by comparing the results from the baseline simulation described in Section 5.1 (all model dynamics turned on) with the results of test simulations, in each of which one motivation alternative was implemented. Scenario design assumed the motivation payments to be fully financed from the DC budget (i.e. not an external financing) and to be paid on the delivery date. In this setting the payments are aimed to encourage agents for selling through the RPO-channel amounts greater than the specified quantity requirement Q. They may also stimulate agents to produce more coffee in general.

The main part of this study illustrates the assessment of five different motivation schemes (M1,..., M5), which were compared with the model baseline (B). Set-ups of these selected schemes are described in Table 5.4. Other optional set-ups with MP-MAS Uganda model (40 in total) were also tested. The compilation of the respective results is provided in appendices (Table E.1).

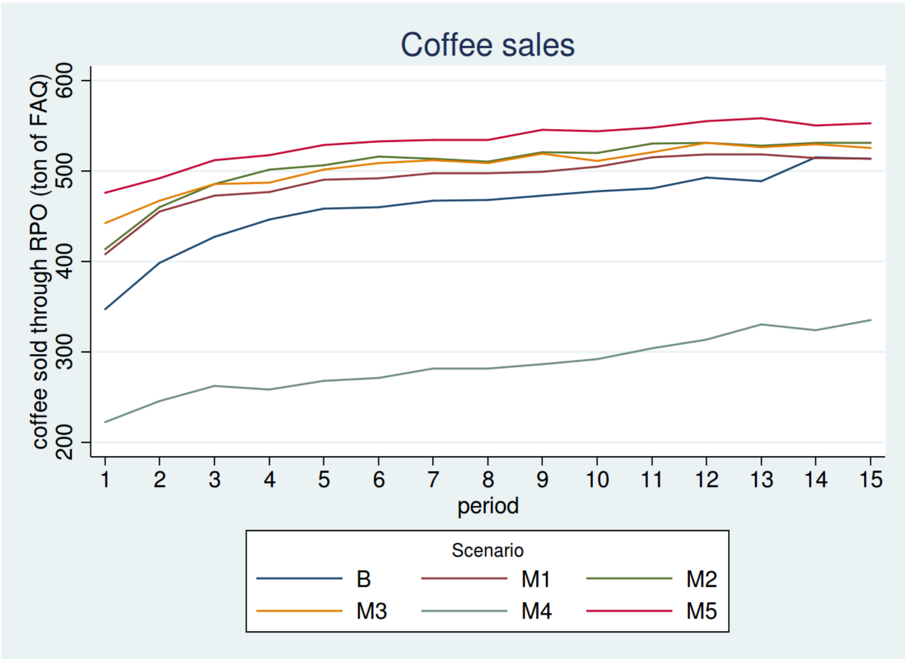
Table 5.4: Selected motivation schemes

Scenario	Qualification requirement, kg	Proportional premium, ugx per kg	One-time bonus, ugx
B	–	0	0
M1	250	100	0
M2	250	0	25,000
M3	250	50	5,000
M4	500	200	0
M5	500	50	50,000

Source: Author, based on MP-MAS simulation input

As was assessed with MP-MAS, the motivation payments for higher quantities may have not only positive, but also negative net effects on RPO agent turnover. This happens, when agents that are targeted by the motivation scheme increase their sales to a smaller extent than those agents on whose expense the scheme is actually financed. Under the self-financing condition of motivation payments, which was implemented in the scenarios, the motivation payments are subtracted from the RPO profit, i.e. reduce regular payments to agents. Figure 5.30 displays the turnover of the RPO agent for the selected scenarios. From this figure it can be seen that options M1, M2, M3 and M5 have a noticeable positive net effect. However, in comparison with the improvement discussed in the previous section (compare Figure 5.30 and Figure 5.24) the effect is much smaller. According to Figure 5.30, option M4 has a substantial negative RPO-level impact. Option M4 discourages agents to such an extent that the amount of coffee sold through the RPO in this case is 38.2% lower than in the baseline scenario. At first glance this negatively affecting option is not that different from the others in terms of the set-up (Table 5.4).

Figure 5.30: Motivation schemes. Sales of RPO agent

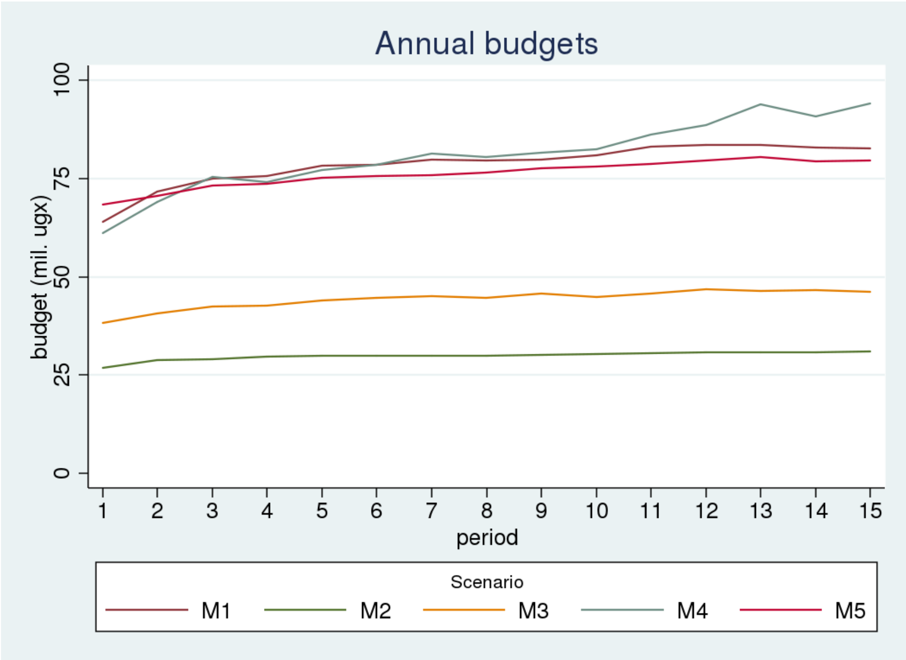


Source: Author, based on MP-MAS simulation results

The sum of the product quantities that individual producers deliver to RPOs in the future time periods is uncertain, and, therefore, the amount of premiums and bonuses that would have to be paid is uncertain as well. MP-MAS Uganda application has been used for ex-ante estimation of the annual budgets of the motivation schemes. The execution of higher budgets is likely to set higher liquidity requirements, therefore, it is important to have precautionary information on this topic. Figure 5.31 shows the estimated budgets for the selected motivation schemes.

Figure 5.32 shows the effect of the selected motivation schemes on agent revenue from coffee sales. The figure shows that schemes M1, M2, M3 and M5 have no significant effect on the mean revenue. So the small positive RPO-level impact observed in Figure 5.30 did not create any considerable difference in terms of the mean agent revenue. However, negative impacts of option M4 translated into a sharp decline in the agent revenue. Simulated effects of all tested motivation schemes in terms of household agent revenue and income, as well as RPO turnover

Figure 5.31: Motivation schemes. Annual budgets



Source: Author, based on MP-MAS simulation results

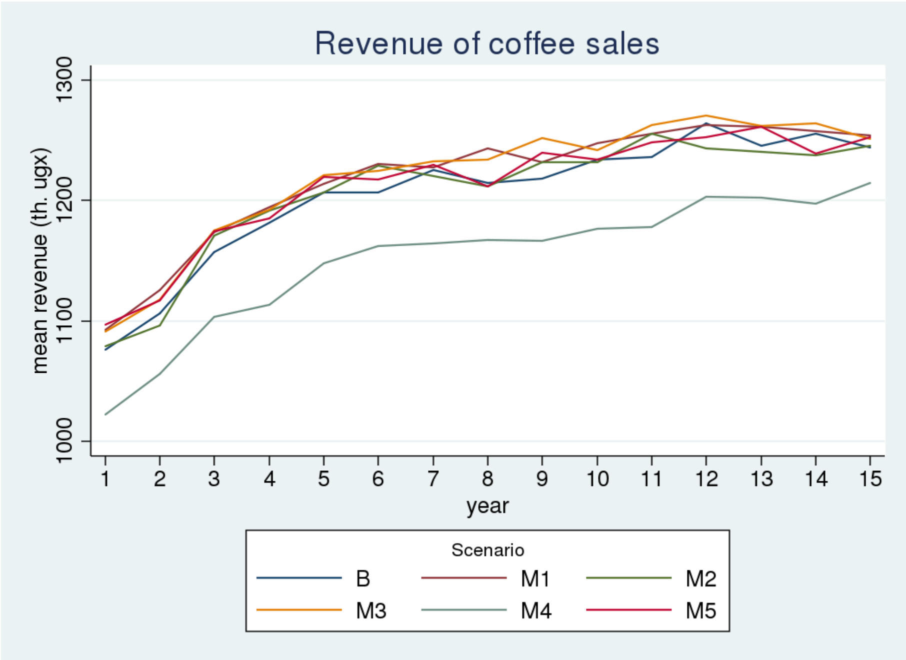
and profit are quantified in Table E.1 of the Appendix.

Figure 5.33 displays disaggregated effects on agent sales revenue. The figure reports the relative change in revenue from coffee sales of household agents when motivation option M3 is applied, compared with the baseline (B). From the figure it can be seen that the tested intervention is expected to have diverse effects on the agent revenue. Although the mean effect of scheme application (see Figure 5.30) is small, we can see that a number of individual agents are significantly affected. As the fitted lowess line shows, on aggregate the model simulates a slightly positive impact for smaller producers.

The results reported in this section indicate that the various schemes considered for producer motivation are simulated to have contrasting effects. Some options stimulate an increase in the simulated turnover of the RPO agent, which in turn increases the simulated profit margin of this agent. On the other hand, some options may have a discouraging effect on household agents as a whole, which results in the reduction of sales volumes of the RPO agent.

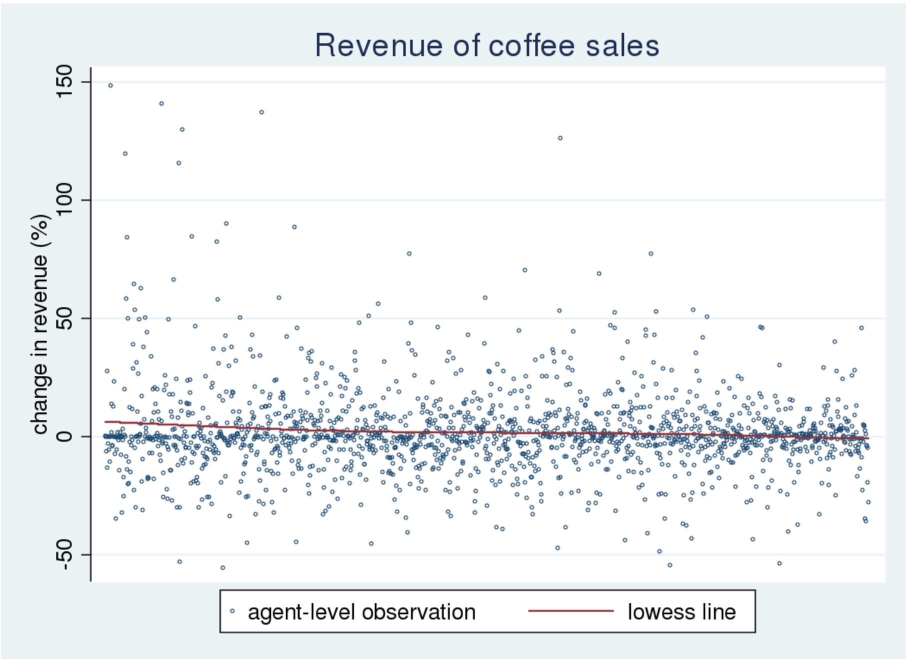
As in the previous section, based on the simulation output, the cost efficiency analysis of implementing the development intervention was performed. Table 5.5 shows the results of the analysis for the scheme with the highest EANB calculated (scenario M15). Since the number and size of payments to be made may be highly variable, the working capital requirement was simulated assuming a coverage ratio of 2.5.

Figure 5.32: Motivation schemes. Sales revenue



Source: Author, based on MP-MAS simulation results

Figure 5.33: Motivation schemes. Sales revenue (disaggregated)



Source: Author, based on MP-MAS simulation results

* average result of 15 simulation periods

** agents ranked in ascending order according to revenue in baseline scenario

Table 5.5: Motivation of large sellers. Results of cost efficiency analysis

EANB, mil. ugx	BCR	ERR, %	Δ* Household income, %	Δ Household revenue, %	Δ RPO turnover, %	Δ RPO profit, %
28.29	7.99	91.74	0.46	1.18	12.58	8.92

Source: Author, based on MP-MAS simulation results
* relative difference with baseline

5.3.3 Group certification

The market for certified coffee is perceived as a promising opportunity for coffee growers, as it may offer higher prices in comparison with the market for conventional coffee (e.g. NUCAFE (2012) reported price premiums of 0.07–0.22 usd per kg of robusta coffee that UTZ CERTIFIED producers receive in Uganda). However, in order to reach the markets of certified coffee, smallholder farmers, because of their low individual production volumes, have to unite and get involved in certification as a group. Therefore, Kibinge DC is engaged in group certification with UTZ CERTIFIED starting from 2008 (NUCAFE 2008, Verkaart 2008). Unfortunately, going through the process of group certification in coffee RPOs is costly. It includes direct costs associated with internal and external audits, farmer training sessions, provision of quality inputs, and opportunity costs associated with compliance with restrictions of envisaged production practices. Given the reluctance of RPOs to make long-term investments (Nilsson 2001), the initialization of a certification process is often done with the help of external funding. For example, the initial costs for UTZ certification in Kibinge DC were fully covered by NUCAFE and various NGOs (NUCAFE 2008, Verkaart 2008). It is interesting to see, whether such certification attempts could be sustained over time, considering annual running costs of certification schemes, and whether the DC could potentially repay the investment costs.

MP-MAS marketing and RPO-agent modules developed in this research (described in Section 3.10) allow for the capture of certification-related activities (example in Table B.16). Therefore, the author of this thesis constructed a set of modeling experiments for the simulation of group certification with the example of UTZ certification in Kibinge DC. Accordingly, additional data related to the costs of UTZ certification in Kibinge DC were requested from the producer union (NUCAFE 2008, 2012) and used to parameterize the certification process in MP-MAS Uganda. This section demonstrates how MP-MAS Uganda was applied for the assessment of group certification and presents the results of the assessment.

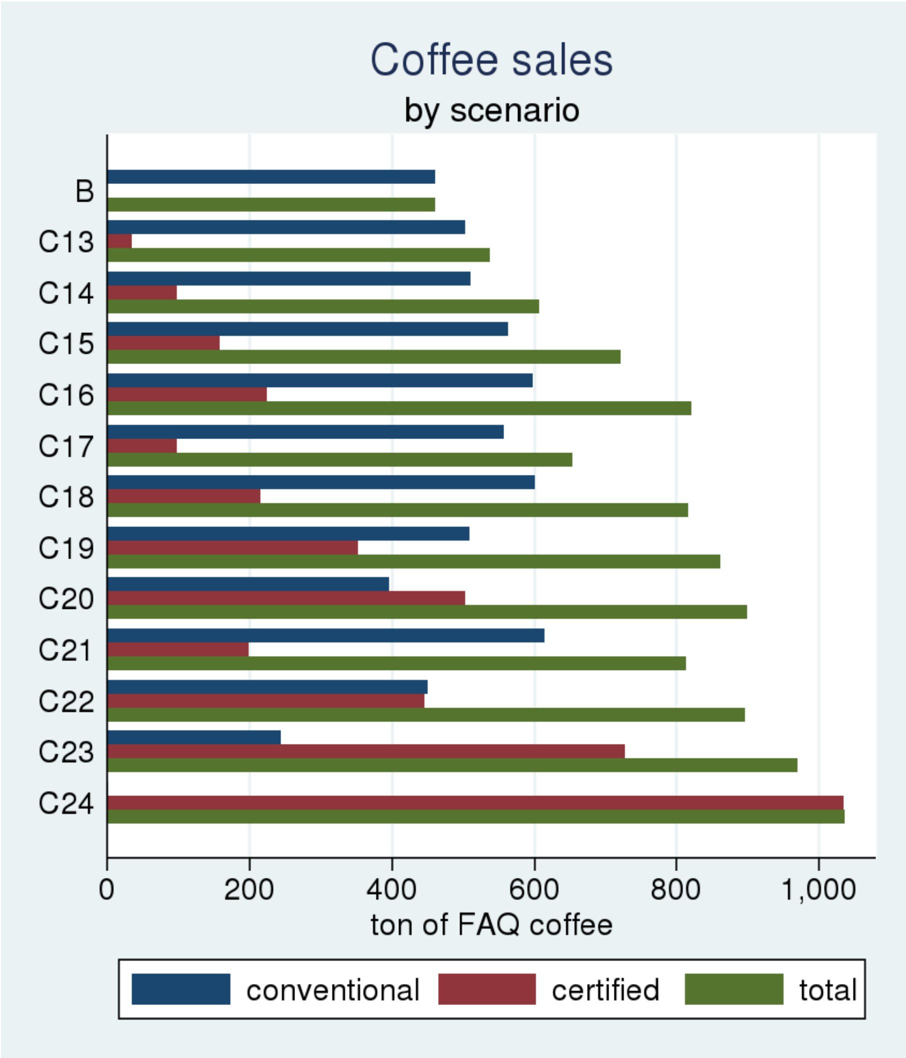
For the group certification analysis, 96 simulation scenarios (Table E.2) were created that reflect different situations and set-ups of UTZ group certification, plus the baseline scenario with no certification happening. The scenarios differ by costs that the RPO agent has to bear. Scenarios C1–C12 have no costs for the RPO, which means that all costs are covered by external sources (e.g. government funding, NGOs etc.). Scenarios C13–C24 reflect the current financing of certification program in Kibinge DC, in which the RPO covers only the running costs of certification, while the costs of initial investments are funded externally. In scenarios C25–C96, the RPO has to repay the initial investment as well: in C25–C48 with zero interest rate, in C49–C72 with risk-free interest rate, and in C73–C96 with market interest rate. Furthermore, the scenarios with initial investment repayment (C25–C96) vary by the length of reinvestment period (i.e. how often the initial investment has to be repeated). The share of RPO members included in the certification program also varies, as does the share of coffee produce that members are permitted to certify.

When analyzing the simulation experiments, the first outcome that was reviewed is whether the certification enterprise of the RPO agent was simulated to be sustainable in the long run (see the second column of Table E.3 of the Appendix). Sustainability there implies sustained certification after 15th period of the simulation. The experiments suggest sustainability and, therefore, positive profitability in all set-ups, where the RPO agent does not have to repay the initial investment (C1-C24). In scenarios with the repayment of investment costs (C25–C96), there are scenarios in which negative profitability occurs: these are the scenarios in which agents are only able to certify a small share of their produce (e.g. C25, C29, C49 etc.). Due to the negative profitability, certification is discontinued (i.e. is not sustainable).

As the next step, let us review more closely the scenarios reflecting the current certification effort of Kibinge DC, where 22% of all members are certified and only the running costs have to be covered by the RPO agent and its members. This part of the analysis refers to scenarios C13–C24 and the baseline scenario (B). Figure 5.34 shows coffee sales of the RPO agent in physical terms. A comparison of the results from scenarios C13–C16 (current share of members involved; 25%, 75%, 50% or 100% of produce can be certified) tells that improving the share of certified coffee in the total amount of produce of individual household agents also has an amplifying effect on the total amount of sales done through the RPO-channel. Comparing Figure 5.34 outcomes of C14, C18 and C22 (50% of produce certified; current, half or full share of population involved) shows that including more members in the certification program also is simulated to increase the sales of the RPO agent in physical terms (despite the increasing running costs). In general, engagement in UTZ certification shows a high potential for attracting members to the RPO selling channel: in the most unrestricted case (C24) the turnover of the RPO agent rises by 135.1% in comparison to the baseline (B).

Simulation results demonstrate that household agents prefer to sell their coffee through the RPO agent as certified produce. Such preference is caused by the added value of coffee from certification (see Figures 5.35 and 5.36, and Table E.3 of the Appendix). In the scenarios reflecting the current certification program (C13–C24), this value is substantially higher than the price of conventional coffee (the price in the baseline scenario is 2,486 ugx per kg of FAQ), therefore, agents prefer to bear the certification-related costs, which in this case are the individual and organizational running costs of the certification. Simulated added values (Figures 5.35 and 5.36)

Figure 5.34: Group certification. RPO sales

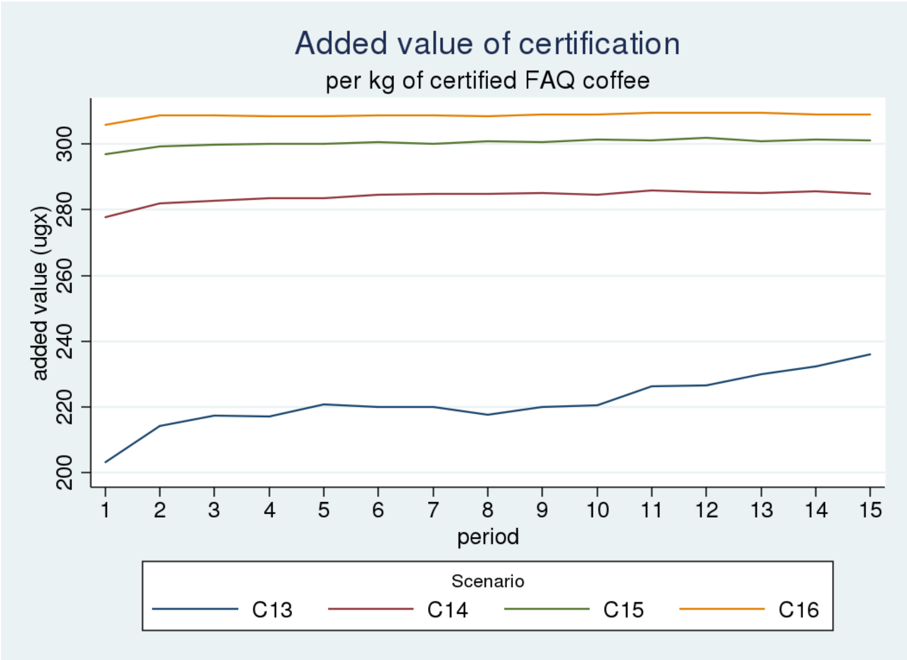


Source: Author, based on MP-MAS simulation results
* average result of 15 simulation periods

increase with larger member inclusion and improvement of certified coffee share as well.

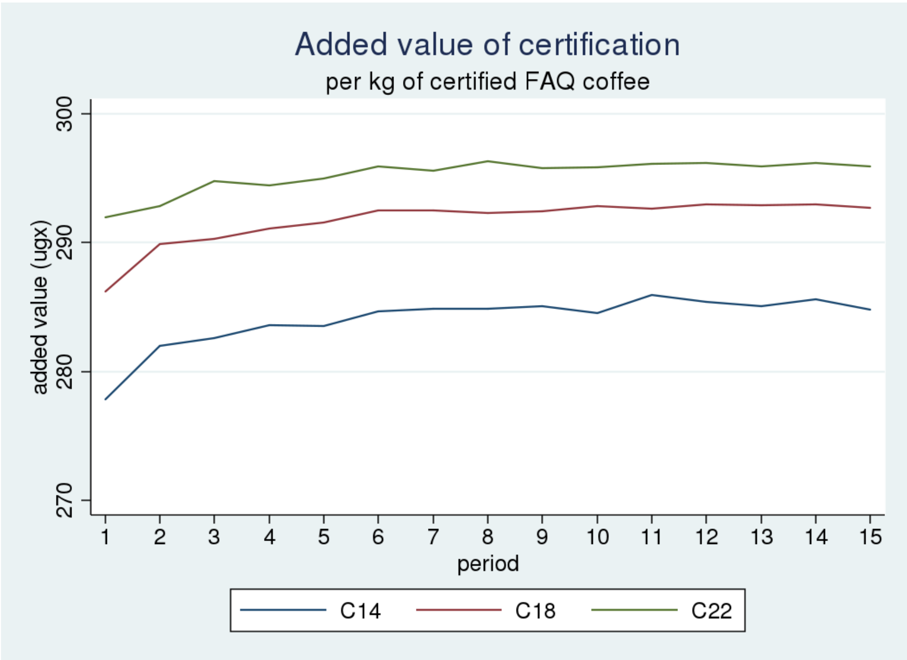
Figure 5.37 displays income effects caused by the certification schemes with current member inclusion (22.4% of members). This figure compares mean per capita incomes simulated in scenarios C13–C16 (current share of members involved; 25%, 75%, 50% or 100% of produce can be certified) with a baseline. The simulation experiments show a moderate aggregate impact of the current certification program on simulated per capita incomes of model agents. Even if agents are able to certify 100% of their coffee (C16), the mean income lies at a rather modest 4.0% above the baseline. If the share of certified coffee falls to 50% (C14), then the mean income exceeds the baseline by only 1.6%. However, the potential impact of certification is much higher. In order to assess the potential impact, Table 5.38 illustrates the development of per capita income when all members are involved in certification and all coffee produce is able

Figure 5.35: Group certification. Added value (1)



Source: Author, based on MP-MAS simulation results

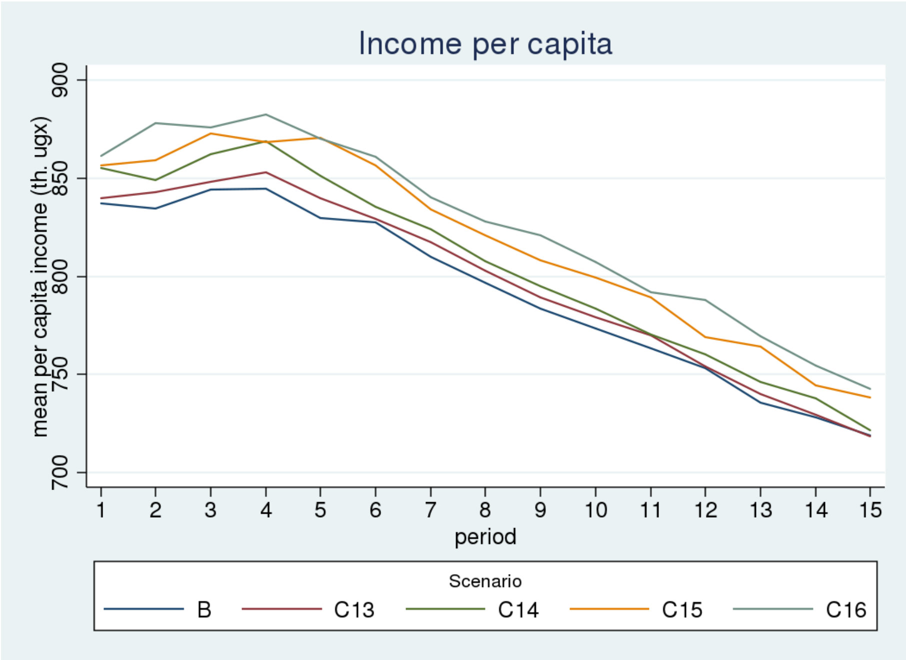
Figure 5.36: Group certification. Added value (2)



Source: Author, based on MP-MAS simulation results

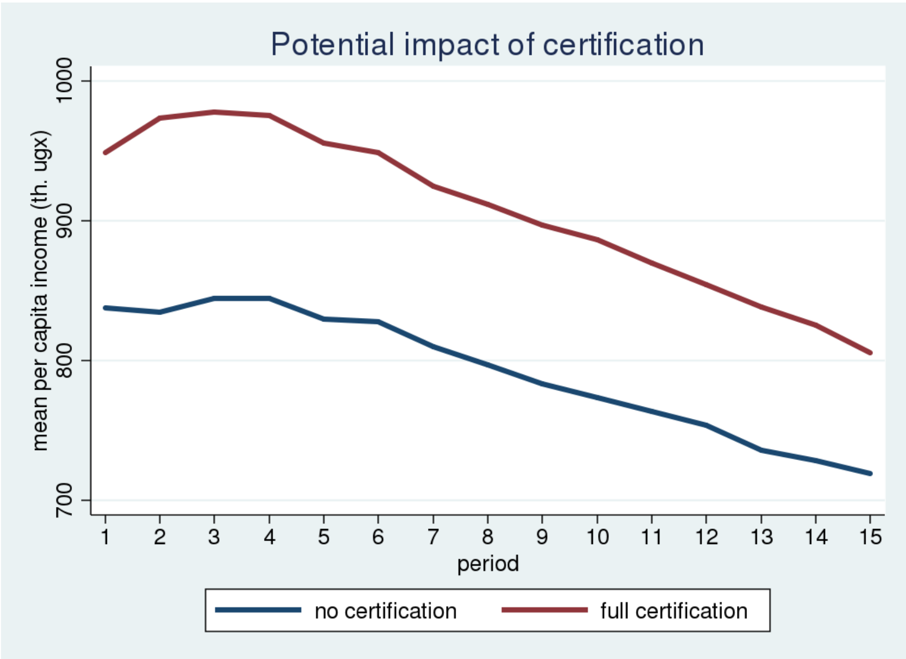
to qualify for certification (C24). In this case, the mean impact of certification constitutes 14.5% of the baseline per capita income. Average income effects for all tested certification set ups are reported in Table E.3 of the Appendix.

Figure 5.37: Group certification. Income effect



Source: Author, based on MP-MAS simulation results

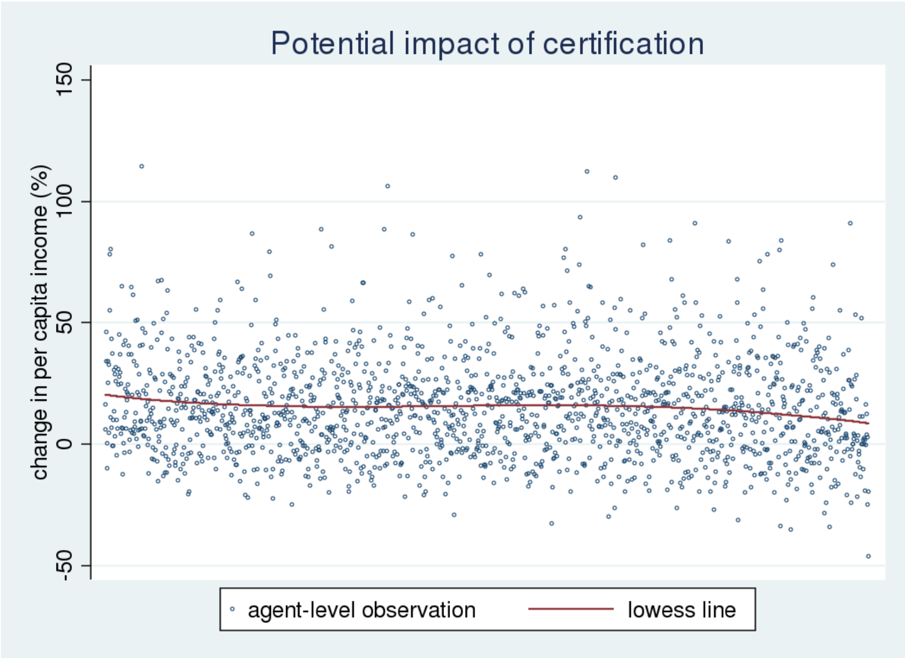
Figure 5.38: Group certification. Potential impact



Source: Author, based on MP-MAS simulation results

Figure 5.39 disaggregates the potential impact of certification in terms of per capita income. This figure displays simulated income changes of all household agents. From the figure it can be seen that the majority of agents benefit from the certification. The positive income effect is significant across all income sizes. The fitted lowess line suggests a larger relative income change for the agents with the lowest baseline income, and a smaller change for the agents with highest baseline income.

Figure 5.39: Group certification. Potential impact (disaggregated)



Source: Author, based on MP-MAS simulation results
* average result of 15 simulation periods
** agents ranked in ascending order according to baseline per capita income

In general, the simulation results show that engagement in UTZ certification gives the RPO agent the potential to attract members to the RPO-sales channel and, therefore, increase the turnover of the RPO agent, which also increases the profit margin of the agent. In a number of scenarios, certification was simulated to add considerable value to the end product of the RPO agent and, therefore, increase the incomes of farm agents. Inclusion of more agents and increasing the share of coffee they can certify were simulated to increase the net effects of the certification program.

Let us again calculate the cost efficiency based on the results that the simulation model produced. Table 5.6 reports the calculated efficiency indicators for six of the tested implementations of the certification program. All scenarios in the table refer to the situation in which the initial investment into certification has to be repeated every five years. In scenario set ups of ongoing certification, agents have to finance only the running costs of certification, while investment costs are funded externally. In scenarios with full self-financing, agents participating in certification also have to repay the initial investment financed by means of a fixed interest rate loan provided with market interest. Both ongoing and self-financing set ups were simulated with the current member inclusion into the certification program (22.4% of agent population) and with the alternative ”improved” inclusion (50% of agent population). In addition, for both programs the maximum potential effect of certification was simulated by running the model with all agents certified at the beginning of simulation. Also, maximum potential scenarios have no restriction on the amount of produce that agents can certify, while in other scenarios in Table 5.6 each agent can certify a maximum of 50% of its produce.

Table 5.6: UTZ certification. Results of cost efficiency analysis

Description	Scenario code	EANB, mil. ugx	BCR	ERR, %	Δ* Household income, %	Sustainability
Ongoing program	C14	124.31	6.74	229.88	1.99	yes
Ongoing program, Improved inclusion	C18	293.56	9.86	358.46	4.57	yes
Ongoing program, Maximum potential	C24	955.67	16.82	647.68	14.54	yes
Full self-financing, Current inclusion	C74	-3.36	0.33	-29.31	0.05	no
Full self-financing, Improved inclusion	C78	198.53	7.54	266.60	2.92	yes
Full self-financing, Maximum potential	C84	911.36	16.84	645.68	13.45	yes

Source: Author, based on MP-MAS simulation results

* relative difference with baseline

Chapter 6

Conclusions and discussion

The results of the literature reviews, participatory assessments, and simulation modeling led to several conclusions and practical recommendations for policy-makers, administrative bodies, researchers, and RPO leaders and members discussed in this chapter. Possible extensions and further uses of the model are also explored.

6.1 Summary of the subjective experience

In this section the author communicates and discusses the important aspects of his subjective experience and insights concerning the organization of the research.

6.1.1 Evaluation of the methodology

In Section 1.2 the potential benefits of the chosen methodological approaches (participatory assessment and agent-based micro-simulation) were discussed. In this section, conclusions are made about the applicability and usability of the applied methodology ex-post. The advantages of the combination of methodologies used in this research are explained, as are the disadvantages and limitations.

Advantages and achievements

- The combination of qualitative and quantitative methods applied in this research provided thorough insight into different aspects of the study. Using both types of research methods facilitated the understanding of RPO and agriculture in Uganda. The results of the literature review, participatory assessments and simulation modeling complemented each other and highlighted different aspects of RPO and provided different perspectives for the analysis. The interactive sessions with stakeholders and key informant interviews served as a base for the model development and the design of simulation scenarios. This composition of several methods enriched and deepened the research outcomes.

- Visualization of stakeholder-provided information by means of collaborative mapping facilitated stakeholder involvement and improved the quality of the dialogue between the respondents and the researcher. The application of the Net-map tool, which is easy and inexpensive, was clearly beneficial for the research.
- MP-MAS framework allowed for the integration of different factors that influence farm decision-making with sub-models of biological and demographic processes in one simulation model. The flexible nature of the framework enabled its extension with household decisions on product marketing and household time preferences. Thereafter, the incorporation of RPO-agent type to the model was accomplished. The resulting MAS is a bio-economic model that systematically reflects numerous properties of the studied real-world system, such as the heterogeneous population of farm households, different farm enterprises of crop and livestock production, biophysical properties of the landscape, household consumption preferences, organizations of coffee producers, etc. Thus, a holistic integration of several modeling concepts was achieved.
- The simulation modeling approach made it possible to assess not only the current, but also alternative states of the studied system. Consequently, investigation of the system under current conditions was followed by a comprehensive testing in different parameter settings (i.e. scenarios).
- The dynamic implementation of the model considered the development of agent and environment characteristics over time. This allowed tracing the long-run trajectories of selected indicators. For example, this added the dimension of RPO sustainability to the analysis.
- The highly disaggregated agent-based nature of the model implied an extra level of analysis (i.e. agent level in addition to system level). Both levels were considered in the model calibration, which improved the model's quality and, therefore, its validity. Disaggregation of simulation results, in turn, provided additional knowledge about the system.
- The one-to-one correspondence between model agents and real-world objects simplified the interpretation of the model results. E.g. effects on incomes, food consumption, RPO profit, etc. could be directly located and assessed. There was no need for additional translation of model outcomes, which is often required in the case of equation-based models.
- Since the MP-MAS software package is a supported freeware product, there is a large potential for reusability of the MP-MAS Uganda application. It can be further used either by the author or other modelers with or without extensions and modifications. For example, one could perform simulation experiments to estimate the impact of improved coffee planting material, once the relevant data are available.

Disadvantages and limitations

- The MP-approach of modeling farm decision making demanded the parameterization of all possible decision alternatives. Therefore, a profound knowledge of the local production system had to be obtained prior to the model construction. Consequently, a large amount of literature and data had to be searched and processed for setting up the model. The extensive size of the MP decision problem sometimes made it difficult to check the correctness of the model set up. These aspects of complexity considerably slowed down the research progress.

- Since the model was constructed based on the empirical data from one sub-county, there is a study area bias in the results. Therefore, one should consider the specifics of the case study reported in this dissertation before making any inferences for other farms and RPO.
- The assessment of social and advocacy functions, for example, such as capacity building or political empowerment, was not incorporated into the applied research methodology. Also, the possible indirect effects on non-member households were not addressed in this research.
- The influence of management capacity on the performance of the RPO and the associated management risks are not considered in the MP-MAS Uganda application. However, the key informants distinguished it as an influential determinant of RPO efficiency (see Chapter 2, Latynskiy & Berger (2011)). The importance of this factor is also often emphasized in the literature (Ragasa & Golan 2012).

6.1.2 Reliability of statistical data in least-developed countries

The simulation model constructed for this study largely relied on statistical data from national surveys. This data was used during both model parameterization and calibration. The quality of the data on agricultural production in such surveys is typically weak (Deininger et al. 2012, World Bank 2010). Lack of appropriate capacity, funding and institutional coordination lead to deterioration in quality of data collected by the national statistical services of developing countries (World Bank 2010). Statistical data from 19 SSA countries, including Uganda, received the lowest aggregate quality grade of D in PWT (2008), the rest of the 24 SSA countries received the second lowest C. Thus, significant challenges were faced when working with the raw data from national surveys, which was rife with various recording errors: wrongly specified units, typos in quantities, etc.

In addition, all the surveys used in this study, either national or project ones, were conducted using respondent recall estimates. The accuracy of such estimates is questionable, since recall errors may occur. Commonly, errors of the following three types occur in agricultural data: (i) telescoping, (ii) recall decay and (iii) heaping (Beegle et al. 2012). Telescoping is related to inaccurate remembrance of an event date, recall decay is forgetting event details, and heaping refers to the coarseness of respondents' rounding of quantitative information (e.g. "around one acre" may in reality be either 1.3 or 0.7 acre.) In order to assess the magnitudes of the recall errors, Deininger et al. (2012) in their experiment in Uganda compared the production records from farm diaries with the respective recall estimates obtained through a standard household survey questionnaire. These authors found substantial discrepancies between diary and recall data in terms of reported crop production quantities and their output values: the differences, depending on the crop, might exceed 50%. Presumably, the low reliability of the recall data impacted the estimations of model parameters in this thesis. Likewise, it may explain low values of the determination coefficient in the case of some of the estimated equations (see Table 4.4 in Section 4.2.2). Schreinemachers (2006) also had similar queries with regard to his estimations of production functions, which were integrated to the simulation model applied in the current research.

Another problem was the usage of local reference units and the lack of conversion tables for those units in the survey datasets. Moreover, outputs of some crops like plantains, cassava or sweet potato were mostly reported in bunches, bags or heaps without specifying the respective weights in kg. In the (UNPS 2010) survey, which was used for the estimation of potential crop yields, farmers reported crop harvests referring to different outputs. (E.g. some respondents apparently referred to “dry maize grain” whereas others referred to “green maize cob with straw”.) Hence the unit conversion was cumbersome and constituted another source of estimation imprecision.

Finally, some information was not specified at a suitable level of precision in the datasets. For example, fertilizer use was recorded by plot, but not by crop, livestock ages and liveweights were not specified, information on pests and pest treatment was not recorded, etc. Therefore, the author had to base estimates of model parameters on the information available from secondary literature, for example pest and disease effects on crop yields (explained in Section 3.6).

Without doubt, the quality and availability of input data is important for applied simulation modeling. It is difficult to assess the impact that the described data issues had on the simulation results reported in this work. Certainly, the availability of better data would improve the simulation model. With this regard the author agrees with World Bank (2010), Just (2003), who stress the need for agricultural economics researchers to have broad access to proper micro-level datasets that contain information on farm wealth, assets and liabilities structure, and that adequately reflect production practices and cover other aspects relevant to conducting farm-focused economic research.

6.1.3 Challenges in technical implementation and management

The described research required substantial computer literacy, more than anticipated, and advanced expertise in usage of certain software packages (MP-MAS, MS Excel, Stata). MS Excel was used for specification of the simulation model, formulation of simulation scenarios, and transformation of input data to specific MP-MAS input format and debugging of agent MP problems. Stata was applied for the estimation of model parameters from the empirical data, creation of agent populations, processing of model output and analysis of simulation results.

Because of the need to go through multiple cycles of debugging and calibration (see Figure D.2 of the Appendix), several processes had to be automatized by means of programming MS Excel macros and Stata scripts. This automation task was challenging, but worthwhile as it eased the subsequent repetitions of the modeling cycle.

One single run of the constructed simulation model itself required around 120,000 agent MILP to be solved. On a modern desktop computer, it takes about 12 hours to complete. Throughout the research many hundreds of the simulation runs had to be executed. (Not only to get the final results, but also during testing, debugging, calibration and production of intermediate results for project reports.) It would not be possible to conduct the current research in the same depth, without having the ability to use the computer grid system of the state of Baden-Wuerttemberg (BW-Grid), on which the simulation runs were performed. Users may interact with the BW-Grid front-end computer only through a command line interface. Therefore, the basic knowledge of using Linux terminals and script writing had to be acquired.

The indicated time of one simulation run does not account for the transformation of input files from Excel to the model format, and the conversion and merging of output files into a statistical dataset ready for analysis. Because of the incompatibility of the instruments applied (e.g. it was not possible to use MS Excel and Stata on the BW-Grid), the restricted amount of disk space and the author's limited skills in programming, this procedure could not be fully automatized. At the end, these issues with input and output file management created a bottleneck for a number of simulations that could have been performed. Thus, the holistic uncertainty analysis and sensitivity testing (like that of Troost (2013)), that would result in the multiplication of the number of simulation runs roughly by a factor of 100, could be done once this technical limitation is breached.

Given the aforesaid, it has to be concluded that agent-based simulation modeling of complex systems in agricultural economics requires a researcher to have a broad combination of various knowledge domains and technical skills in information technology. Therefore, it may be recommendable to conduct such technically challenging research in teams that include a qualified IT-specialist, who can improve technical efficiency of a modeling cycle. Also, appropriate hardware and software resources have to be at disposal.

From the obtained experience the author may conclude that application of simulation modeling in Ph.D. studies not only foster the analytic capabilities and theoretical knowledge of the students conducting such studies, but also improves the technical skills in computer information processing and data analysis and the ability to self-learn different software packages. These skills help to improve the quality of the research and use available resources more efficiently, and may be beneficial in the following academic career as well.

6.2 Practical recommendations and insights

This section derives practical recommendations based on the research experience and findings.

6.2.1 Rural development and empowerment of RPO

Coffee sales comprise around 23% of farm revenues (Hill 2010*b*) of coffee-growing households in Uganda, therefore, reduction of transaction costs in coffee marketing through collective action of farmers is considered to be a promising pathway of rural development (Markelova & Mwangi 2010, Bernard & Spielman 2009). The simulation modeling results reported in Chapter 5 support this anticipation. The results show that RPO contribute to the improvement of the welfare of their members: RPO activities caused on average an 11% increase in sales revenue and a 2.8% increase in income of household agents (page 141). The fieldwork revealed that besides the functions of marketing and product transformation, Kibinge DC also serves as a distributor of coffee planting material (Section 2.2). Also, in reality RPO are expected to positively influence the terms of trade of rural farmers, since in situations without RPO, due to the reduced competition, local middlemen traders would lower their buying prices (Dejene-Aredo et al. 2009, Markelova & Mwangi 2010). This effect was not considered in the simulation model, which means that the real impact of RPO is rather underestimated in the simulation results. Since results of the simulation experiments reveal that RPO can create a positive difference, the author recommends considering the engagement in collective marketing of other crops largely produced in the lakeshore Uganda (such as plantains or maize).

The results of this work go beyond the assessment of impacts that RPO create. Based on the research results, the author formulated several insights and recommendations concerning possible rural development strategies in the study area. These are reported in the paragraphs below.

Identification of effective RPO-level interventions The MP-MAS Uganda application allowed for the simulation of the effects of RPO-level interventions and for the assessment of the cost efficiency of their implementation. Table 6.1 provides a cross-comparison of the results of cost efficiency analyses. This table shows that all three types of tested interventions, namely on-spot payments, monetary motivation and group certification (ongoing program) can produce a positive net benefit. Provision of on-spot payments yields the highest equivalent annual net benefit (EANB), monetary motivation has the highest benefit-cost ratio (BCR), and ongoing UTZ certification has the highest economic rate of return (ERR).

However, simulation results from Section 5.3.2 showed that the provision of monetary schemes for producer motivation is not a straight-forward decision that can be implemented without a solid ex-ante analysis. In general, with regard to the studied DC, the positive net effects of motivation schemes appear rather small: producers are already well motivated by the higher prices

Table 6.1: Cost efficiency of development interventions

Intervention	EANB, mil. ugx	BCR	ERR, %	Δ Household income, %
Provision of on-spot payments	174.86	2.54	29.21	4.25
Monetary motivation of large sellers	28.29	7.99	91.74	0.46
Ongoing UTZ certification	124.31	6.74	229.88	1.99
Ongoing UTZ certification, Improved inclusion	293.56	9.86	358.46	4.57
Ongoing UTZ certification, Maximum potential	955.67	16.82	647.68	14.54
Fully self-financed UTZ certification, Current inclusion	-3.36	0.33	-29.31	0.05
Fully self-financed UTZ certification, Improved inclusion	198.53	7.54	266.60	2.92
Fully self-financed UTZ certification, Maximum potential	911.36	16.84	645.68	13.45

Source: Author, based on MP-MAS simulation results

that the RPO offers. The best of the tested schemes was simulated to cause only a 0.46% increase in agent income on average. The improper design of such schemes, however, may result in the discouragement of producers, which may significantly harm the performance of the RPO: 12 out of 40 tested set ups of motivation payments actually led to a decline in average agent income (see Table E.1 of the Appendix). Therefore, monetary motivation in practice is cumbersome and has a considerable risk of mal-implementation. Additionally, price discrimination of small selling farmers resulting from implementation of motivation of large sellers can create tension between RPO members (see Section 2.3).

Because of its high net effects, the relatively straightforward realization and the egalitarian character of treatment, the organization of on-spot payments is recommended for implementation. Setting up the arrangements with payments on the spot will require the provision of additional liquid assets for the RPO: in the case of Kibinge DC, a required increase in DC working capital of 986 million ugx was estimated. The cost of providing this capital could, however, be compensated by the intervention benefits in the ratio of 2.54 (BCR from (Table 6.1). The model simulated the provision of on-spot payments to result in an increase of RPO members' incomes of 4.25% on average.

Simulation results on UTZ certification suggest that, in order to be sustainable and to create a positive impact for the study DC, UTZ group certification has to either (i) be subsidized in the form of coverage of initial costs (ongoing program) or (ii) ensure the inclusion of a high share of members (in the case of full self-financing). But, as Kibinge DC administration reported to Verkaart (2008), in any case the liquidity constraint of the DC has to be breached (for example, by providing credit from development aid) in order to initiate the certification process, given the relatively high costs of initial investment for UTZ group certification. In general, the simulation results (Section 5.3.3) showed that engagement in UTZ certification has a potential for Kibinge DC in terms of attracting members to the RPO-sales channel and, therefore, increasing the turnover of the RPO, which would increase the profit margin of the organization and improve its sustainability. Under adequate arrangement, the certification may add considerable value to the end product of RPO (Table E.3 of the Appendix) and, therefore, increase the incomes of rural farmers. As Table 6.1 suggests, there is great potential for improvement of the ongoing certification program. The simulated potential net effect of the ongoing certification is 7.69 times higher than the simulated current effect. Based on the results of this study, it is recommended that development authorities support the implementation of UTZ group certification in coffee-producing RPO. For the Kibinge DC it might be most useful to work on improving the efficiency of the ongoing certification process, which means including more farmers in the certification and ensuring larger shares of produce to meet the certification requirements.

Need to cope with price risks Empirical studies of (Bussolo et al. 2006, Hill 2010*b*, Deininger & Okidi 2003) identified the price of coffee as highly important for household incomes of Ugandan farmers. The MP-MAS simulation results also showed the high sensitivity of household income with respect to domestic coffee prices (Section 5.2). These prices influence the profitability of RPO as well. The prices are highly dependent on the state of the world coffee market, that is transmitted from exporters to Ugandan traders and producers (Fafchamps & Hill 2008). Obviously, households and RPO have no control over these price formations. Therefore, provision of safety mechanisms may be required, in order to dampen the negative effects of probable future decreases in price. (According to Figure 1.7 from Section 1.3.3 between 2000 and 2003, producer prices for robusta coffee in Uganda constituted only 30–50% of 2010 level.) In addition to the situation with low coffee prices, RPO profit may significantly decrease in periods of excessively high food prices (i.e. food crisis). Hence, as with any other kind of business, RPO have to monitor market trends and developments. Provision of precautionary market information for the RPO, hence, may be required.

The volatility of domestic prices for coffee has a large impact on household welfare, because in the absence of insurance schemes against this risk, it drives farmers to make suboptimal management decisions (Hill 2010*b*). Section 5.2 showed that the variability in coffee price affects both coffee producing households and RPO. On average, the income effect of the price variability is negative (2.34% lower income), but it varies across the population. The poverty headcount is negatively affected by price fluctuations, although, the overall impact on poverty is small – it lies within 1%. Also, simulation results showed that price variability harms the sustainability of RPO. In the baseline setting, the price variability led to the long-run collapse of the RPO agent in one out of ten simulated cases. Accordingly, for RPO not only the long-term levels of prices matter, but also the short- and mid-term dynamics. The simulation experiments with agent expectations (page 155) showed that in order to improve the sustainability of RPO, measures for smoothing the effects of price fluctuations are required. An example of such a measure is a price guarantee or price insurance for the coffee producers, that will enable long-term planning, which in turn will lead to stabilization of the coffee supply that they generate, and consequently their incomes. Also, the reduction of the variability of coffee price will reduce the vulnerability of farm households and reduce their chances to appear below the poverty threshold. The role of the development community is, therefore, to provide training on price formation and forming right price expectations together with price risk insurances. (Similar measures are also advised by Hill (2010*b*).)

Accounting, transparency, tractability and trust Participatory sessions with the DC administration and members of village-level POs (Sections 2.2–2.4) revealed a lack of understanding regarding the functionality of the organization on the side of regular members, which leads to mistrust. The reason is the absence of clearly communicated and transparent rules of reception of DC services and allocation of earned benefits. Group discussions indicated that the information sharing via annual member meetings is not sufficient. Therefore, introduction of more frequent and formal reporting could create additional trust in the organization, which would motivate the members to sell larger shares of produce through the RPO-channel and make long-term contributions into the capital of the organization. The results of the public goods games (Section 2.4) suggest that trust and cooperativeness within the members of village-level POs have an influence on the amount of coffee sold through the PO.

Improvement of agricultural productivity The achievement of sustainable growth in SSA agriculture requires an increase in total factor productivity in the sector (Asenso-Okyere & Jemaneh 2012, Hazell 2005). Large yield gaps explained by low use of improved varieties, low intensity of fertilizer application and lack of knowledge about appropriate agricultural practices, suggest that the required productivity increase is attainable in SSA (Asenso-Okyere & Jemaneh 2012).

Simulation with MP-MAS described in this thesis helped to assess the likely impacts of possible productivity increases in the study area. In Section 5.2 agent incomes were simulated to have a good response to increases in crop yields (either of coffee or staple crops). For instance, a 50% increase in coffee yield resulted in a 26.6% increase in agent income. The income growth resulting from the respective yield increase translated into the improvement of agent consumption intakes and to the reduction of poverty headcounts in the model. This result indicates that the provision of quality planting material and high yielding varieties, as well as improving access to fertilizers and better crop management might have a highly positive effect on the welfare of real-world households. Higher coffee yields would also translate into more effective RPO dealing with marketing of coffee. In this regard, RPO networks could be used as vehicles for reaching smallholder farmers and improving their access to quality inputs and agricultural extension services (Hazell 2005). The involvement of RPO would also reduce transaction costs in input procurement (Hazell 2005). The fact that fertilizers and planting material were the most frequently mentioned problems during the group discussions with farmers (Table 2.2) shows that there is a definite demand for input provision policy from the farmers' side.

The integrated TSPC module of MP-MAS simulated a gradual decline in soil fertility in the study area (Section 5.1.2). Losses of soil fertility have a depressive effect on farm gross margins and incomes. As measures of dealing with the soil fertility decline on Ugandan farms, Onduru et al. (2007), Nkonya et al. (2004) propose the stimulation of improved soil management strategies and the reduction of farmer costs of related technologies. The promotion of mixed crop-livestock production systems complemented by the provision of better access to livestock input-output markets (Onduru et al. 2007, Nkonya et al. 2004), training and extension on agricultural practices and site specific technologies (Nkonya et al. 2004), capacity building for substituting natural capital with other forms of capital (Nkonya et al. 2004) – all these measures are expected to be beneficial in terms of sustainable land use and increased agricultural land productivity.

Motivation of PO leaders As was determined during the fieldwork in Uganda, in the RPO from the presented case study (Kibinge DC) the important function of village-level PO leaders was disparate with the remuneration that they receive. This resulted in low contributions and commitment by PO leaders. Therefore, the development of the system that would motivate PO leaders might be beneficial for the RPO as a whole, given the leaders' importance (discussed in Section 2.3). Such a motivation system could be monetary or service-based (i.e. leaders get paid or get preferences in reception of RPO services).

Challenges of population growth The simulation experiments with population dynamics (Section 5.1.2) demonstrate the decline in per capita income under current population growth. This result suggests that the income-related driver for rural-urban migration will increase, when yields and prices remain at current levels. Therefore, rural development policies in Uganda should include the provision off-farm employment opportunities and strategies for long-term reduction of population pressure. This recommendation is also shared by Pender et al. (2004), Nkonya et al. (2004).

Rural road infrastructure When discussing enhancing market access of smallholder farmers in Uganda, improvement of the road network and infrastructure should not be forgotten (Balat et al. 2009, Ashraf et al. 2009, Pender et al. 2004, Deininger & Okidi 2003). Public investments here will result in a decrease of transportation costs and consequently, better commercialization of rural farmers and will also improve farmer access to quality inputs and financial services.

6.2.2 Related knowledge gaps and recommendations for research

The previous section identified measures of RPO support that are likely to be beneficial and effective. However, the appropriate mechanism for provision of the support on the large scale is yet to be found. More research is needed for the evaluation of various types of institutional frameworks (public and private) with regard to their ability to assist the formation, functioning and securing sustainability of RPO.

Currently, little is known about the impacts that RPO have on other actors in agricultural supply chains of developing countries. Impact assessments are required in order to understand the potential of private sector involvement in RPO support. The incentives for the private sector to invest in RPO still needs to be investigated.

Current research efforts in the field of RPO are limited to case studies (Ragasa & Golan 2012). Depending on the local specifics, these case studies (Bernard & Spielman 2009, Bernard et al. 2008, Shiferaw et al. 2008, Chibanda et al. 2009) present varied evidence and come to different conclusions. Therefore, a broad cross-country analysis is needed to identify the political, legal and socioeconomic environments in which RPO are likely to succeed. Also, studies have to reveal which of the many existing types of RPO (see Section 1.1.2) are most effective in different environments.

As discussed in the previous section, the equipment of RPO with financial instruments to help them to withstand price volatility and the associated risks will improve their long-term sustainability and economic performance. However, as Poulton et al. (2010) argue, so far viable and sustainable models of insurance provision for smallholder agriculture are missing. Therefore, the role of future research should be to continue searching and empirically testing various experimental designs of the respective risk insurance schemes.

6.3 Possible extensions of the model

The developed simulation model is a complete product with the MS Excel-based user interface and commented input files. Hence, the current specification of the MP-MAS Uganda application can be used by other researchers in the future. Moreover, the flexibility of MP-MAS allows for the creation of certain extensions of the model without additional changes in the source code.

Modeling cooperativeness and trust in RPO The analysis of the results of public goods games conducted in ten village POs suggested that the share of coffee produce that a member decides to sell through the RPO can be explained by his behavior in a public goods game (Section 2.4). Therefore, the author could hypothesize that it is related to the individual's trust in other RPO-members and their cooperativeness and willingness to contribute to the common pool, which was represented by member public goods game contribution. However, the econometric models estimated in Section 2.4 are imprecise due to the small number of observations for the dependent variables.

In the current specification of MP-MAS Uganda, the MP-optimization approach is used to model the household marketing decisions (see Section 3.10). The agent decision on selling channels is subject to the constraints captured during the fieldwork. However, modeling of marketing decisions can be done by implementing an econometric approach. (For example, in the case of modeling household consumption decisions, econometric models were successfully integrated into the MILP format (see Section 3.7).) Such alternative implementation, of course, requires an estimation of a stable econometric relationship between household characteristics and the share of coffee that is sold through the RPO, where one of the household characteristic is its contribution in the public goods game (or some other proxy for trust and cooperativeness). A step towards estimation of such a relationship would be conducting social experiments in a larger sample and collecting data on coffee production and sales from experiment-participating RPO members.

Simulating innovation diffusion As discussed previously in Section 6.2.1, the provision of access to technological innovations (for example, improved high-yielding varieties) may improve the agricultural productivity in the study area. However, as we know from Rogers (1995) "Diffusion of Innovations" theory, the access to innovation does not necessarily lead to its successful diffusion among the population. According to Rogers (1995), the diffusion of innovation is defined by several factors, such as characteristics of innovation or properties of the social system in which it diffuses.

Berger (2001) implemented in MP-MAS the frequency-dependent process of innovation diffusion based on the Rogers (1995) theory (simulation mechanism explained in Berger (2001)). Therefore, MP-MAS Uganda application can be used for simulation experiments with respect to innovation diffusion. These experiments may reflect development policies aimed at supporting the processes of innovation diffusion and adoption. The simulation model could then deliver quantitative information for the assessment of such policies and the exploration of economic potential of innovative technologies. Implementing this extension would require (i) an empirically-based categorization of households into groups of adopters according to Rogers (1995) (i.e. innovators, early adopters, early majority etc.) and (ii) an estimation of thresholds to adoption (see Berger (2001)).

Modeling the dynamics of RPO membership The project survey (IFPRI 2010) covered only the households that were RPO members at the time of the survey, while data from other producers were not collected in the study area. Consequently, the simulation model did not include any non-member agents and agent membership in the RPO was fixed during simulation. However, the model is capable of inclusion of non-member agents, once the respective missing survey data are available. Such an expansion of the agent population would make it possible to simulate the dynamics of RPO membership through the implementation of agent decisions of whether to pay membership fees. This would, in turn, enable the possibility of testing interventions timed and targeted to support RPO formation and its inclusion of new members.

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Appendix A

Participatory assessment

Table A.1: List of key informant interviews

	Occupation	Company, Institution
1*	Two researches in agricultural economics	IFPRI
2	IFPRI (2010) survey coordinator	freelancer
3	Development project manager	Ssemwanga group (extension services provider, IFPRI subcontractor in development interventions)
4	Executive director	NUCAFE
5	Facilitator, extension agent, Ph.D. student	Ssemwanga group, University of Pretoria
6	Postdoc, agricultural scientist	University of Leuven
7	Market analyst	UCDA
8	Field assistant, facilitator, IFPRI (2010) survey enumerator	freelancer
9	Systems agronomist	IITA
10	Manager on commercial and operations	Ibero Ltd (coffee exporter)
11	Economist	UCA
12	Agronomist	COREC
13*	Administration of Namayumbe DC (covered by IFPRI (2010) survey)	NUCAFE
14*	Members of Biyinzika PO (covered by IFPRI (2010) survey)	NUCAFE

Source: Author

* indicates interviews with a group of informants

Table A.2: Key informant interviews: Matrix of topics

Topic	Interview number													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Casual labor												x		
Certification and quality incentives								x	x	x	x			
Coffee pests and diseases					x	x						x		
Coffee price formation and trends	x	x	x	x		x			x					
Coffee-banana intercropping			x		x	x			x			x		
Cooperative savings								x			x			
External development interventions								x		x	x	x	x	
Factors determining coffee yield					x	x			x			x		
Factors for RPO sustainability and success		x						x		x	x			
Farmer problems and constraints							x					x	x	x
Group decision-making and actions			x	x		x	x	x			x			
Harvesting of coffee	x			x								x		
Incentives to act as a group				x				x		x	x			
Information channels		x						x						
Institutional framework							x							x
Investments in new coffee plantations					x									
Planting material for coffee						x			x			x		
Production inputs				x		x			x			x		
RPO functionality and services			x		x		x	x			x		x	x
RPO leadership								x			x			
RPO problems and constraints		x						x		x	x		x	x
Sales channels	x	x	x	x						x	x	x	x	x
Transportation	x	x												

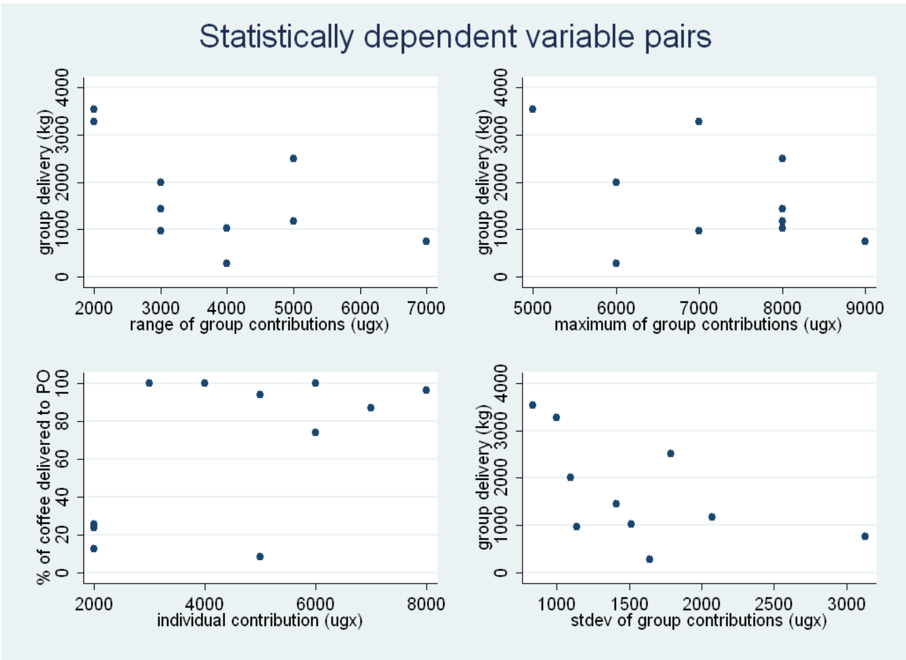
Source: Author

Table A.3: List of variables used in factor analyses

Variable	Type
Year of foundation	integer
Was founded on own or external initiative?	binary
Number of members	integer
Ever received external help?	binary
Price decision is taken by members or administration?	binary
Receives payment on delivery?	binary
Provides inputs?	binary
Organizes transportation?	binary
Involved in processing?	binary
Involved in certification?	binary
Provides market information?	binary
Has storage facility?	binary
Provides credit?	binary

Source: Author

Figure A.1: Scatter plots of statistically dependent variable pairs



Source: Author, based on public goods games results

Table A.4: PO selection

PO name	Cluster	Distance to centroid	Sales data available?	Pick?
Magando Twekembe	1	0.807	1	0
Kyetume farmers group	1	0.888	1	1
Kalunduka NUCAFE farmers group	1	0.896	1	0
Tusitukire wamu farmers group	1	1.015	1	0
Kijampiki farmers group	1	1.535	1	0
Maleku farmers group	2	0.625	1	1
Mitugo farmers club	2	0.636	1	1
Kisojo farmers group	2	0.786	1	1
Buligita farmers group	2	0.865	1	0
Kabulanda farmer group	2	0.930	1	0
Serinya Twekembe UTZ kapeh group	3	0.429	1	1
Kamanda coffee farmers group	3	0.743	1	1
Kalybaya farmers group	3	1.475	1	1
Bunyenya farmers group	4	0.562	1	1
Kiryasaka farmers group B	4	0.625	1	1
Katoma coffee farmers group	4	0.694	1	1
Kisojo farmers group B	4	0.731	1	0
Bbaale coffee farmers association	4	0.807	1	0
Kalisizo coffee farmers	1	0.736	0	0
Agali Awamu coffee farmers group	1	0.787	0	0
Makukulu NUCAFE farmers group	1	0.942	0	0
Kyambogo NUCAFE farmers group	2	0.475	0	0
Misanvu farmers group	2	0.540	0	0
Mpalampa coffee farmers group	3	0.522	0	0
Mitugo coffee farmers association	3	0.783	0	0
Budda farmers group	3	0.850	0	0
Katolerwa farmers group	3	0.852	0	0
Tala farmers group	3	0.855	0	0
Kyabiiri coffee farmers group	3	0.981	0	0
Twezimbe farmers group	3	0.990	0	0
Lukenke NUCAFE farmers group A	3	1.073	0	0
Mitugo coffee farmers cooperative	4	0.300	0	0
Kiryasaaka NUCAFE farmers group A	4	0.699	0	0
Kyamabale coffee farmers association	4	0.732	0	0
Mirambi Tusitukire Wamu group	4	1.155	0	0
Lukenke NUCAFE farmers group A	4	1.230	0	0

Source: Own analysis, based on IFPRI (2010) data

Table A.5: Characteristics of visited POs

	Bunyenya farmers group	Kalubaya farmers group	Kamanda coffee farmers group	Katoma coffee farmers group	Kiryasaka farmers group B
Intercropping: coffee trees per acre	450	450	n/a	450	n/a
Intercropping: banana trees per acre	50	200	n/a	50	0
Fertilizers and pesticides with coffee	CAN, NPK, manure, herbicide	CAN, NPK, manure	manure	NPK, manure	n/a
Access to inputs	yes	yes	yes	yes	yes
Planting material from DC	yes	yes	yes	yes	no
Coffee sold through DC, %	50	80	85	70	100
Mean willingness to invest in coffee (max land share), %	50	61	n/a	58	n/a
Labor scarcity	no	no	scarce during land preparation	no	n/a
Labor specialization	no	n/a	n/a	no	n/a
Access to SACCO or VSLA	no	yes	yes	yes	yes
Credits from traders	yes	no	no	no	no
Bulking at PO level	no	no	no	no	yes
DC credit approval scheme	3 members	chairperson + 2 members	n/a	all members	chairperson
Cash on delivery	yes	yes	yes	partially	no
Notes	had visits from Fairtrade				own store, organize transport by themselves

Table A.5 (cont.): Characteristics of visited POs

	Kisojo farmers group	Kyetume farmers group	Maleku farmers group	Mitugo farmers club	Serinya Twekembe UTZ kapeh group
Intercropping: coffee trees per acre	n/a	75%	400	400	n/a
Intercropping: banana trees per acre	n/a	25%	100	150	n/a
Fertilizers and pesticides with coffee	manure	manure	NPK, urea, manure	manure	CAN, manure
Access to inputs	no	no	yes	no	yes
Planting material from DC	yes	no	yes	yes	yes
Coffee sold through DC, %	0	n/a	30	75	65
Mean willingness to invest in coffee (max land share), %	n/a	65	72	71	n/a
Labor scarcity	yes	n/a	scarce, except harvesting period	no	yes
Labor specialization	n/a	no	no	yes	no
Access to SACCO or VSLA	no	no	no	no	no
Credits from traders	no	yes	yes	yes	no
Bulking at PO level	no	no	no	yes	no
DC credit approval scheme	references + business plan	all members	n/a	chairperson	individual enquiry
Cash on delivery	no	n/a	n/a	no	yes
Notes	sell to Kampala buyer occasionally	recieved help form NAADS, exposed to coffee thefts			recieved seedlings from UCDA

Source: Author, based on Net-Map results

Appendix B

MILP-implementation of decision problems

Table B.1: Investment decisions

	Invest in coffee	Grow crop	Sell coffee future	Sell crop	Consume crop	Buy food item		
Maximize	-Cc	-C	Pc	P_1	P_2			
Land	1	1					$\leq$	$Land$
Labor	Lc	L					$\leq$	Lab
Liquidity	Cc	C				P_3	$\leq$	$Cash$
Maximum coffee	1						$\leq$	Max_{cof}
Balance coffee	-Yc		1				$\leq$	0
Balance crop		-Y		1	1		$\leq$	0
Food requirement					F_1	F_2	$=$	$Food$

* Cc – annuity of investment costs in coffee plantation; C – input costs;
Pc – expected coffee price of future years; P_i – expected market prices of this year;
$Land$, Lab, $Cash$ – household resource endowments; Max_{cof} – upper bound on size of coffee plantation;
$Food$ – household food consumption requirements; Lc – average labor requirements of coffee production;
L – labor requirements of crop production; Yc – annuity of expected yields over coffee plantation lifespan;
Y – crop yield; F_i – food content;

Table B.2: Transfer activities

	Grow seasonal crop		Grow annual crop	Transfer			
	Season 1	Season 2		Land	Labor		
Total land				1		$\leq$	$Land$
Total labor					1	$\leq$	Lab
Land season 1	1		1	-1		$\leq$	0
Land season 2		1	1	-1		$\leq$	0
Labor season 1	L_1		L_3		-0.5	$\leq$	0
Labor season 2		L_2	L_4		-0.5	$\leq$	0

* $Land$, Lab – household resource endowments; L_i – labor requirements

Table B.3: Certainty equivalents and future value coefficients

	Grow crop	Sell crop			
	-C	current	future		
Maximize		Pc	$Pf * V$		
Land	1			$\leq$	$Land$
Yield balance	-Yc	$1 * Eq$		$\leq$	0
Future yield balance	-Yf		1	$\leq$	0

* C – input costs; Pc – expected market price of this year;
Pf – expected market price of future years;
V – valuation coefficients of future returns;
$Land$ – household land endowment; Yc – expected yield in current year;
Yf – annuity of expected yields over remaining lifespan of plantation;
Eq – certainty equivalent;

Table B.4: Allocation of income between savings and expenditures

	Income transfer	Binary	Savings	Cancel savings *	Expenditure		
Maximize				-10^{-9}	1		
Upper bound (for solution)		1					
Household income	1					$=$	I
Min income for savings	-1	Ψ				$\leq$	0
Save / not save		-10^9				$\leq$	0
Cancel savings		10^9		1		$\leq$	10^9
Savings balance	-1		β	1		$=$	0
Budget balance	1		-1		-1	$=$	0

*solution of this activity is not considered in the final calculation of the LP objective value – the activity was introduced in order to avoid LP infeasibility in case of not saving agents;
I – household income; Ψ – agent-specific zero-savings bound; β – slope of the savings function;

Table B.5: Cash flow

	Transfer liquidity	Grow crops	Sell crops	Consume crops	Purchase food	Remaining cash		
Maximize		-C	P_1	P_2				
Land		1					$\leq$	$Land$
Starting liquidity	1	C					$\leq$	$Cash$
Food energy demand				E_1	E_2		$=$	$En.r$
Crop yield balance		-Y	1	1			$\leq$	0
Cash flow end of year	-1		-P_1		P_3	1	$=$	0

*C – production costs; P_i – market prices; $Land$, $Cash$ – household resource endowments; $En.r.$ – household food energy requirement; E_i – food energy contents; Y – crop yield;

Table B.6: Remittances transfer

	Grow crops	Production costs	Remittances	Income		
Maximize	P	-1	1			
Land	1				$\leq$	$Land$
Income	P		1	-1	$=$	0
Costs	C	-1			$\leq$	0
Remittances			1		$\leq$	Rem

*$Land$ – household land endowment; Rem – received remittances

Table B.7: Motivation payments in household MILP

	Grow coffee	Sell coffee RPO-channel	Sell coffee trader	Receive premium	Receive bonus	Requirement binary		
Maximize	-C	P_1	P_2	M_1	M_2			
Upper bound (for soultion)					1	1		
Coffee plantation	1						$\leq$	Cof
Balance coffee	-Y	1	1				$\leq$	0
Payment base		-1		1		Q	$\leq$	0
Requirement binary				1	1	-10^9	$\leq$	0

* C – variable costs per unit; P_i – expected market prices of current year; M_i – values of motivation payments Cof – size of coffee plantation; Y – yield; Q – sales quantity requirement for motivation payments

Table B.8: Crop management practices

	Grow crop														
	Lab min	Lab med	Lab max	Lab min	Lab med	Lab max	Lab min	Lab med	Lab max	Buy NPK	Buy CAN	Buy seed	Sell crop		
	Manure	Manure	Manure	NPK	NPK	NPK	CAN	CAN	CAN						
Maximize										-C_1	-C_2	-C_3	P		
Land	1	1	1	1	1	1	1	1	1					$\leq$	$Land$
Labor	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3					$\leq$	Lab
Seed	S	S	S	S	S	S	S	S	S			-1		$\leq$	0
NPK fertilizer				F_1	F_1	F_1				-1				$\leq$	0
CAN fertilizer							F_2	F_2	F_2		-1			$\leq$	0
Yield balance	-Y_1	-Y_2	-Y_3	-Y_4	-Y_5	-Y_6	-Y_7	-Y_8	-Y_9				1	$\leq$	0

* C_i – input costs; P – crop market price; $Land$, Lab – household resource endowments; L_i, S, F_i – labor, seed and fertilizer requirements; Y_i – expected crop yields

Table B.9: Chicken production

	Maintain	Hatch	Buy	Raise	Replace	Grow	Collect	Sell			
	Hen	Eggs	Chick	Chicken	Hen	Crops/Pasture	Manure	Chicken	Eggs		
Maximize	-C_1	-C_2	-C_3	-C_4		-C_5		P_1	P_2		
Land						1				$\leq$	$Land$
Labor	Lb_1	Lb_2		Lb_3		Lb_4				$\leq$	Lab
Liquidity	C_1	C_2	C_3	C_4		C_5				$\leq$	$Cash$
Chicken limit	1			T						$\leq$	Ch_{max}
Feed balance	F_1			F_2		-Y				$\leq$	0
Chick balance		-1	-1	1						$\leq$	0
Replacement hens	$1/Ls$				-1					$\leq$	0
Chicken balance				-1	1			1		$\leq$	0
Eggs balance	-E	$H \times W$							1	$\leq$	0
Manure balance	-M_1			-M_2			1			$\leq$	0

* C_i – input and production costs; P_i – expected market prices of this year; $Land$, Lab, $Cash$ – household resource endowments;
Ch_{max}, – maximum number of chicken and pigs household can manage at once;
Lb_i, F_i – labor and feed requirements; Y – stover yield; T_i – age of chicken maturity (in years);
Ls – hen productive lifespan (in years); E – yearly egg production (per laying hen); H – egg hatchability rate;
W – percentage of chicks weaned; M_i – manure outputs of chicken production;

Table B.10: Pig production

	Maintain	Buy		Raise to			Grow	Collect	Sell			
	Breeding sow	Weaner	Sow	Weaner	Finisher	Sow	Crops/Pasture	Manure	Weaner	Finisher		
Maximize	-C_1	-C_2	-C_3	-C_4	-C_5	-C_6	-C_7		P_1	P_2		
Land							1				$\leq$	$Land$
Labor	Lb_1			Lb_2	Lb_3	Lb_4	Lb_5				$\leq$	Lab
Liquidity	C_1	C_2	C_3	C_4	C_5	C_6	C_7				$\leq$	$Cash$
Pig limit	1			T_1	T_2	T_3					$\leq$	Pig_{max}
Feed balance	F_1			F_2	F_3	F_4	-Y				$\leq$	0
Weaner balance		-1		-1	1	1			1		$\leq$	0
Replacement sows	$1/Ls$		-1			-1					$\leq$	0
Litter balance	-Lt			1							$\leq$	0
Finisher balance					-1					1	$\leq$	0
Manure balance	-M_1			-M_2	-M_3	-M_4		1			$\leq$	0

* C_i – input and production costs; P_i – expected market prices of this year; $Land$, Lab, $Cash$ – household resource endowments;
Pig_{max} – maximum number of pigs household can manage at once;
Lb_i, F_i – labor and feed requirements; Y – stover yield; T_i – durations of various stages of pig growth (in years);
Ls – sow productive lifespan (in years); Lt – yearly litter size (per sow); M_i – manure outputs of various stages of pig production;

Table B.11: Durable livestock (example of nanny-goats)

	Maintain	Sell goat				Grow	Collect	Sell					
	Goat	Age 0 start	Age 0 end	Age 1 start	Age 1 end	Crops/Pasture	Manure	Meat	Milk	Meat future	Milk future		
Maximize	-C_1		-C_2		-C_3			-P_1	-P_2	-Pf_1	-Pf_2		
Land						1						$\leq$	$Land$
Labor	Lb_1		Lb_2		Lb_3	Lb_4						$\leq$	Lab
Liquidity	C_1		C_2	-$Mt_1 * P_1$	C_3							$\leq$	$Cash$
Feed balance	F_1		F_2		F_3	-Y						$\leq$	0
Meat balance			-Mt_1	-Mt_1	-Mt_2			1				$\leq$	0
Future meat bal.	-Mtf									1		$\leq$	0
Milk balance			-Mk_1		-Mk_2				1			$\leq$	0
Future milk bal.	-Mkf										1	$\leq$	0
Offspring balance			-O_1		-O_2			W				$\leq$	0
Future offspring bal.	-Of									W		$\leq$	0
Manure balance	-Mn_1		-Mn_2		-Mn_3		1					$\leq$	0
Total goats	1	1	1	1	1							$\leq$	Gts_{tot}
Goats of age 0		1	1									$\leq$	Gts_0
Goats of age 1				1	1							$=$	Gts_1

* C_i – production costs; P_i – expected market prices of this year; Pf_i – expected market price of future years; $Land$, Lab, $Cash$ – household resource endowments; Gts_{tot} – total number of goats; Gts_i – number of goats of a specific age; Ln, Lb_i, C_i, F_i – land, labor, cash and feed requirements; Y – stover yield; Mt_i, Mk_i, O_i, Mn_i – meat, milk, offspring and manure outputs of livestock production; W – offspring liveweight
Mt_i, Mk_i, O_i – annuity of the meat, milk, offspring outputs of the remaining years of livestock unit;

Table B.12: Coffee production

	Grow coffee				Switch practice				Grow plantain		Sell				
	Soil 1 Pr. A	Soil 1 Pr. B	Soil 2 Pr. A	Soil 2 Pr. B	Soil 1 A to B	Soil 1 B to A	Soil 2 A to B	Soil 2 B to A	Soil 1	Soil 2	Coffee	Coffee future	Plan-tain		
Maximize											P_1	Pf	P_2		
Soil 1	1	1			1	1			1					$\leq$	S_1
Soil 2			1	1			1	1		1				$\leq$	S_2
Labor	Lc_1	Lc_2	Lc_1	Lc_2	Lc_2	Lc_1	Lc_2	Lc_1	Lp	Lp				$\leq$	Lab
Coffee soil 1 pr. A	1				1									$=$	$C\_S_1\_A$
Coffee soil 1 pr. B		1				1								$=$	$C\_S_1\_B$
Coffee soil 2 pr. A			1				1							$=$	$C\_S_2\_A$
Coffee soil 2 pr. B				1				1						$=$	$C\_S_2\_B$
Intercrop soil 1	Ir	Ir			Ir	Ir			-1					$\leq$	0
Intercrop soil 2			Ir	Ir			Ir	Ir		-1				$\leq$	0
Coffee balance	-Yc_1	-Yc_2	-Yc_3	-Yc_4	-Yc_2	-Yc_1	-Yc_4	-Yc_3			1			$\leq$	0
Future coffee bal.	-Ycf_1	-Ycf_2	-Ycf_3	-Ycf_4	-Ycf_2	-Ycf_1	-Ycf_4	-Ycf_3				1		$\leq$	0
Plantain balance									-Yp_1	-Yp_2			1	$\leq$	0

* P_i – expected market prices of this year; Pf – expected market price of future years; S_i household soil endowments; Lab – household labor endowment; $C\_S_i\_j$ – sizes of coffee plantations (by soil and initial management practice); Lc_i – age-specific labor requirements of coffee; Lp – labor requirements of plantain; Ir – coffee/plantain intercropping ratio; Yc_i – age-specific expected yields of coffee; Ycf_i – annuity of expected yields of the remaining years of the coffee plantation; Yp_i – expected yields of plantain;

Table B.13: Partitioning of total expenditure

	Exp. transfer	Const.	H. size	Seg. 1	Seg. 2	Seg. binary	Food exp.	Non-f. exp.		
Maximize							1	1		
Upper bound (for solution)				E_1	E_2	1				
Total exp.	1								$=$	E
Exp. balance	1						-1	-1	$=$	0
Food exp.		β_0	$\beta_2 HS$	Υ_1	Υ_2		-1		$=$	0
Constant	1	-1							$=$	0
H. size part	1		-1						$=$	0
Exp. part	1			-1	-1				$=$	0
Upper bound 1				-1		E_1			$\leq$	0
Lower bound 2				-1	-1				$\leq$	0
Upper bound 2					1	-E_2			$\leq$	0

*β_0, β_1 – regression coefficients of estimated Working-Leser model, E – household expenditure budget;
HS – agent household size in gigajoules; Υ_1, Υ_2 – segment average food expenditure coefficients;
E_1, E_2 – segment upper bound (expressed as total expenditure);

Table B.14: Choice between food categories

	Food exp.	Const.	H. size	Price	Seg. 1	Seg. 2	Seg. binary	Consume cat. 1	Consume cat. 2		
Maximize								UV_1	UV_2		
Upper bound (for solution)					FE_1	FE_2	1				
Category 1		$\beta_{0,1}$	$\beta_{2,1}HS$	$\sum_1^k \varepsilon_{1,k} lnUV_k$	$\Omega_{1,1}$	$\Omega_{2,1}$		-1		$=$	0
Category 2		$\beta_{0,2}$	$\beta_{2,2}HS$	$\sum_1^k \varepsilon_{2,k} lnUV_k$	$\Omega_{1,2}$	$\Omega_{2,2}$			-1	$=$	0
Constant	1	-1								$=$	0
Household size part	1		-1							$=$	0
Expenditure part	1				-1	-1				$=$	0
Upper bound 1					-1		FE_1			$\leq$	0
Lower bound 2					-1	-1				$\leq$	0
Upper bound 2						1	-FE_2			$\leq$	0

*UV_1, UV_2 – monetary unit values of food items; FE_1, FE_2 – segment upper bound (expressed as total expenditure spent on food);
$\beta_{i,k}$,$\varepsilon_{i,k}$ – regression coefficients of estimated linear approximation of almost ideal demand system;
$\Omega_{i,k}$ – segment average food category expenditure coefficients; HS – agent household size in gigajoules;

Table B.15: Food consumption requirement

	Produce food	Purchase food	Make investments	Energy demand	Energy supply	Energy deficit	Protein supply	Utility loss (due to hunger)		
Maximize	I_c		I_f					-10^9 *		
Land	L_1		L_2						$\leq$	$Land$
Liquidity		P	C						$\leq$	$Cash$
Energy demand				-1					$=$	$En.r.$
Energy supply	E_1	E_2			-1				$\leq$	0
Energy balance				1	-1	-1			$\leq$	0
Energy deficit						1		-1	$=$	0
Protein supply	Pr_1	Pr_2					-1		$=$	0

*sufficiently large negative value ensures preference for current food consumption; I_c – current contribution margin; I_f – expected future contribution margin; $Land$, $Cash$ – household resource endowments; $En.r.$ – household food energy requirement; L_i – land requirements of production alternatives; P – food price; C – investment cost; E_i, Pr_i – food energy and protein contents;

Table B.16: RPO-agent MILP with basic and certified products

	Process basic	Process certified	Sell basic	Sell certified	Fixed costs	Cert. costs	Profit * base	Cert. * premium		
Maximize	-C_1	-C_2	P_1	P_2	-1	-1				
Raw volume basic	1								$\leq$	Q_1
Raw volume certified		1							$\leq$	Q_2
Processed volume basic	-(1-R)		1						$\leq$	0
Processed volume certified		-(1-R)		1					$\leq$	0
Fixed costs					1				$=$	FC
Certification costs						1			$=$	CC
Profit base	-C_1	-C_2	P_1	P_1	-1		-1		$=$	0
Certification premium		-(C_2-C_1)		(P_2-P_1)		-1		-1	$=$	0

* solutions of these activities are allowed to be negative;
C_i – variable costs per unit; P_i – market prices of current year;
Q_i – available quantity; FC – fixed costs; CC – certification costs; R – weight reduction coefficient;

Table B.17: RPO-agent MILP with motivation payments

	Process produce	Sell produce	Fixed costs	Pay premiums	Pay bonuses	Profit	Budget premiums	Budget bonuses		
Maximize	-C	P	-1	-M_1	-M_2					
Raw volume	1								$\leq$	Q
Processed volume	-(1-R)	1							$\leq$	0
Fixed costs			1						$=$	FC
Profit	-C	P	-1	-M_1	-M_2	-1			$=$	0
Budget premiums				1			-1		$=$	0
Budget bonuses					1			-1	$=$	0

* C – variable costs per unit; P – expected market prices of current year; M_i – values of motivation payments
FC – fixed costs; R – weight reduction coefficient;

Appendix C

Estimation of the consumption model

Table C.1: Logit estimates on propensity to make savings

Dependent variable = 1 if household makes savings, 0 – otherwise	coef	se
Farm income, .00 ugx	6.57e-06	7.66e-06
Household size, GJ	-0.016	0.015
Apac	-2.207**	1.047
Bushenyi	-1.911*	1.099
Kabalore	-1.927*	1.141
Kamuli	-1.155	1.082
Kasese	-1.243	1.173
Masaka	-1.564	1.087
Mituyana	-1.648	1.251
Mpigi	-2.145	1.476
Mubende	-2.187*	1.186
Mukono	-1.181	1.246
Nebbi	-2.874***	1.042
Ntungamo	-1.582	1.137
Constant	4.299***	1.060
LR-test (14)	30.52***	
Pseudo R-squared	0.0624	
N obs	757	

Source: Own estimation from IFPRI (2010) survey

* implies a significance at 10%-level, ** – at 5%, *** – at 1%

Table C.2: Savings model

Dependent variable = Savings in a "good month", .00 ugx	coef	se
Farm income, .00 ugx	0.033***	0.005
Farm income squared, .00 ugx	-8.21e-08*	4.55e-08
Household size, GJ	8.163	5.452
Apac	218.149	454.286
Bushenyi	56.127	462.219
Kabalore	-157.737	475.627
Kamuli	274.397	448.122
Kasese	4.197	467.023
Luwero	218.313	480.258
Masaka	607.573	449.739
Mituyana	787.290	498.061
Mubende	400.046	509.492
Mukono	121.688	476.221
Nebbi	336.937	460.975
Ntungamo	917.574**	465.061
Wakiso	195.770	498.925
Constant	-209.124	456.279
F-test (16, 663)	11.45***	
R-squared	0.2165	
N obs	680	

Source: Own estimation from IFPRI (2010) survey for households with non-zero savings;
* implies a significance at 10%-level, ** – at 5%, *** – at 1%

Table C.3: Savings model (as represented in MILP)

Dependent variable = Savings in a "good month", .00 ugx	coef	se
Farm income, .00 ugx	0.030***	0.002
F-test (1, 681)	282.12***	
R-squared	0.2929	
N obs	682	

Source: Own estimation from IFPRI (2010) survey for households with non-zero savings;
*** implies a significance at 1% level

Table C.4: Food expenditure model

Dependent variable = Share of household expenditure budget spent on food	coef	se
Ln(Expenditure)	-0.0864***	0.004
Household size, GJ	0.0020***	0.0004
Urban	0.0664***	0.0082
Agricultural	-0.0355***	0.0093
Central Region (without Kampala)	-0.0221*	0.0131
Eastern Region	-0.0280**	0.0139
Northern Region	-0.0122	0.0141
Western Region	-0.0009	0.0140
Constant	1.430***	0.047
F-test (8, 2922)	147.41***	
R-squared	0.2875	
N obs	2931	

Source: Own estimation from UNPS (2010) survey

* implies a significance at 10%-level, ** – at 5%, at *** – at 1%

Table C.5: Almost ideal demand system. Food category 1 (plantain)

Dependent variable = share of food category 1 (plantain) in household food expenditures	coef	se
Ln(category 1 unit value)	0.00095	0.00715
Ln(category 2 unit value)	0.00126	0.00353
Ln(category 3 unit value)	0.01273***	0.00395
Ln(category 4 unit value)	0.00032	0.00323
Ln(category 5 unit value)	-0.00675***	0.00208
Ln(category 6 unit value)	-0.00615*	0.00319
Ln(category 7 unit value)	-0.00348	0.00225
Ln(category 8 unit value)	0.00111	0.00362
Ln(per capita expenditure)/Stone's index	0.03101***	0.00677
Central Region (without Kampala)	0.03805***	0.01207
Eastern Region	-0.08158***	0.01410
Northern Region	-0.14719***	0.02126
Western Region	0.08784***	0.01317
Household size, GJ	0.00224***	0.00038
Agricultural	0.02130**	0.00826
Urban	0.00951	0.00743
Nonselection hazard	0.03845**	0.01643
Constant	-0.18514***	0.06283
Chi-squared test	985.25***	
R-squared	0.2518	
N obs	2794	

Source: Own estimation from UNPS (2010) survey

* implies a significance at 10%-level, ** – at 5%, *** – at 1%

Table C.6: Almost ideal demand system. Food category 2 (tubers)

Dependent variable = share of food category 2 (tubers) in household food expenditures	coef	se
Ln(category 1 unit value)	0.00126	0.00353
Ln(category 2 unit value)	0.03671***	0.00608
Ln(category 3 unit value)	0.00104	0.00423
Ln(category 4 unit value)	-0.01981***	0.00299
Ln(category 5 unit value)	-0.01081***	0.00173
Ln(category 6 unit value)	0.00055	0.00331
Ln(category 7 unit value)	-0.00274	0.00218
Ln(category 8 unit value)	-0.00620	0.00401
Ln(per capita expenditure)/Stone's index	-0.01500**	0.00711
Central Region (without Kampala)	0.00074	0.01528
Eastern Region	0.05055***	0.01698
Northern Region	0.03695**	0.01649
Western Region	0.02388	0.01646
Household size, GJ	0.00056	0.00042
Agricultural	0.07166***	0.01153
Urban	-0.05514***	0.00914
Nonselection hazard	0.01471	0.02811
Constant	0.21908***	0.06512
Chi-squared test	530.29***	
R-squared	0.134	
N obs	2794	

Source: Own estimation from UNPS (2010) survey

* implies a significance at 10%-level, ** – at 5%, *** – at 1%

Table C.7: Almost ideal demand system. Food category 3 (cereals)

Dependent variable = share of food category 3 (cereals) in household food expenditures	coef	se
Ln(category 1 unit value)	0.01274***	0.00395
Ln(category 2 unit value)	0.00104	0.00423
Ln(category 3 unit value)	0.02982***	0.00777
Ln(category 4 unit value)	-0.00841**	0.00328
Ln(category 5 unit value)	-0.00138	0.00204
Ln(category 6 unit value)	-0.01172***	0.00329
Ln(category 7 unit value)	-0.00972***	0.00229
Ln(category 8 unit value)	-0.01237***	0.00396
Ln(per capita expenditure)/Stone's index	-0.02597***	0.00813
Central Region (without Kampala)	-0.01748	0.01378
Eastern Region	0.04106***	0.01492
Northern Region	0.00855	0.01464
Western Region	-0.03791**	0.01507
Household size, GJ	0.00023	0.00045
Agricultural	-0.00097	0.01002
Urban	-0.00534	0.00938
Nonselection hazard	0.06625*	0.03763
Constant	0.30597***	0.07247
Chi-squared test	220.28***	
R-squared	0.0624	
N obs	2794	

Source: Own estimation from UNPS (2010) survey

* implies a significance at 10%-level, ** – at 5%, *** – at 1%

Table C.8: Almost ideal demand system. Food category 4 (legumes and bakery)

Dependent variable = share of food category 4 (legumes and bakery) in household food expenditures	coef	se
Ln(category 1 unit value)	0.00032	0.00323
Ln(category 2 unit value)	-0.01981***	0.00299
Ln(category 3 unit value)	-0.00841**	0.00328
Ln(category 4 unit value)	0.03281***	0.00458
Ln(category 5 unit value)	-0.00418**	0.00206
Ln(category 6 unit value)	-0.00275	0.00278
Ln(category 7 unit value)	0.00198	0.00201
Ln(category 8 unit value)	0.00005	0.00276
Ln(per capita expenditure)/Stone's index	-0.03059***	0.00571
Central Region (without Kampala)	-0.01705*	0.00974
Eastern Region	-0.03210***	0.01085
Northern Region	0.03127***	0.01058
Western Region	0.02252**	0.01105
Household size, GJ	-0.00110***	0.00031
Agricultural	0.01721**	0.00698
Urban	-0.00057	0.00612
Nonselection hazard	-0.10228***	0.02679
Constant	0.37866***	0.04959
Chi-squared test	476.6***	
R-squared	0.1449	
N obs	2794	

Source: Own estimation from UNPS (2010) survey

* implies a significance at 10%-level, ** – at 5%, *** – at 1%

Table C.9: Almost ideal demand system. Food category 5 (additives)

Dependent variable = share of food category 5 (additives) in household food expenditures	coef	se
Ln(category 1 unit value)	-0.00675***	0.00208
Ln(category 2 unit value)	-0.01081***	0.00173
Ln(category 3 unit value)	-0.00138	0.00204
Ln(category 4 unit value)	-0.00418**	0.00206
Ln(category 5 unit value)	0.03223***	0.00179
Ln(category 6 unit value)	-0.00221	0.00151
Ln(category 7 unit value)	-0.00295**	0.00128
Ln(category 8 unit value)	-0.00394**	0.00181
Ln(per capita expenditure)/Stone's index	-0.01505***	0.00232
Central Region (without Kampala)	0.02127***	0.00529
Eastern Region	0.01031*	0.00568
Northern Region	-0.00209	0.00575
Western Region	-0.02222***	0.00566
Household size, GJ	-0.00066***	0.00015
Agricultural	-0.01556***	0.00381
Urban	0.02155***	0.00324
Nonselection hazard	-0.22471***	0.04807
Constant	0.21103***	0.01936
Chi-squared test	859.11***	
R-squared	0.2318	
N obs	2794	

Source: Own estimation from UNPS (2010) survey

* implies a significance at 10%-level, ** – at 5%, *** – at 1%

Table C.10: Almost ideal demand system. Food category 6 (animal products)

Dependent variable = share of food category 6 (animal products) in household food expenditures	coef	se
Ln(category 1 unit value)	-0.00616*	0.00319
Ln(category 2 unit value)	0.00055	0.00331
Ln(category 3 unit value)	-0.01172***	0.00329
Ln(category 4 unit value)	-0.00275	0.00278
Ln(category 5 unit value)	-0.00221	0.00151
Ln(category 6 unit value)	0.03762***	0.00426
Ln(category 7 unit value)	-0.00223	0.00190
Ln(category 8 unit value)	-0.01310***	0.00315
Ln(per capita expenditure)/Stone's index	0.04874***	0.00615
Central Region (without Kampala)	0.01979	0.01209
Eastern Region	0.02992**	0.01281
Northern Region	0.02344*	0.01292
Western Region	0.01188	0.01291
Household size, GJ	0.00115***	0.00034
Agricultural	-0.03750***	0.00863
Urban	0.00292	0.00742
Nonselection hazard	-0.05589***	0.01003
Constant	-0.17524***	0.05157
Chi-squared test	381.75***	
R-squared	0.1290	
N obs	2794	

Source: Own estimation from UNPS (2010) survey

* implies a significance at 10%-level, ** – at 5%, *** – at 1%

Table C.11: Almost ideal demand system. Food category 7 (fruits and vegetables)

Dependent variable = share of food category 7 (fruits and vegetables) in household food expenditures	coef	se
Ln(category 1 unit value)	-0.00348	0.00225
Ln(category 2 unit value)	-0.00274	0.00218
Ln(category 3 unit value)	-0.00972***	0.00229
Ln(category 4 unit value)	0.00198	0.00201
Ln(category 5 unit value)	-0.00295**	0.00128
Ln(category 6 unit value)	-0.00223	0.00190
Ln(category 7 unit value)	0.02146***	0.00230
Ln(category 8 unit value)	-0.0023	0.00192
Ln(per capita expenditure)/Stone's index	-0.02428***	0.00311
Central Region (without Kampala)	-0.01441**	0.00723
Eastern Region	0.01272*	0.00767
Northern Region	0.00156	0.00774
Western Region	-0.02008**	0.00801
Household size, GJ	-0.00146***	0.00019
Agricultural	0.00351	0.00522
Urban	-0.00175	0.00453
Nonselection hazard	-0.03454*	0.02041
Constant	0.30114***	0.02599
Chi-squared test	315.22***	
R-squared	0.0972	
N obs	2794	

Source: Own estimation from UNPS (2010) survey

* implies a significance at 10%-level, ** – at 5%, *** – at 1%

Table C.12: Almost ideal demand system. Food category 8 (food luxuries)

Dependent variable = share of food category 8 (food luxuries) in household food expenditures	coef	se
Ln(category 2 unit value)	-0.00620	–
Ln(category 3 unit value)	-0.01237	–
Ln(category 4 unit value)	0.00005	–
Ln(category 5 unit value)	-0.00394	–
Ln(category 6 unit value)	-0.01310	–
Ln(category 7 unit value)	-0.00230	–
Ln(category 8 unit value)	0.03675	–
Ln(per capita expenditure)/stone index	0.03114	–
Central Region (without Kampala)	-0.03091	–
Eastern Region	-0.03087	–
Northern Region	0.04750	–
Western Region	-0.06591	–
Household size, GJ	-0.00095	–
Agricultural	-0.05966	–
Urban	0.02882	–
Nonselection hazard	0.29802	–
Constant	-0.05551	–
Chi-squared test	–	
R-squared	–	
N obs	2794	

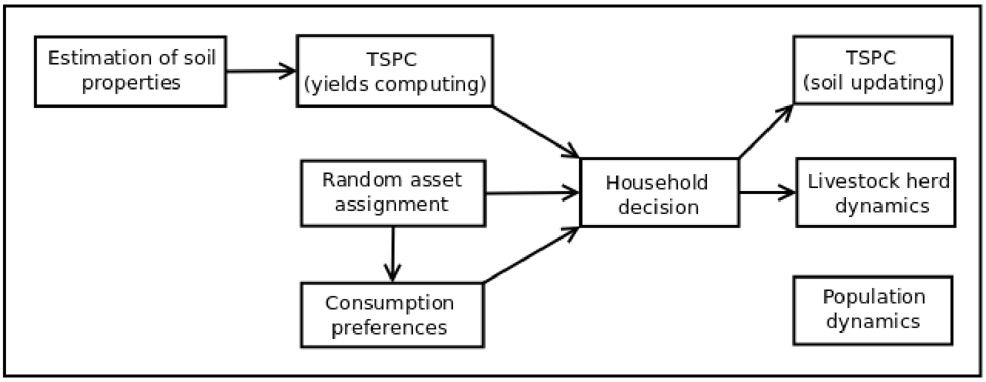
Source: Own estimation from UNPS (2010) survey

* coefficients are derived from estimates for other food categories (tables C.5 -C.11) using equations 3.17 - 3.19

Appendix D

Model calibration and validation

Figure D.1: Hierarchy of model components



Source: Author

Table D.1: Calibration benchmarks

Model component	Benchmark
Random asset assignment	Asset distribution functions from IFPRI (2010)
Household decision model	Household production estimated from IFPRI (2010) survey
Livestock	Amount of livestock kept or sold according to IFPRI (2010)
Population dynamics	World Bank (2012), CIA (2012) and UDHS (2007) demographic estimates for Uganda

Source: Author

Table D.2: Calibration parameters

Model component	Parameters
Random asset assignment	Number of copula bins Minimum/maximum values Interpolation method used
Crop production	Certainty equivalents Valuation coefficients of future returns Values assigned to home consumption of own produce Wage rate of hired labor
Livestock	Labor requirements External grazing effect Feed security buffer Farm-gate prices for livestock products Wage rate of hired labor Valuation coefficients of future returns
Demography and population dynamics	Age group definition Coefficients of Brass relational model lifetable

Source: Author

Table D.3: Household size

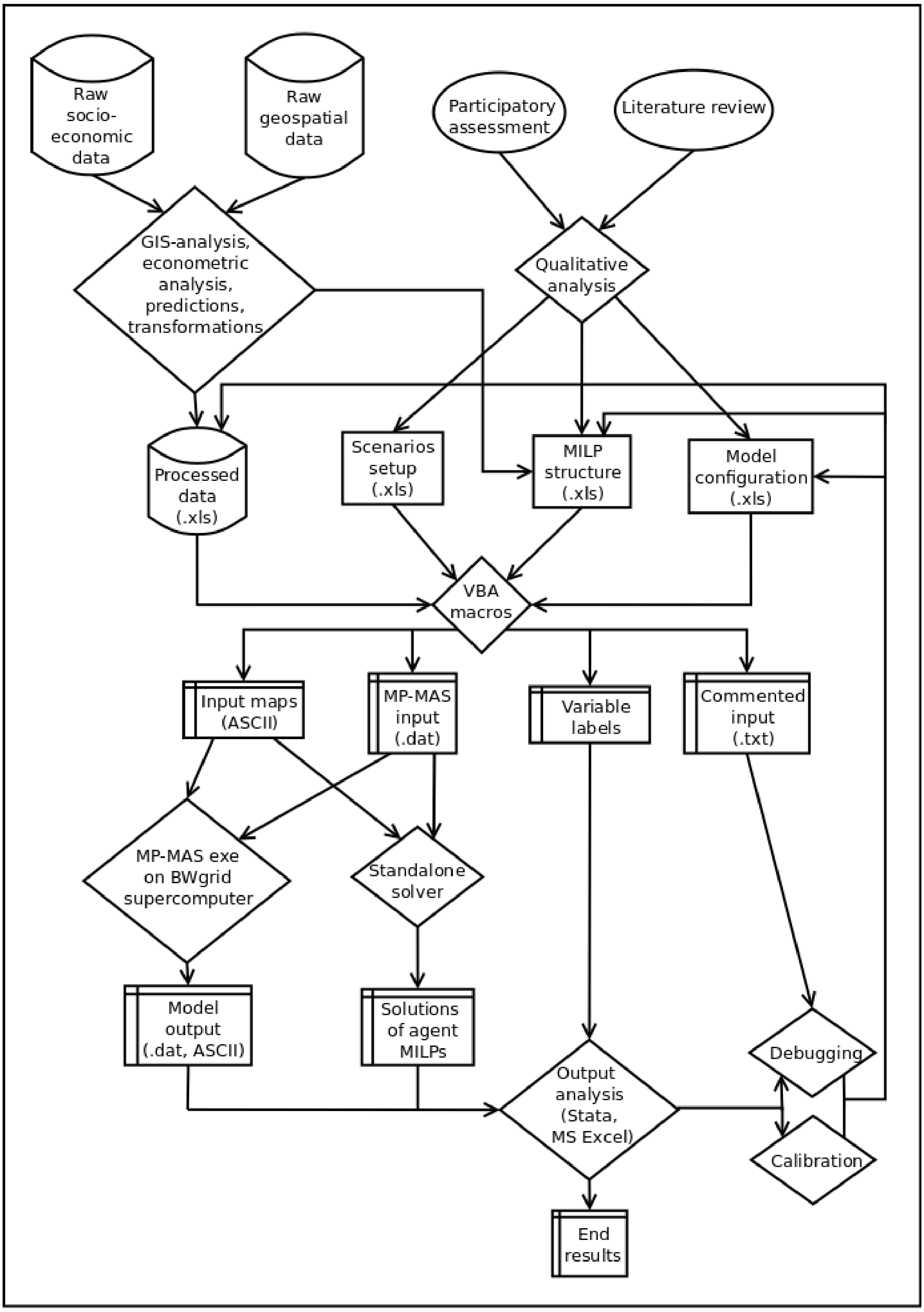
Characteristic	Populations	Mean	Median	Stdev	10%	25%	75%	90%
Total, persons	survey	6.55	6.00	2.51	4.00	5.00	8.00	10.00
	generated	6.78	6.96	2.46	4.00	5.00	8.91	10.00
Males, persons	survey	3.48	3.00	1.80	1.00	2.00	5.00	6.00
	generated	3.60	3.67	1.74	1.10	2.08	5.00	6.00
Females, persons	survey	3.07	3.00	1.60	1.00	2.00	4.00	5.00
	generated	3.19	3.00	1.64	1.00	2.00	4.00	5.04
Total, male adult	survey	4.93	4.72	1.88	2.73	3.46	6.26	7.67
equivalent	generated	5.11	5.02	1.87	2.72	3.66	6.47	7.62
Males, male adult	survey	2.82	2.76	1.50	1.03	1.69	3.85	4.90
equivalent	generated	2.92	2.86	1.47	1.03	1.90	3.79	4.88
Females, male adult	survey	2.11	2.15	1.11	0.78	1.31	2.75	3.69
equivalent	generated	2.19	2.11	1.14	0.78	1.38	2.91	3.69
Density,	survey	3.67	3.29	2.40	1.37	2.02	4.94	6.18
persons per ha	generated	3.84	3.32	2.67	1.28	2.04	4.92	6.78

Source: Author, based on results of sampling from empirical copula

* characteristics of survey population are estimated from IFPRI (2010)

** generated populations are represented by average values over 50 populations drawn with different random seeds

Figure D.2: Construction and calibration of model baseline



Source: Author

Table D.4: Household coffee plantations

Characteristic	Populations	Mean	Median	Stdev	10%	25%	75%	90%
Coffee,	survey	48.10	46.65	21.57	22.22	33.33	59.83	79.37
% of land	generated	48.63	46.90	21.61	22.22	33.25	60.41	82.34
Coffee, ha	survey	1.15	0.81	0.91	0.28	0.45	1.62	2.25
	generated	1.18	0.89	0.93	0.30	0.50	1.61	2.34

Source: Author, based on results of sampling from empirical copula

* characteristics of survey population are estimated from IFPRI (2010)

** generated populations are represented by average values over 50 populations drawn with different random seeds

Table D.5: Household livestock ownership

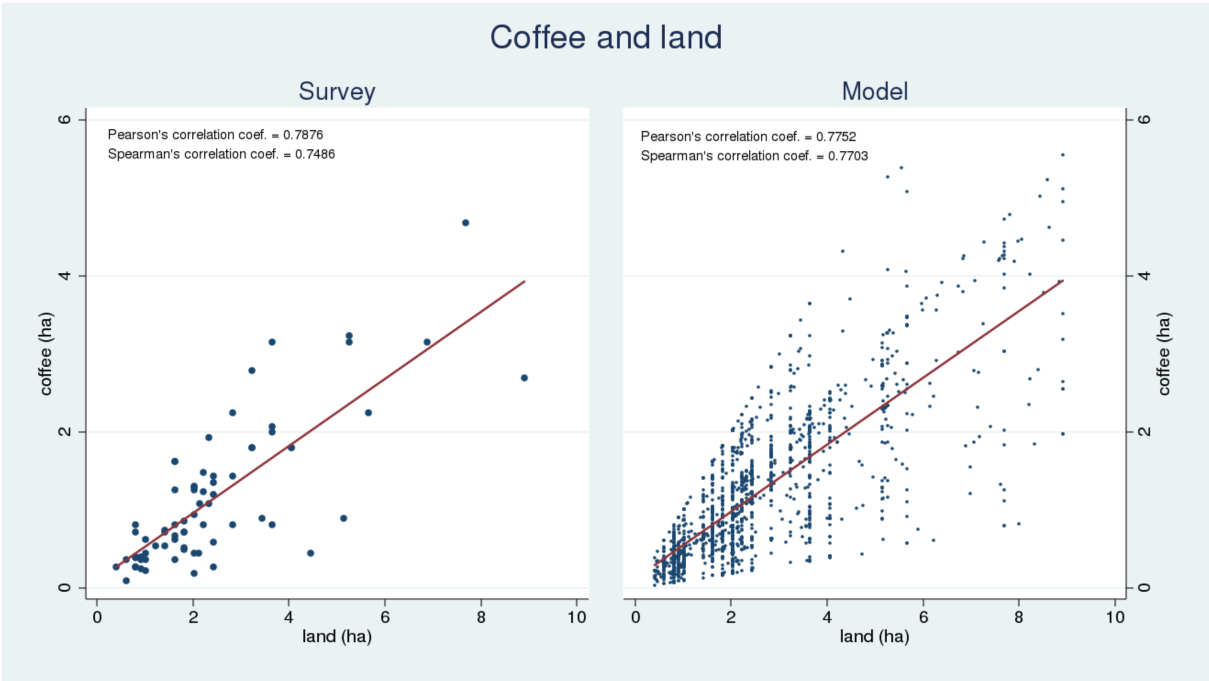
Characteristic	Populations	Mean	Median	Stdev	10%	25%	75%	90%
Cattle, head	survey	2.46	2.00	5.05	0.00	0.00	3.00	4.00
	generated	2.44	2.00	4.41	0.00	0.00	3.00	4.82
Goats, head	survey	2.32	1.00	3.56	0.00	0.00	3.00	6.00
	generated	2.36	0.98	3.49	0.00	0.00	3.47	5.98
Chicken, head	survey	11.37	0.00	19.33	0.00	0.00	18.00	35.00
	generated	11.63	0.26	19.06	0.00	0.00	18.52	34.80
Pigs, head	survey	1.17	0.00	1.59	0.00	0.00	2.00	3.00
	generated	1.18	0.29	1.57	0.00	0.00	2.00	3.00
Total livestock,	survey	1.81	1.30	2.66	0.20	0.70	2.20	2.94
FAO units	generated	1.81	1.37	2.32	0.18	0.54	2.26	3.33
Stocking rate,	survey	1.05	0.62	2.02	0.12	0.26	1.08	1.82
FAO units per ha	generated	1.00	0.59	1.54	0.07	0.25	1.16	2.27

Source: Author, based on results of sampling from empirical copula

* characteristics of survey population are estimated from IFPRI (2010)

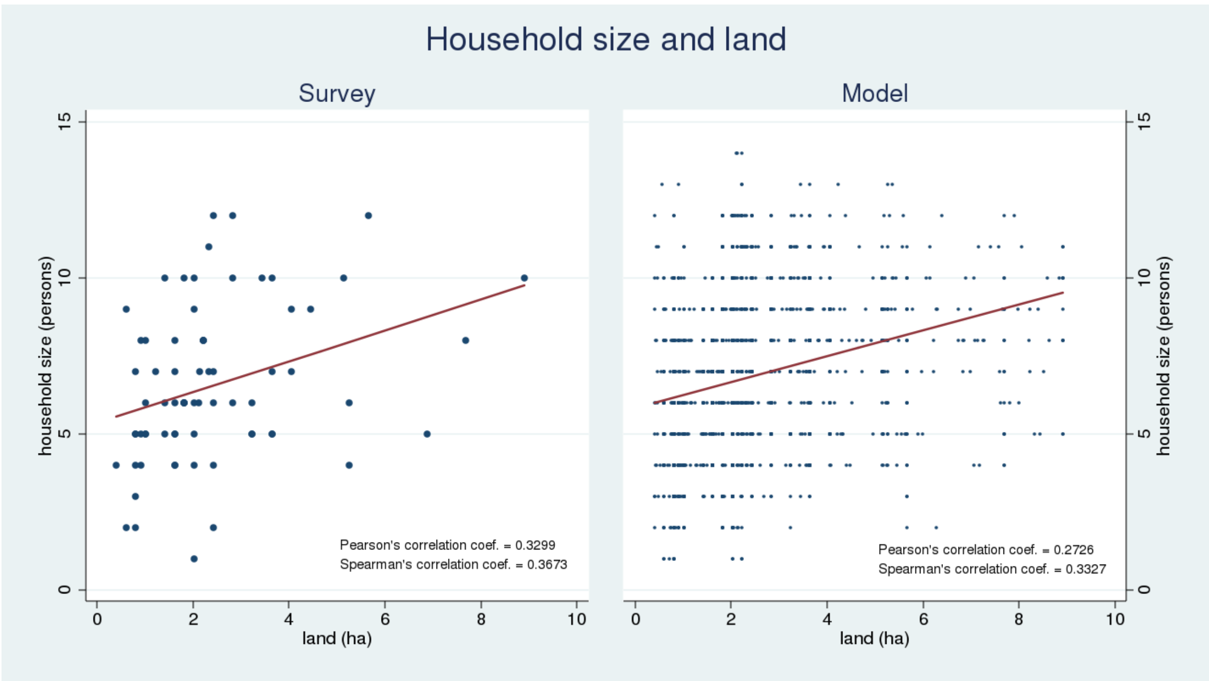
** generated populations are represented by average values over 50 populations drawn with different random seeds

Figure D.3: Correlations between area under coffee plantations and available land



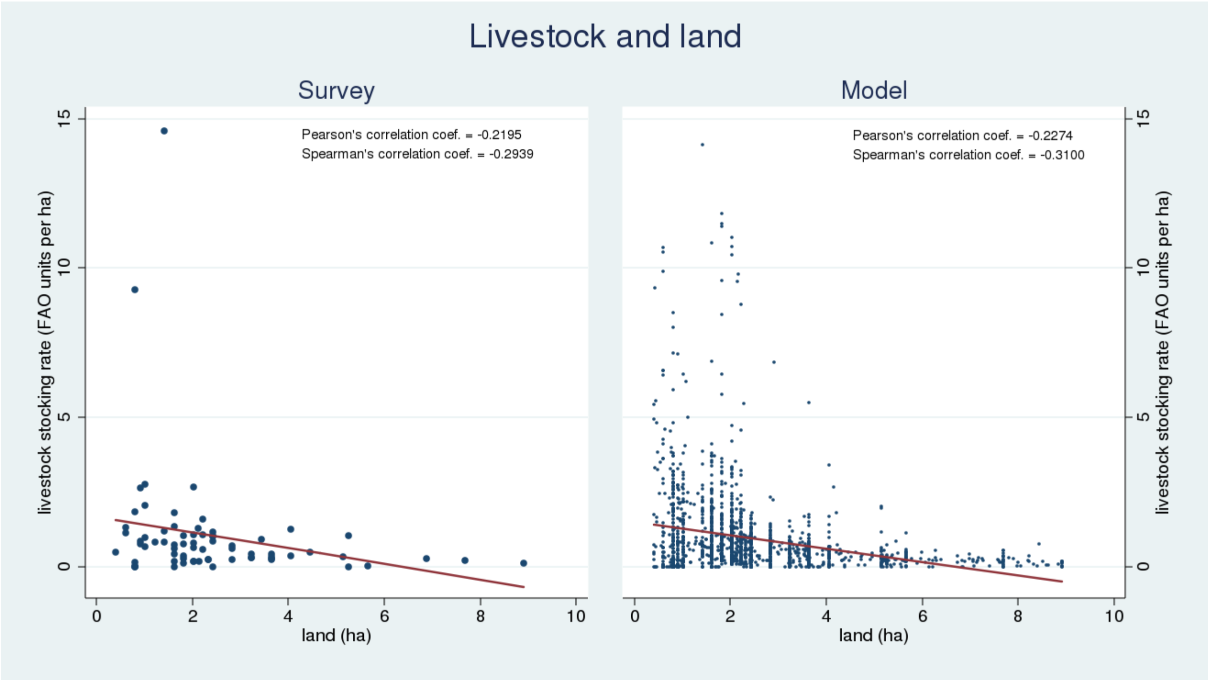
Source: Author, based on results of sampling from empirical copula
* characteristics of survey population are estimated from IFPRI (2010)

Figure D.4: Correlations between household size and available land



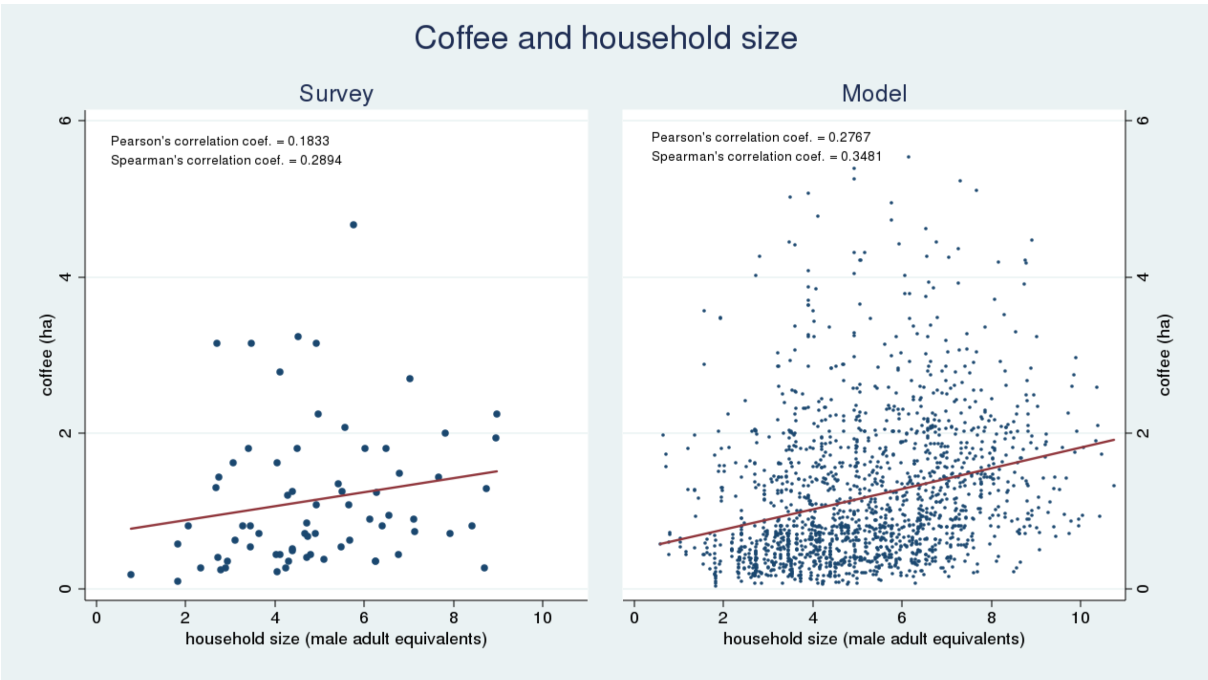
Source: Author, based on results of sampling from empirical copula
* characteristics of survey population are estimated from IFPRI (2010)

Figure D.5: Correlations between amount of livestock and available land



Source: Author, based on results of sampling from empirical copula
* characteristics of survey population are estimated from IFPRI (2010)

Figure D.6: Correlations between area under coffee plantations and household size



Source: Author, based on results of sampling from empirical copula
* characteristics of survey population are estimated from IFPRI (2010)

Table D.6: Farm livestock, heads

		Type of livestock			
Population	Random seed	Cattle	Chicken	Goats	Pigs
Survey*	N/A	2.46	4.59	2.32	0.79
Model** 1	1	2.12	4.22	1.82	0.83
Model 2	2	2.01	4.33	2.19	0.85
Model 3	3	2.09	4.81	1.99	0.86
Model 4	4	2.08	4.69	2.15	0.82
Model 5	5	2.15	5.11	1.94	0.85
Model 6	6	2.07	4.54	2.07	0.81
Model 7	7	2.06	4.42	2.13	0.83
Model 8	8	2.01	4.23	1.99	0.79
Model 9	9	2.10	4.62	2.14	0.83
Model 10	10	2.12	4.77	1.86	0.80
Model Average		2.08	4.57	2.03	0.83
Stdev		0.047	0.284	0.127	0.022
CV		0.023	0.062	0.063	0.026

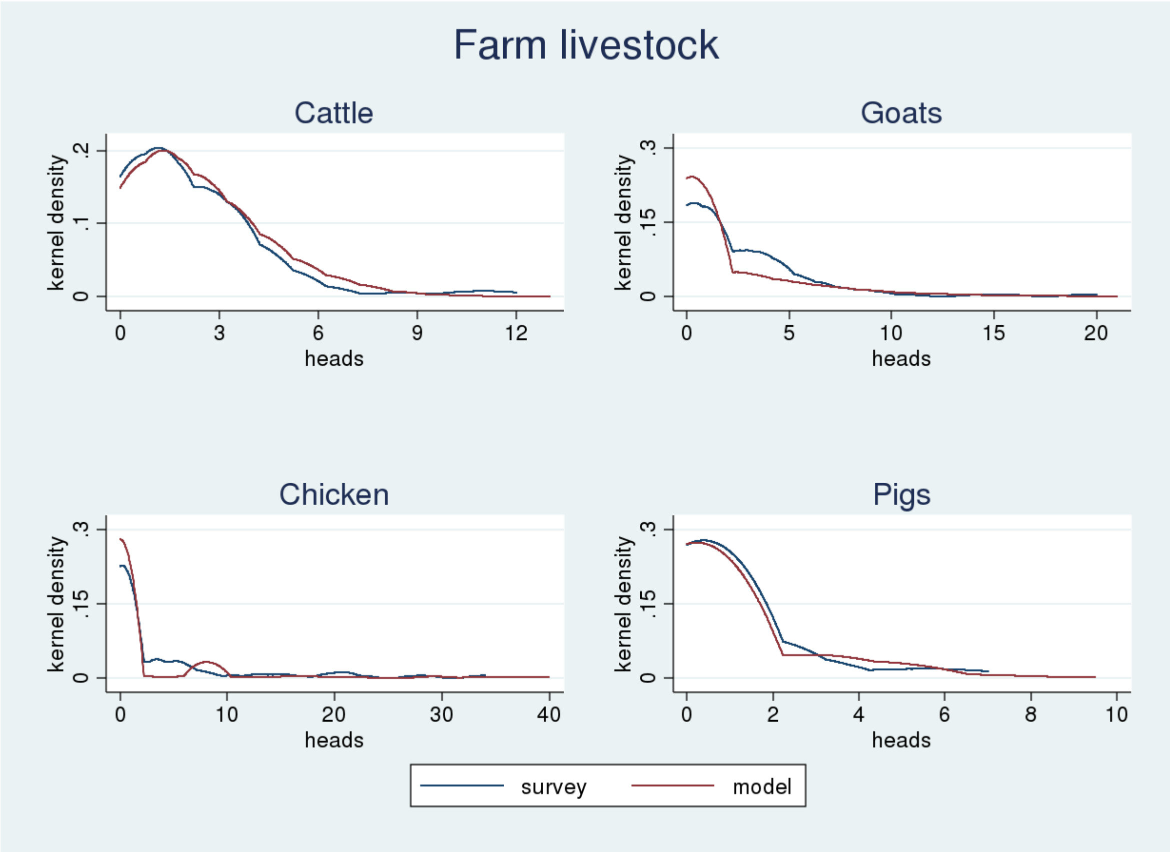
Source: Author, based on MP-MAS simulation results
* livestock of survey population are estimated from IFPRI (2010)
** model livestock are reported as annual means of 5 period simulation

Table D.7: Model prediction errors, absolute value percentage difference

		Type of livestock			
Population	Random seed	Cattle	Chicken	Goats	Pigs
1	1	13.94	8.07	21.48	5.20
2	2	18.60	5.73	5.68	7.50
3	3	15.29	4.81	14.40	8.49
4	4	15.74	2.22	7.59	4.25
5	5	12.90	11.31	16.62	8.02
6	6	16.16	1.12	10.75	2.55
7	7	16.50	3.80	8.51	4.63
8	8	18.46	7.88	14.31	0.76
9	9	14.61	0.54	8.04	5.62
10	10	13.81	3.78	19.97	1.09
Average error		15.60	4.93	12.73	4.81
Maximum error		18.60	11.31	21.48	8.49

Source: Author, based on MP-MAS simulation results

Figure D.7: Farm livestock. Density functions

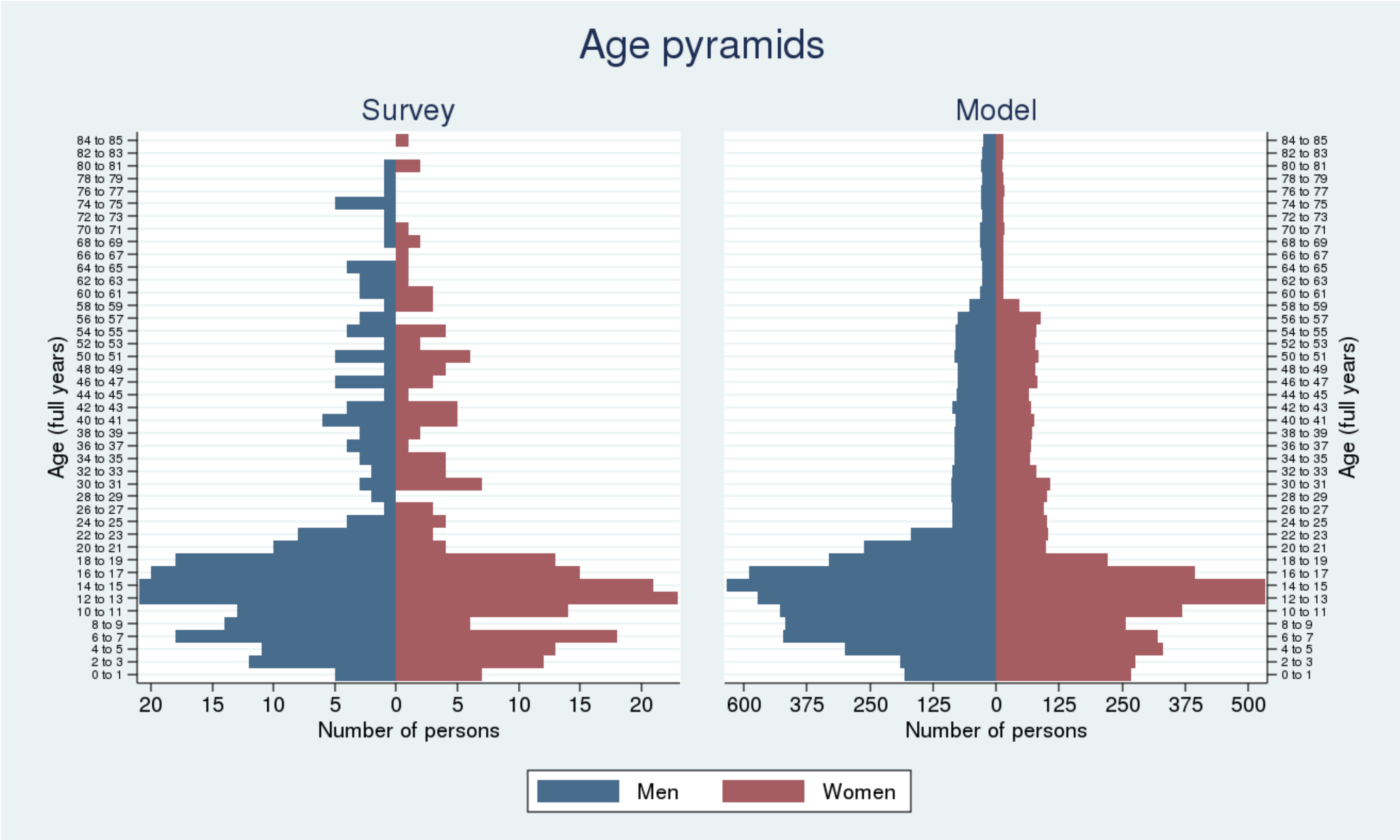


Source: Author, based on MP-MAS simulation results

* survey livestock are estimated from IFPRI (2010)

** model livestock are reported as annual means of 5 period simulation

Figure D.8: Demography model. Population structure



Source: Author, based on MP-MAS simulation results

* characteristics of survey population are estimated from IFPRI (2010)

Appendix E

Scenario description and simulation results

Table E.1: Motivation schemes. Results compilation

Scenario code	Requirement, kg	Premium, ugx/kg	Bonus, ugx	Budget, th. ugx	△* Household income	△ Household revenue, %	△ RPO turnover, %	△ RPO profit, %
M1	250	100	0	78.5	0.34	1.12	7.06	-0.33
M2	250	0	25,000	29.9	0.13	0.12	10.31	10.56
M3	250	50	5,000	44.3	0.32	1.23	10.13	6.49
M4	500	200	0	80.9	-1.19	-4.42	-38.21	-46.85
M5	500	50	50,000	76.1	0.08	0.63	16.08	13.80
M6	250	25	0	19.2	0.40	0.90	4.34	2.60
M7	250	50	0	38.6	0.38	0.81	5.04	1.45
M8	250	200	0	148.5	-0.10	-0.24	-2.83	-17.15
M9	250	0	5,000	4.3	0.20	0.64	2.50	2.56
M10	250	0	10,000	8.9	0.21	0.59	3.21	3.29
M11	250	0	50,000	67.0	0.11	-0.25	12.43	12.73
M12	250	0	100,000	11.2	-2.55	-8.41	-96.35	-98.54
M13	250	25	5,000	23.8	0.38	0.89	8.52	6.83
M14	250	25	10,000	27.7	0.39	0.68	6.83	5.17
M15	250	50	10,000	49.5	0.46	1.18	12.58	8.92
M16	500	50	0	28.9	0.27	0.68	2.90	0.19
M17	500	100	0	57.7	0.27	0.60	2.83	-2.64
M18	500	0	25,000	19.5	0.17	0.45	5.50	5.64
M19	500	0	50,000	48.9	0.39	0.86	14.93	15.28
M20	500	0	100,000	49.6	-2.21	-7.63	-72.53	-74.18
M21	500	0	200,000	89.9	-2.51	-8.25	-75.25	-76.97
M22	500	50	25,000	49.9	0.41	1.10	11.87	9.15
M23	500	100	25,000	78.2	0.20	0.26	7.91	2.28
M24	1,000	50	0	14.0	0.21	0.47	-0.49	-1.84
M25	1,000	200	0	59.5	0.06	0.10	1.67	-3.99
M26	1,000	0	50,000	22.6	-0.14	-0.07	1.85	1.90
M27	1,000	0	300,000	1.8	-2.85	-10.05	-99.15	-101.43
M28	1,000	50	50,000	37.6	-0.01	0.50	4.84	3.48
M29	1,000	50	100,000	66.9	0.10	0.45	10.18	9.09

Table E.1 (cont.): Motivation schemes. Results compilation

Scenario code	Requirement, kg	Premium, ugx/kg	Bonus, ugx	Budget, th. ugx	Δ* Household income	Δ Household revenue, %	Δ RPO turnover, %	Δ RPO profit, %
M30	1,000	100	50,000	52.0	0.13	0.21	3.43	0.62
M31	2,000	50	0	2.3	0.18	0.64	-0.17	-0.40
M32	2,000	200	0	8.9	0.16	0.36	-1.84	-2.74
M33	2,000	300	0	13.2	0.13	0.19	-2.40	-3.73
M34	2,000	0	100,000	9.9	0.01	0.09	-1.53	-1.57
M35	2,000	0	300,000	29.6	0.12	0.78	-0.67	-0.68
M36	2,000	0	500,000	50.6	-0.10	0.11	-1.64	-1.67
M37	2,000	50	50,000	6.9	-0.16	-0.36	-1.75	-1.99
M38	2,000	50	100,000	12.1	-0.04	-0.08	-0.94	-1.19
M39	2,000	100	50,000	8.8	-0.09	-0.23	-2.49	-2.93
M40	2,000	100	100,000	14.8	0.09	0.44	-1.07	-1.56

Source: Author, based on MP-MAS simulation input

* relative difference with baseline

** results reported as annual averages of 15 period simulation

Table E.2: Group certification. Scenario description

Scenario code	Costs covered by RPO	Annual interest rate	Reinvestment period, years	Certified members, % of all members	Share of produce certified
C1	none	n/a	n/a	current (22.4 %)	25%
C2	none	n/a	n/a	current	50%
C3	none	n/a	n/a	current	75%
C4	none	n/a	n/a	current	100%
C5	none	n/a	n/a	half (50%)	25%
C6	none	n/a	n/a	half	50%
C7	none	n/a	n/a	half	75%
C8	none	n/a	n/a	half	100%
C9	none	n/a	n/a	all (100%)	25%
C10	none	n/a	n/a	all	50%
C11	none	n/a	n/a	all	75%
C12	none	n/a	n/a	all	100%
C13	running only	n/a	n/a	current	25%
C14	running only	n/a	n/a	current	50%
C15	running only	n/a	n/a	current	75%
C16	running only	n/a	n/a	current	100%
C17	running only	n/a	n/a	half	25%
C18	running only	n/a	n/a	half	50%
C19	running only	n/a	n/a	half	75%
C20	running only	n/a	n/a	half	100%
C21	running only	n/a	n/a	all	25%
C22	running only	n/a	n/a	all	50%
C23	running only	n/a	n/a	all	75%
C24	running only	n/a	n/a	all	100%
C25	full	zero (0%)	5	current	25%
C26	full	zero	5	current	50%
C27	full	zero	5	current	75%
C28	full	zero	5	current	100%
C29	full	zero	5	half	25%
C30	full	zero	5	half	50%
C31	full	zero	5	half	75%
C32	full	zero	5	half	100%
C33	full	zero	5	all	25%
C34	full	zero	5	all	50%
C35	full	zero	5	all	75%
C36	full	zero	5	all	100%

Table E.2 (cont.1): Group certification. Scenario description

Scenario code	Costs covered by DC	Annual interest rate	Reinvestment period, years	Certified members, % of all members	Share of produce certified
C37	full	zero	10	current	25%
C38	full	zero	10	current	50%
C39	full	zero	10	current	75%
C40	full	zero	10	current	100%
C41	full	zero	10	half	25%
C42	full	zero	10	half	50%
C43	full	zero	10	half	75%
C44	full	zero	10	half	100%
C45	full	zero	10	all	25%
C46	full	zero	10	all	50%
C47	full	zero	10	all	75%
C48	full	zero	10	all	100%
C49	full	risk-free (8.5%)	5	current	25%
C50	full	risk-free	5	current	50%
C51	full	risk-free	5	current	75%
C52	full	risk-free	5	current	100%
C53	full	risk-free	5	half	25%
C54	full	risk-free	5	half	50%
C55	full	risk-free	5	half	75%
C56	full	risk-free	5	half	100%
C57	full	risk-free	5	all	25%
C58	full	risk-free	5	all	50%
C59	full	risk-free	5	all	75%
C60	full	risk-free	5	all	100%
C61	full	risk-free	10	current	25%
C62	full	risk-free	10	current	50%
C63	full	risk-free	10	current	75%
C64	full	risk-free	10	current	100%
C65	full	risk-free	10	half	25%
C66	full	risk-free	10	half	50%
C67	full	risk-free	10	half	75%
C68	full	risk-free	10	half	100%
C69	full	risk-free	10	all	25%
C70	full	risk-free	10	all	50%
C71	full	risk-free	10	all	75%
C72	full	risk-free	10	all	100%
C73	full	market (19.21%)	5	current	25%
C74	full	market	5	current	50%
C75	full	market	5	current	75%
C76	full	market	5	current	100%
C77	full	market	5	half	25%
C78	full	market	5	half	50%
C79	full	market	5	half	75%
C80	full	market	5	half	100%
C81	full	market	5	all	25%
C82	full	market	5	all	50%
C83	full	market	5	all	75%
C84	full	market	5	all	100%
C85	full	market	10	current	25%
C86	full	market	10	current	50%
C87	full	market	10	current	75%
C88	full	market	10	current	100%
C89	full	market	10	half	25%
C90	full	market	10	half	50%
C91	full	market	10	half	75%
C92	full	market	10	half	100%
C93	full	market	10	all	25%
C94	full	market	10	all	50%
C95	full	market	10	all	75%
C96	full	market	10	all	100%

Source: Author, based on MP-MAS simulation input

Table E.3: Group certification. Simulation results

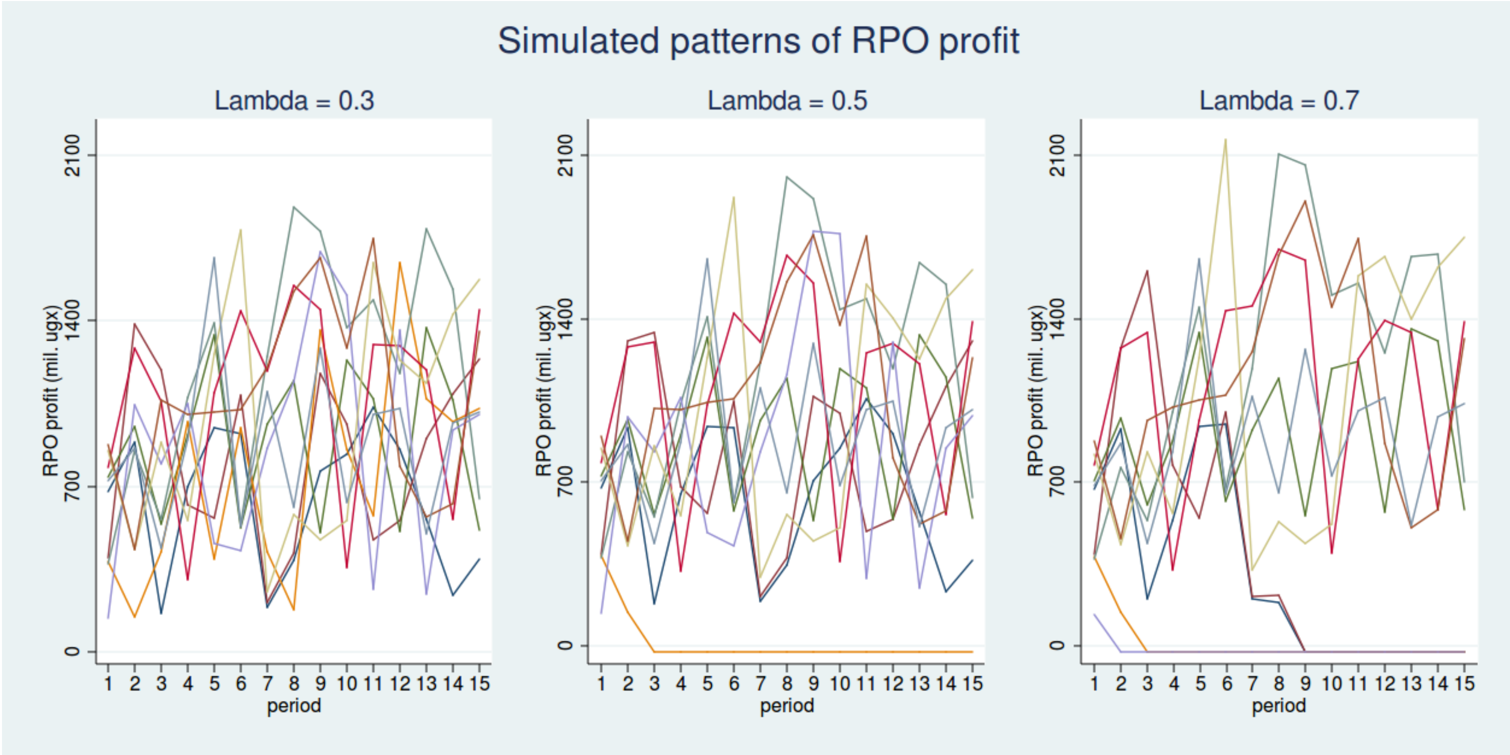
Scenario	Arrangement sustainability	Added value*, ugx/kg	Δ** Household income, %	Δ RPO profit, %
C1	+ (sustainable)	331	1.33	31.55
C2	+	331	2.25	37.08
C3	+	331	3.45	69.80
C4	+	331	4.69	85.82
C5	+	331	2.20	49.27
C6	+	331	4.57	86.74
C7	+	331	6.26	100.90
C8	+	331	8.13	114.58
C9	+	331	4.24	86.19
C10	+	331	7.42	115.06
C11	+	331	11.04	140.93
C12	+	331	14.73	162.31
C13	+	222	0.84	17.59
C14	+	284	1.99	35.33
C15	+	300	3.37	62.32
C16	+	309	4.79	86.97
C17	+	256	2.24	45.42
C18	+	292	4.57	85.06
C19	+	305	6.24	99.84
C20	+	312	7.93	113.41
C21	+	261	3.91	83.73
C22	+	295	7.07	109.91
C23	+	308	10.70	135.78
C24	+	314	14.54	160.60
C25	- (not sustainable)	n/a	-0.01	n/a
C26	+	189	1.56	29.94
C27	+	240	2.43	40.89
C28	+	266	4.21	83.73
C29	-	n/a	0.42	n/a
C30	+	233	3.77	80.17
C31	+	267	5.38	93.03
C32	+	284	7.18	107.12
C33	+	180	2.98	68.16
C34	+	251	6.01	97.46
C35	+	278	10.14	127.87
C36	+	292	14.03	154.63
C37	+	107	0.68	9.96
C38	+	249	1.70	34.32
C39	+	277	2.84	46.83
C40	+	292	4.40	85.33
C41	+	206	1.61	36.15
C42	+	268	3.98	83.22
C43	+	289	5.68	96.56
C44	+	301	7.81	111.83
C45	+	227	3.60	80.59
C46	+	277	6.81	104.76
C47	+	296	10.15	131.25
C48	+	305	14.29	157.91
C49	-	n/a	0.08	n/a
C50	+	148	1.34	25.75
C51	+	221	2.24	38.10
C52	+	252	4.04	82.16
C53	-	n/a	-0.11	n/a
C54	+	216	3.65	76.83
C55	+	255	5.38	90.47
C56	+	275	7.30	105.91
C57	+	136	1.67	34.29
C58	+	238	6.17	95.80
C59	+	270	9.77	126.23
C60	+	286	13.71	154.06

Table E.3 (cont.1): Group certification. Simulation results

Scenario	Arrangement sustainability	Added value*, ugx/kg	∆** Household income, %	∆ RPO profit, %
C61	-	n/a	0.18	n/a
C62	+	222	1.58	31.82
C63	+	260	2.72	43.04
C64	+	280	4.05	84.20
C65	+	147	0.83	18.91
C66	+	252	3.94	80.71
C67	+	280	5.78	96.71
C68	+	293	7.50	109.44
C69	+	205	3.18	75.76
C70	+	265	6.29	101.45
C71	+	288	10.14	128.87
C72	+	299	14.30	156.87
C73	-	n/a	-0.05	n/a
C74	-	n/a	0.05	n/a
C75	+	192	2.05	33.82
C76	+	231	3.75	77.97
C77	-	n/a	-0.08	n/a
C78	+	191	2.92	60.77
C79	+	237	4.87	88.09
C80	+	263	6.79	103.34
C81	-	n/a	-0.01	n/a
C82	+	219	5.30	91.02
C83	+	257	9.41	121.55
C84	+	277	13.45	152.23
C85	-	n/a	0.12	n/a
C86	+	176	1.35	28.86
C87	+	234	2.18	39.15
C88	+	262	4.06	83.98
C89	-	n/a	0.17	n/a
C90	+	227	3.69	77.93
C91	+	263	5.29	92.67
C92	+	281	7.22	106.69
C93	+	170	2.77	63.73
C94	+	246	6.05	96.68
C95	+	275	9.69	125.46
C96	+	290	13.78	154.46

Source: Author, based on MP-MAS simulation results
* added value of certification calculated per kg of certified FAQ coffee
** relative difference with baseline
*** implies sustained group certification after 15 period simulation
**** added value, ∆ income and ∆ profit reported as annual averages over 15 periods

Figure E.1: Price variability. Effect of expectations



Source: Author, based on MP-MAS simulation results

Appendix F

Other tables and figures

Table F.1: List of distributed household variables

Variable	Unit
Spatial	
Elevation	masl
Slope	%
Flow accumulation	30 m grid cell
Demographic	
Female household members (by age groups*)	persons
Male household members (by age groups)	persons
Financial	
Starting liquidity (as annual cash requirement)	ugx
Annual value of received remittances	ugx
Monthly rate of time preference	%
Physical assets	
Available land	ha
Size of coffee plantations (as share of total land)	%
Cattle	number of units
Goats	number of units
Chicken	number of units
Pigs	number of units
Symbolic assets	
Access to mineral fertilizers	yes/no

Source: Author

* age groups are described in section 3.8

Table F.2: Correlations between survey variables. Spearman's rho

	Land	Members	Mean age	Elevation	Slope	Flow accum.	Coffee	Trad. cattle	Imp. cattle	Goats	Sheep	Pigs	Chicken	Savings
Members	**0.360**	1												
Mean Age	0.127	**-0.398**	1											
Elevation	-0.036	0.042	**-0.304**	1										
Slope	0.040	0.030	0.143	0.067	1									
Flow accum.	0.012	- 0.097	**0.308**	**-0.301**	0.022	1								
Coffee	**0.719**	0.220	0.135	-0.020	0.073	0.130	1							
Trad. cattle	0.126	0.158	- 0.189	0.095	0.043	0.011	0.079	1						
Imp. cattle	0.289	0.108	0.095	-0.053	0.045	-0.031	0.282	-0.285	1					
Goats	0.067	0.160	- 0.065	0.083	0.119	-0.164	-0.011	0.165	0.275	1				
Sheep	0.155	**0.304**	-0.013	-0.002	0.186	-0.049	0.199	-0.031	- 0.093	0.108	1			
Pigs	-0.008	-0.019	-0.079	-0.022	0.060	-0.003	-0.183	-0.048	- 0.065	0.119	-0.115	1		
Chicken	0.120	**0.318**	-0.100	0.055	0.031	0.012	0.063	0.053	0.246	**0.359**	-0.037	0.234	1	
Savings	0.157	0.104	- 0.053	-0.098	-0.039	0.014	0.256	-0.137	0.046	0.012	0.024	0.177	0.147	1
Credit	0.055	0.058	0.050	0.091	0.013	0.084	0.123	-0.124	-0.120	0.013	**0.322**	0.060	0.083	0.184

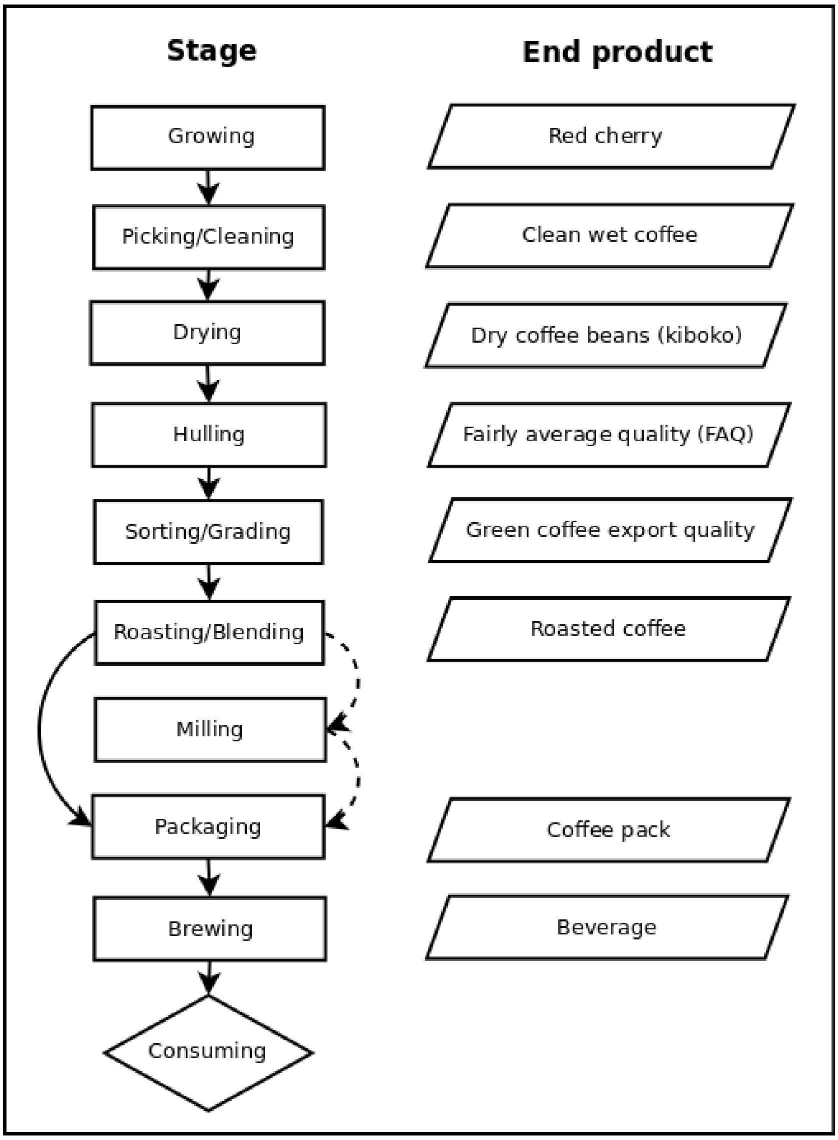
Source: Author, based on the IFPRI (2010) data

Table F.3: Correlations between survey variables. Error probability of dcov test

	Land	Members	Mean age	Elevation	Slope	Flow accum.	Coffee	Trad. cattle	Imp. cattle	Goats	Sheep	Pigs	Chicken	Savings
Members	**0.030**	1												
Mean Age	0.140	**0.005**	1											
Elevation	0.825	0.500	**0.005**	1										
Slope	0.785	0.745	0.695	**0.050**	1									
Flow accum.	0.240	0.170	**0.015**	**0.030**	**0.075**	1								
Coffee	**0.015**	**0.065**	0.390	0.635	0.895	0.300	1							
Trad. cattle	0.675	0.155	0.210	0.520	0.650	0.730	0.845	1						
Imp. cattle	**0.060**	0.130	0.625	0.955	0.720	0.925	0.250	0.125	1					
Goats	0.825	0.410	0.975	0.655	0.350	**0.050**	0.865	**0.005**	**0.030**	1				
Sheep	0.675	**0.005**	0.805	0.480	0.105	0.840	0.460	0.095	0.375	**0.045**	1			
Pigs	**0.070**	0.670	0.870	0.955	0.880	0.815	**0.100**	0.665	0.475	0.545	0.260	1		
Chicken	0.220	**0.015**	0.630	0.440	0.410	0.850	0.230	0.315	**0.060**	**0.045**	0.700	**0.030**	1	
Savings	0.645	0.490	0.935	0.195	0.410	0.960	0.170	0.105	0.690	0.530	0.865	0.115	**0.015**	1
Credit	**0.100**	**0.030**	0.515	0.125	0.770	0.320	**0.020**	0.595	0.555	0.860	**0.045**	0.480	0.140	**0.040**

Source: Author, based on the IFPRI (2010) data

Figure F.1: Value chain of robusta coffee



Source: Author

Table F.4: Institutions influential for the Uganda’s coffee sector

Name	**Status**	**Related functions**	**Source of funding**
Ministry of Agriculture, Animal Industry and Fisheries (MAAIF)	Government	– Governance of agricultural sector in general	State budget
Ministry of Finance, Planning and Economic Development (MFPED)	Government	– Planning and implementation of public expenditure programs	State budget
Ministry of Tourism, Trade, and Industry (MTTI)	Government	– Development of trade policies and export regulations	State budget
National Agricultural Advisory Services (NAADS)	Statutory	– Promotion of market-oriented agriculture through the provision of extension services	MAAIF
National Agricultural Research Organization (NARO)	Statutory	– Guidance and coordination of all agricultural research activities	MAAIF, donors
Coffee Research Center (COREC)	Statutory	– Research and development of effective coffee production technologies	NARO, donors
Uganda Coffee Development Authority (UCDA)	Statutory	– Promoting the development of the coffee sector – Provision of extension services – Registration and licensing of businesses in the coffee sector – Price and production forecasts – Propagation, development and distribution of safe planting materials – Registration of trade contracts	Coffee export tax
Uganda Cooperative Alliance (UCA)	Private	– Apex body for all registered cooperatives – Advocacy and representation of the cooperative entities on national and international levels – Capacity building for cooperative members – Mobilization of the resources for the development of the cooperative movement	Membership fees, donors
Uganda Coffee Trade Federation (UCTF)	Private	– Promotion and maintenance of sustainable development of the coffee sector – Lobbying and guarding interests of persons and organizations engaged in the coffee production and trade	Membership fees

Table F.4 (cont.): Institutions influential for the Uganda's coffee sector

Name	**Status**	**Related functions**	**Source of funding**
National Union of Coffee Agribusinesses and Farm Enterprises (NUCAFE)	Private	– Ensuring better position of the farmers within the coffee value chain – Establishment of a sustainable farmer-ownership model of a coffee marketing – Representation and advocacy of interests of coffee farmers	Membership fees, donors
National Organic Agriculture Movement of Uganda (NOGAMU)	Private	– Promotion of organic agriculture – Advocacy and representation for related POs and NGOs – Capacity building and provision of certification services	Membership fees
Uganda Coffee Roasters Association (UCRA)	Private	– Representation of interests of local coffee roasters	Membership fees

Source: Author

Table F.5: Coffee research in African countries

	Ethiopia	Kenya	Tanzania	Uganda
Research staff, persons	68	31	27	4
Annual budget, mln. usd	3.5	3.0	4.0	0.2
Annual coffee production, kt.	280	47	50	200
Export revenue share, %	70	5	20	25

Source: UCTF (2010)