Understanding smallholder farming systems for food security in Burundi

Sanctus Niragira

"*Most of the people in the world are poor, so if we knew the economics of being poor we would know much of the economics that really matters. Most of the world's poor people earn their living from agriculture, so if we knew the economics of agriculture we would know much of the economics of being poor.*"

Theodore William Schultz during his Nobel Lecture in 1979; published in 1980.

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List of abbreviations and acronyms

AAAE	: African Association of Agricultural Economists
AEASA	: Agricultural Economists Association of South Africa
ANOVA	: Analysis of Variance
BIF	: Burundi Franc
BTC	: Belgian Technical Cooperation
CAADP	: Comprehensive African Agriculture Development Programme
CRS	: Constant Return to Scale
DEA	: Data Envelopment Analysis
ENAB	: Enquête Nationale Agricole au Burundi
FACAGRO	: Faculté d'Agronomie
FAO	: Food and Agriculture Organisation
FFS	: Farmer Field School
FIDA	: Fonds International de Développement Agricole
GAPSYM7	: Ghent Africa Platform, 7th Symposium
GDP	: Gross Domestic Product
GPS	: Global Positioning System
HFIAS	: Household Food Insecurity Access Scale
ICG	: International Crises Group
IFAD	: International Funds for Agricultural Development
IMF	: International Monetary Fund
INEAC	: Institut National pour Etude Agronomique du Congo
IFPRI	: International Food Policy Research Institute
ISABU	: Institut des Sciences Agronomiques du Burundi
ISTEEBU	: Institut des Statistiques et d'Etudes Economiques du Burundi
IUC	: Institutional University Cooperation
MDCOM	: Ministère de Développement Communal
MDGs	: Millennium Development Goals
MEEATU	: Ministère de l'Eau, de l'Environnement, de l'Aménagement du Territoire et de l'Urbanisme
MINAGRIE	: Ministère de l'Agriculture et de l'Elevage
MININTER	: Ministère de l'Intérieur
MPDRN	: Ministère de la Planification du Développement et de la Reconstruction Nationale

NAIP	: National Agricultural Investment Programme
NALEP	: National Agriculture and Livestock Extension Programme
NAPA	: National Adaptation Plan of Action
NCEA	: Netherlands Commission for Environmental Assessment
NEPAD	: New Partnership for Africa's Development
NGO	: Non-Governmental Organisation
NPFS	: National Programme for Food Security
OECD	: Organisation for Economic Co-operation and Development
PMSAN	: Plateforme Multisectoriel de Sécurité Alimentaire et Nutritionnelle
PRODEFI	: Programme de Développement des Filières
PRSP	: Poverty Reduction Strategic Paper
QUIBB	: Questionnaire Unifié des Indicateurs de Base du Bien-être
SADeR	: Sécurité Alimentaire et Développement Durable des zones densément peuplées du Nord du Burundi
SAN	: Stratégie Nationale Agricole
SDGs	: Sustainable Developments Goals
SPSS	: Statistical Package for Social Sciences
SUN	: Scaling Up Nutrition
TLU	: Tropical Livestock Unit
UNICEF	: United Nations Children's Fund
UNDP	: United Nations Development Programme
USAID	: United States Agency for International Development
VLIR-UOS	: Vlaamse Interuniversitaire Raad-*Universitaire Ontwikkelings Samenwerking*
VRS	: Variable Return to Scale
WHO	: World Health Organisation
WFP	: World Food Programme

Summary

There is an increasing concern on how to sustainably feed the growing population on continuously decreasing resource base in Sub-Saharan African countries. While food demand continues to increase as a result of high population growth, declining land availability has led to high rate of rural poverty and food insecurity. This requires to search for approaches and strategies that can increase land and labour productivity in smallholder farming systems. In this thesis, an analysis is made to assess the potential sustainable production systems that can improve the households' welfare in small-scale farms of Burundi. The majority of the country's population lives in rural areas with almost 90% depending on agriculture for food security and income. Yet, demographic pressure has greatly impacted on landholdings and almost 70% of farmers live on an income below the national poverty line. While farmers cannot invest in inputs to boost productivity, the possibility for land resource expansion is very limited. Therefore, improved resource use in agricultural production stands as their only pathway out of poverty. The main challenge is then how to increase production with the same quality and quantity of production factors while accounting for the prevailing circumstances.

The main goal for this thesis is to increase understanding on the country's agrarian systems and to identify possible trajectories that can improve households' food security levels and welfare. A household model which optimises resources use, farm practices and activity choice as to achieve household food security in a context of subsistence farming provides clues on such trajectories. Five data sources were used to achieve three research objectives discerned based on the empirical application.

The first objective was to increase understanding of past trends in agrarian systems in the rural areas of Burundi. A review of the evolution of the smallholder farming systems shows that farming societies have evolved by adapting their livelihoods to the changing environment, especially the population pressure and the subsequent fragmentation and atomisation of the agricultural land. As the population grew, land resources became scarce which induced a search for new technologies and ways to achieve agricultural intensification. Farmers and policy makers tried to counter the effect of the rapid population growth through several strategies. Yet, major changes

in farming system are mainly attributed to farmers themselves. Agricultural policies have had several limitations including farmers' reluctance to adopt new proposed technologies. Traditional adjustments in land use and management included the colonisation of new mostly marginal land (exploiting the extensive margin) and the adoption of new short-cycle crops (intensive margin), traditional ways to restore soil fertility, and finally the adaptation of livestock keeping to the shrinking grazing lands. Yet, it seems that the farmers' intensification levels have reached limits. Farmer households became more and more poor as a consequence of resources over-exploitation with less means and mechanisms to increase productivity.

The second objective was to investigate the recent developments and efficiency in both crop and livestock production at farm level and their implication for the households' living conditions. The recent evolution in agricultural sector shows that farmers' adaptation to demographic pressure continued by dealing with the unreliability of food markets and policy failures. Farmers adopted diversified subsistence farming as a consequence of risk-averse behaviour. They grow a diverse range of crops, on highly fragmented lands, for the household's own consumption with very limited external inputs. In addition, several changes have occurred in livestock keeping toward a progressive adoption of small animals. The livestock activity shifted progressively towards more intensive practices by keeping animals in compounds and feeding them on 'cut and carry' feeds which limits the scope for nearly landless farmers to engage in livestock activities, especially cattle.

As a result, the overall farm productivity is very low and household poverty is increasing among farm households. Only 25% of the population has an income that is sufficient to meet households' food and non-food needs. Most landholdings have become very small that they do not provide enough income or food for the household to survive. They diversify their income sources by working off-farm or in non-farm activities. Yet, the wage levels at the off-farm jobs are very low, and the income households get from off-farm activities is not enough to improve the food security situation of the households. More diversified households are even more likely to be poor and food insecure. This raises true concerns on the small farm viability in these densely populated regions.

The third objective was to investigate the optimum agricultural production plan that could increase returns to scarce factors and raise household food security levels.

These problems of poverty and food insecurity require radical changes in the way food is produced, stored and consumed by the households. This implies measures directed to increase both productivity and market access. The results of an optimisation model highlight possibilities for households to achieve production to satisfy family consumption and to induce trade between farmers at micro-level. Specialisation in crops choice among farms according to their comparative advantages has a positive impact on farms' output and the opportunity cost of family labour as well as on investment. Thus, a reduced number of crops could stimulate optimal land use that further stimulates trade between farms while raising the income of both producer and farm workers. Large and medium farms are better off and are willing to hire extra labour to complement the family workforce which exerts a strong demand in their neighbourhood. This provides an increasing off-farm employment opportunity for less endowed farmers who remained unable to achieve the minimum household food needs (30% of the sample).

Yet, this production model could yield mixed results showing the highest returns but with unacceptable risk levels. Specialization actually may not suit the specific case of Burundi smallholder farmers due to the higher risks it would entail and the unreliability of the markets. The fact that farmers do not adopt this strategy is mainly due to limited reliability of markets, production variability and weak storage systems in case of surplus. Results show that risk perception is the driving force to livelihood diversification. The number of crops on the farm is large and may even double on small farms when risk is considered in the production models. This significantly affects the farm's returns. Yet, even under the severe constraints of land shortage in subsistence production and risk, an optimal land allocation between the crops could attenuate food insecurity among farm households. Yet, the seasonality in many staple food crops may cancel out these efforts due to high post-harvest losses. Moreover, farmers may fail to take their produce to markets as most agricultural products are perishable and therefore sold at low prices immediately after harvest.

For farmers to take the pathway of specialisation, they require a conducive production and market environment. This calls for more research and development, an effective extension service, access to credit and a good market infrastructure.

Samenvatting

Er is een toenemende bezorgdheid over hoe een groeiende bevolking duurzaam te blijven voeden met alsmaar minder beschikbare hulpbronnen in landen ten zuiden van de Sahara. Terwijl de vraag naar voedsel blijft stijgen door de grote bevolkingstoename, heeft de druk op de productiefactoren en in het bijzonder land geleid tot meer rurale armoede en voedselonzekerheid. Om verdere verslechtering in armoede en voedselonzekerheid tegen te gaan, zijn aangepaste strategieën vereist die land- en arbeidsproductiviteit in kleinschalige landbouwsystemen kunnen verhogen. De doctoraatsthesis analyseert het potentieel van duurzame productiesystemen om het welzijn van families met kleinschalige landbouwbedrijven in Burundi te verbeteren. De meerderheid van de Burundese bevolking leeft in rurale gebieden waar maar liefst 90% afhankelijk is van landbouwactiviteiten voor hun inkomen en voedsel. Bij 70% van de landbouwers ligt dit inkomen onder de nationale armoedegrens. Bovendien heeft de demografische druk een grote invloed gehad op het beschikbare grondoppervlak. De mogelijkheden om het productieoppervlak uit te breiden zijn beperkt en landbouwers hebben de middelen niet om te investeren in *grondstoffen* die de productiviteit kunnen verhogen. Daarom is een optimalisatie in het gebruik van hulpbronnen in landbouwproductie de enige mogelijke uitweg uit armoede. De grootste uitdaging ligt dan ook in hoe de productie te verhogen met dezelfde hoeveelheid en kwaliteit van productiefactoren onder de huidige omstandigheden.

Het doel van dit onderzoek is om de Burundese landbouwsystemen beter te begrijpen en om mogelijke veranderingen in landbouwproductiesystemen te identificeren die de voedselzekerheid van de landbouwgezinnen kunnen verbeteren. Het uitstippelen van deze veranderingen is gebaseerd op een huishoud-economisch model dat het gebruik van hulpbronnen, landbouwmethoden en activiteiten om de voedselzekerheid van de landbouwfamilie te garanderen in de context van zelfvoorzienende landbouw optimaliseert. Aan de hand van vijf datasets en beschrijvende en econometrische modellen worden de drie vooropgestelde onderzoeksdoelen getest.

Een eerste doelstelling is om een beter inzicht te krijgen in de historische trends van de landbouwsystemen in de rurale gebieden van Burundi. Een overzicht van de

evolutie in kleinschalige landbouwsystemen toont aan dat de landbouwsamenleving zich verder heeft ontwikkeld door hun levenswijze aan te passen aan de veranderende omgeving, vooral de bevolkingsdruk en daaruit volgende versnippering van de landbouwgrond. Door de bevolkingstoename werd grond steeds schaarser wat de zoektocht stimuleerde naar nieuwe technologieën en meer intensieve landbouwmethoden. Landbouwers en beleidsmakers poogden dit effect van de bevolkingstoename te milderen en productiesystemen aan te passen. Toch blijken de grootste veranderingen in landbouwsystemen te danken te zijn aan de landbouwers zelf. De beleidsmaatregelen stuiten onder meer op de terughoudendheid van landbouwers om nieuwe technologieën te gebruiken. Meer traditionele geleidelijke aanpassingen in grondgebruik en management bestaan uit de kolonisatie van nieuwe, vooral ondergeschikte grond (het exploiteren van de extensieve marge) en het toepassen van nieuwe korte-cyclus gewassen (intensieve marge), traditionele manieren om de bodemvruchtbaarheid te herstellen, en de aanpassing van de veehouders aan de verminderde toegang tot weilanden. Toch lijkt de landbouwintensivering z’n grenzen te bereiken. Over de jaren werden landbouwfamilies alsmaar armer ten gevolge van de overexploitatie met minder middelen en mechanismen om de productiviteit te verhogen.

De tweede doelstelling van deze studie is om de recente ontwikkelingen in en de efficiëntie te onderzoeken van zowel de plantaardige als de dierlijke productie op bedrijfsniveau en de implicaties ervan voor de levensomstandigheden van de landbouwgezinnen na te gaan. De recente evoluties in de Burundese landbouwsector tonen aan hoe de effecten van demografische druk zich ook verderzetten in hoe landbouwers omgaan met de onregelmatigheden van de voedselmarkt en het falend beleid.

De landbouwers diversifiëren hun zelfvoorzienende productiestrategie als gevolg van hun risicomijdend gedrag. Ze telen een brede waaier van gewassen op erg versnipperde stukken land voor eigen verbruik met erg beperkte externe grondstoffen. Daarnaast hebben zich verschillende veranderingen voorgedaan in dierlijke productie gekenmerkt door een toename van het aandeel kleine dieren in de veestapel. Als een gevolg van verminderde toegang tot graaslanden, is de dierlijke productie geleidelijk verschoven naar meer intensieve activiteiten door dieren te hokken en voeder aan te voeren. Dit beperkt dan ook de mogelijkheden voor landloze boeren om deel te nemen aan dierlijke productieactiviteiten, vooral voor het houden van koeien.

Bovenstaand geschetste problematiek resulteert in erg lage productiviteit waardoor de armoede van de landbouwfamilies toeneemt. Slechts 25% van de bevolking heeft een inkomen dat voldoende is om aan de voedings en niet-voedingsbehoeften te voldoen. Het grondbezit in de meeste landbouwfamilies is erg klein geworden waardoor ze niet in voldoende inkomen en voedsel kunnen voorzien. Vaak diversifiëren ze hun inkomensbronnen door te gaan werken bij andere landbouwers of in niet landbouw gerelateerde activiteiten. De lonen die ze in deze activiteiten verdienen zijn er laag en niet genoeg om de huishoudelijke voedselzekerheid situatie te verbeteren. Meer gediversifieerde huishoudens hebben zelfs meer kans om arm en in een voedsel onzekere situatie te leven. Dit geeft een verontrustend beeld over de leefbaarheid van kleinschalige landbouw in deze dichtbevolkte gebieden.

De derde doelstelling is om te onderzoeken wat een optimaal productieplan kan zijn dat beoogt de opbrengst van schaarse productiefactoren en de voedselzekerheid te verhogen. Deze problemen gelinkt aan armoede en voedselonzekerheid vergen radicale veranderingen in hoe voedsel wordt geproduceerd, opgeslagen en geconsumeerd door de huishoudens. Dit impliceert maatregelen die gericht zijn op het verhogen van zowel de productiviteit als de markttoegang. De resultaten van het optimalisatiemodel benadrukken de mogelijkheden voor huishoudens om genoeg te produceren voor eigen consumptie en om handel te stimuleren tussen de landbouwers op microniveau. Het model toont aan dat een specialisatie in bepaalde gewassen (bepaald door hun comparatieve voordelen) een positieve invloed heeft op de productiehoeveelheid en de opportuniteitskost van familiale arbeid alsook op de investeringen. Bijgevolg kan het telen van minder gewassen bijdragen tot optimaal grondgebruik dat verder handel bevordert tussen landbouwers met een stijgend inkomen als resultaat voor zowel de producenten als arbeiders. Grote en middelgrote landbouwbedrijven zijn beter af en meer bereid om extra arbeiders aan te werven om de familiale arbeidskrachten aan te vullen. Dit resulteert in een grotere vraag naar arbeid in de regio en biedt meer werkgelegenheid buiten hun eigen bedrijf voor minder bedeelde landbouwers die niet in staat zijn om aan de voedselbehoeften van het huishouden te voldoen (30% van de steekproef). Toch levert dit productiemodel gemengde resultaten op en toont het aan dat de hoogste opbrengsten gepaard gaan met risiconiveaus die als onaanvaardbaar hoog worden beschouwd. Rekening houdend met de mogelijke risico die specialisatie van productie inhoudt, is dit misschien niet de best passende oplossing zolang de landbouwers geconfronteerd worden met onberekenbare markten. De redenen waarom landbouwers deze specialisatiestrategie niet toepassen zijn vooral de onbetrouwbaarheid van de markten, de productievariabiliteit en de ontbrekende mogelijkheden voor opslag en bewaring bij overaanbod. De resultaten tonen aan dat risicoperceptie de drijvende kracht is voor diversificatie van productie en inkomensbronnen binnen het huishouden. Het aantal gewassen is zelfs dubbel zo hoog op kleinschalige landbouwbedrijven als wat de optimalisatie modellen voorspellen. Dit heeft een significante invloed op de opbrengsten van de landbouwers. Nochtans, een optimale allocatie van land tussen de gewassen kan de voedselzekerheid verbeteren bij landbouwfamilies zelfs wanneer beschikbare grond beperkt is. Helaas, kan de seizoens gebondenheid van de belangrijkste voedselgewassen het positieve effect te niet doen door de hoge verliezen na de oogst. In sommige gevallen is het ook onmogelijk voor de landbouwer om zijn product te verkopen op de markt aangezien de meeste landbouwproducten snel bederven en daardoor onmiddellijk na de oogst aan lagere prijzen verkocht worden. Een bevorderende productie- en marktomgeving is noodzakelijk voor landbouwers die de specialisatie optie verkiezen. Dit vergt meer onderzoek, ontwikkeling, doeltreffende vulgarisatie van betere productietechnieken, toegang tot krediet, en goede infrastructuur.

Chapter 1:

General introduction

Abstract

This chapter lays the foundation for the dissertation. It provides the general background, the context and the research problem. Research questions, objectives and the framework of the study are identified and discussed in this chapter. It provides the scope of the study and highlights the general thesis outline. The chapter concludes with stressing how this study contributes to literature and difficulties encountered during the study.

1.1. Concepts and background

1.1.1. Concept of food security

Since decades, African governments and donors have implemented a series of approaches towards alleviating rural poverty (Jayne et al., 2003). Several strategies, policies, and programmes were conceived with the aim to stimulate pro-poor growth (Heidhues et al., 2002). Achieving progress in enhancing food security and reducing poverty was set as a prerequisite to kick-start economic growth in rural areas (Maxwell and Smith, 1992). The design of development models conducive to food security did change over time and new paradigms were proposed as persistence of poverty defied all the prevailing approaches (Jayne et al., 2003).

The widely accepted definition that “Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life” was adopted by the World Food Summit of 1996 (FAO, 2006). This definition was agreed upon after successive attempts to design food security approaches and definitions including a national, local or individual self-sufficiency focus, and also issues of coping with vulnerability and risk in food and nutrition access were introduced (Heidhues et al., 2002). In the 1970s, food security was associated with adequate food production and emphasis was put on national and global food supplies (Maxwell and Smith, 1992; Pinstrup-Andersen, 2009). The food crisis that hit many African countries in the early 1970s raised concerns of food supply shortfalls. Failure in local food production was recognized as the major cause of food insecurity during the 1974 World Food summit (Frankenberger and McCaston, 2000).

In the 1980s, the focus of food security approaches turned to problems of *food access*. The food crisis that plagued the continent in 1984 showed that adequate food availability at the national level did not necessary translate into food security at household level due to failure in household entitlements to food (Maxwell and Smith, 1992). Scholars and practitioners widely recognized that distribution of the available food is critical as availability alone is necessary but not sufficient to assure households’ access to food (Pinstrup-Andersen, 2009). Henceforth, academics and practitioners searched to understand how food production systems and other factors influence the composition of food supply, and the household's year-round access to that supply (Frankenberger and McCaston, 2000).

In the 1990s, the importance of nutrition was increasingly recognized, and the concept of food security was considered together with that of *nutrition security*. Household food access was recognized as a necessary but not sufficient condition for household food security (Frankenberger and McCaston, 2000). Enough calories do not guarantee the nutritional sound composition of diets. Thus, food security was defined as access by all people to enough food to live a healthy and productive life (Pinstrup-Andersen, 2009). This definition was further elaborated by FAO by introducing nutritional values and food preferences. The terms 'safe' and 'nutritious' in the definition of food security now emphasize the nutritional composition while food preferences imply access to food that is socially and culturally acceptable (Pinstrup-Andersen, 2009). In the 2000s, vulnerability, risk coping, and risk management considerations were more prominent (Heidhues et al., 2002).

The recent interpretation of household food and nutritional security emphasizes its multidimensional nature including food access, food availability, food use and stability. This has enabled the design of policy responses based on livelihood options (FAO, 2006) which led to the development of the concept of *household livelihood security* in search of strategies and actions to end hunger and malnutrition. The livelihood security framework includes all means that can provide adequate and sustainable access to income and resources necessary to meet household's basic needs (Frankenberger and McCaston, 2000). This is translated into mechanisms capable to raise food production and employment creation, as well as the provision of an institutional and policy framework for agricultural growth, which also includes the rehabilitation and expansion of physical and social infrastructure in rural areas (Heidhues et al., 2002). Today, efforts aim at promoting environmentally and socially sustainable agricultural development as cornerstones for sustainable economic growth (FAO, 2006; FAO et al., 2014). The focus of programmes in African agriculture is on increased productivity as land has become gradually more scarce (Jayne et al., 2003; Headey and Jayne, 2014; Nin-Pratt and McBride, 2014).

This thesis analyses how changes toward sustainable agricultural systems can improve the food security situation in Burundi. More in particular, we study how land management could be optimized at individual farms in order to make households achieve food security. Along with the above described evolutions in the conceptualization of food security, this study is concerned with aspects of availability, access to food and stability.

1.1.2. Challenges of food security

Achieving food security implies that agricultural production has to increase considerably (Tscharntke et al., 2012; Tomlinson, 2013; FAO et al., 2014), which can be achieved by either taking more land into production (extensive margins) or by increasing productivity (intensive margins). The limits in availability of arable land have raised a lot of concerns especially in developing countries where a large share of the population depends on land to secure their livelihoods (Jayne et al., 2003; Headey and Jayne, 2014). Land expansion has indeed allowed farmers to sustain household income in the past. Yet, fertile arable land has become more scarce. On the other hand, increasing productivity by intensifying land use and the increased application of inputs is causing damage to the environment. The permanent cultivation of land and use of fertilizers, pesticides, and other chemicals have greatly impacted the ecosystems (Hamuda and Patkó, 2010) with land degradation, degradation of water (quality and quantity), health problems to farmers and other environmental related problems as a result (Subramanyachary, 2012). Therefore, agriculture, especially in Sub-Saharan Africa, where land resources are scarce and the demand for food high, must undergo a significant transformation in order to achieve food security while responding to climate change (FAO, 2010).

Moreover, food security is achieved with a balanced diet that can provide all necessary nutrients for a healthy and productive life. In many developing countries, including Burundi, high value nutritious food crops are scarce and often substituted (in both diets and farming systems) with less demanding crops but with low quality. This is reported to have seriously contributed in worsening malnutrition. The availability of food might not solve the problem of access to nutritious food especially in poor households. Making agricultural systems and agricultural policies more nutrition-sensitive is of great importance. This implies a continuous search for new instruments and approaches (Pinstrup-Andersen, 2010; Ruel and Alderman, 2013) which include climate-smart but also nutrition-sensitive agricultural practices.

1.1.2.1. Climate-smart agriculture

Food security and climate change are closely linked in the agricultural sector. While efforts to achieve food security have impacted the productive environment, increased frequency of droughts and flooding resulted into seasonal crop failures and therefore reduced food availability and dietary diversity (Alderman, 2010). Moreover, the long term changes in the patterns of temperature and precipitation, as an effect of climate changes, have affected pest and disease patterns, modified the set of feasible crops, prices, incomes and hence people livelihoods (FAO, 2010). In many areas where agricultural productivity is already low, the means to offset climate changes are limited and productivity is expected to further decrease while production might become more erratic (Cline, 2008; FAO, 2008b).

Climate smart agriculture is put forward to safeguard the productive environment and to guarantee food security. First presented during the Conference on Food Security, Agriculture and Climate Change in 2010, this approach intends to strengthen food security today and for future generations, including necessity to adapt to climatic changes. To succeed, farming techniques should (i) sustainably increase agricultural productivity, to support equitable increases in farm incomes, food security and development; (ii) adapt and build resilience of agricultural and food security systems to climate change at multiple levels; and (iii) reduce greenhouse gas emissions from agriculture (Kaczan et al., 2013). Changing the agricultural sector accordingly requires institutional and policy support (FAO, 2010). Today, the concept has wide ownership among governments, regional and international agencies, civil society and private sector.

1.1.2.2. Nutrition sensitive agriculture

Enhanced agricultural productivity and global food supply is crucial for long term reductions in poverty, hunger and malnutrition. Investments in agriculture contributes to increasing household availability and access to food from own production which as well as from the income through wages earned by agricultural workers and the purchasing power of consumers (Ruel and Alderman, 2013). Increasing investments was the main objective of the Comprehensive Africa Agriculture Development Programme (CAADP) presented in Maputo in 2003, where the heads of African states committed to invest at least 10% of the national budgets in agriculture.

Yet, figures of food insecurity and inequality are still alarmingly high on the African continent (FAO et al., 2014). Complementary measures are needed to support livelihoods by enhancing access to diverse diets in poor populations including systems and structures that sustain individual's or household's ability to withstand shocks that threaten their access to food. A country can claim food security when the poor and vulnerable people living in marginal areas, have a secure access to safe and preferred food (Opara, 2013). High levels of food insecurity led to an increased interest in nutrition sensitive agriculture with the focus on leveraging the value chains to improve nutrition (IFPRI, 2011; Ruel and Alderman, 2013).

Nutrition sensitive refers to development of efforts that, beyond the agricultural focus on increasing incomes, improving availability of food and market linkages, aim to improve the underlying determinants of nutritional status, such as the consumption of required micro- and macronutrients (IFPRI, 2011; Worldbank, 2013). In order to achieve the positive nutrition outcomes within an agricultural value chain, there is the need to consider the specific macronutrient and micronutrient requirements and select necessary crops within the agriculture specific objectives (FAO and WHO,2013).

1.1.2.3. Food intakes

Food supplies the body with energy in the form of carbohydrates and other macronutrients mainly fat and protein. Food provides also micronutrients like amino acids, vitamins and minerals which are needed for growth and maintenance of cells and tissue. Any deficit in the body might result into pathologies. Moreover, if the intake is above requirements, the individual gains much weight and becomes exposed to health hazards of obesity (Passmore et al., 1974). Inadequate energy intake puts limits on the potential of people in many developing countries, while excess energy intakes are (increasingly) causing obesity burden in both developing and developed world (FAO, 2002).

The FAO and WHO provided recommendations of intake of energy and food nutrients[1] (per age, gender, activity …) as guide to plan agricultural production and food trade in order to ensure a sufficient food supply. The intake recommendations

[1] http://www.fao.org/docrep/W0078E/w0078e11.htm#P984 (last accessed 11/09/2016)

are often compared with actual consumption figures determined by the food consumption surveys. Tables of food analysis are available for many countries and regions (including Africa)[2]. The Adult Equivalent scale is often used to provide an indication of household food intake accounting for the household structure (Weisell and Dop, 2012). The Adult Equivalent scale indicates the requirements of an individual of a particular age and sex as a percentage of a standard or reference person (Buse and Salathe, 1978; Weisell and Dop, 2012).

The recommended intakes are criticized as not being an adequate tool to assess health conditions because each figure represents an average augmented by a factor that takes into account inter-individual variability. It is the amount of food considered sufficient for the maintenance of health in nearly all populations (Passmore et al., 1974). Moreover, food and nutrients losses occurring along the food chain are not well captured while they are very important for some food commodities. Losses occur either on the farm, in the home (stock) due to spoilage, method of cooking and meal preparations. In Burundi, NEPAD and FAO (2006) estimated that losses can go up to 50% of the harvest (e.g. sweet potatoes). Estimates of such losses are not always easy to make, and their extent is very hard to measure and incorporate in food security assessments (Passmore et al., 1974).

1.2. Problem statement

Food security is among the major challenges dominating today's world development debate. A particular concern is how a global population of 9 billion by 2050 will be fed. This will require an estimated 70 to 100% increase in food production (Tscharntke et al., 2012; Tomlinson, 2013). Despite the increased food productivity over the last half century and that sufficient food is produced worldwide, the current estimates indicate that almost 805 million people are still chronically hungry (FAO et al., 2014). Generally, more than one out of seven people still do not have access to sufficient proteins and energy, and suffer from micronutrient malnourishment (Godfray et al., 2012). Malnutrition in sub-Saharan Africa, and paradoxically in rural areas where food is produced, is particularly high (FAO et al., 2014). Food insecure rural households depend on agriculture or agriculture-related activities, earning their

[2] ibid.

meagre income from off-farm labour and spending half and more of their income on food (Christiaensen and Demery, 2007; WorldBank, 2007; FAO et al., 2014).

Hence, agricultural growth is of key importance to improve the welfare of the poor (Schultz, 1980; Hedden-Dunkhorst and Mollel, 1999). Development amongst the smallholder farming communities contribute to reducing unemployment, improving income distribution and providing an effective demand for non-agricultural products to be supplied by other sectors in the national economy (Bravo-ureta and Pinheiro, 1997). These potential direct and indirect linkages effects of agriculture should not be underestimated (Kuyvenhoven, 2004) and motivate a policy for smallholder farmers. Since mid-2000s, donors and governments have shown a renewed interest in the agricultural sector and small farms in particular as actors for poverty reduction and as possible engines for economic growth (Pingali, 2012). After decades of neglect[3], interest in agricultural investments as an opportunity to create employment, and take advantage of new technological developments has grown significantly (Deininger, 2013). Direct public support for innovation and agricultural productivity are again high on many policy and research agendas of African countries with the 2003 commitment to invest at least 10% of the national budget in agriculture (Nin-Pratt and McBride, 2014; Poulton et al., 2014).

Looking at the Sub-Saharan African context, yet, there is still a great concern whether agriculture as an economic sector is capable to achieve sufficient growth and reduce poverty. The policies implemented over the last decades only had a limited effect in increasing agricultural production (Nin-Pratt and McBride, 2014) and productivity remained too low to adequately address poverty and food insecurity (WorldBank, 2007; Salami et al., 2010). Several factors curb productivity growth in Africa such as land scarcity, the poor state of infrastructure and irrigation systems, lack of qualified human capital, and limited access to credit (Christiaensen and Demery, 2007). As a result, many poor African rural households are still heavily depending on subsistence farming for their survival (Savadogo et al., 1998; Fulginiti et al., 2004; Cunguara and Darnhofer, 2011). Dominant production systems in the poorest areas are characterized by low input use, mixed cropping and extensive livestock keeping (Pender and Ruben, 2004). In poor African agriculture-based

[3] Since the 1980s with the failure in government led approach, strategies shifted away from government intervention and also away from agriculture-led development (e.g. Structural Adjustment Programs promoted the development of private sector) (Nin-Pratt and McBride, 2014).

communities, smallholder farmers operate in an environment of incomplete and poorly functioning markets for everything from labour, land, credit, commodities, risk and information (Timmer, 1997) while support policies are limited (Adesina, 2010). This has greatly affected the farmers' willingness and ability to invest (Pender and Ruben, 2004) and might explain the persistent food insecurity, hunger and malnutrition (Nkala et al., 2011).

Especially in regions with high population density, there is an urgent need to change traditional modes of production (Headey and Jayne, 2014). Numerous post-Green Revolution studies proposed approaches that can increase land and labour productivity in smallholder systems (Collier and Hoeffler, 1998; Eicher and Staaz, 1998; Hazell, 2005). In order to be effective, scholars suggested that priority should be given to overcome the most limiting factors in agricultural returns (Pender and Ruben, 2004; Schreinemachers and Berger, 2006). This requires a good understanding of the scarcity constraints and how these affect the choices made by poor farmers. Detailed empirical assessments at country or regional level are necessary as the country-specific insights are relevant to policy design (Christiaensen and Demery, 2007) and to design pathways out of poverty in line with the household's comparative advantages (Pender and Ruben, 2004) and preferences.

Particularly in the poorest region of the African continent such as Burundi, increased productivity in agriculture stands as both a strategic necessity and an economic opportunity. As a resource-poor country with an underdeveloped manufacturing and service sector, agriculture dominates the economy by accounting for almost 40% of GDP, 80% of all export commodities and 90% of the labour force (MINAGRIE, 2011b). Yet, land has become particularly scarce and increasingly fragmented, highly degraded, overexploited and deforested, and less fertile due to low organic and inorganic fertiliser availability.

In the past, traditional adaptations to land use and labour allocation contributed to a steady increase in food production that allowed to maintain the country's self-sufficiency in food production (Bergen, 1986; Guichaoua, 1989; Bidou, 1991; Verhaegen and Dégand, 1993; Cochet, 2004; FAO, 2015). Today, a growing number of family farms are actually too small to secure the household food supply. Households strive to produce the bulk of the food they consume by growing a mix of crops, often associated with cash crops and some livestock units on less than one hectare of land. As a consequence, the already seasonal or endemic food deficits of the past are affecting an even larger share of the population during even longer periods of the year.

Mixed cropping and the subsistence nature of smallholder farming limited the potentials to further increase productivity. Moreover, less demanding – but also less nutritious crops are grown at the expense of highly nutritious crops (MINAGRIE, 2011a). Farmers in the overpopulated areas started to gradually depend on casual labour in the neighbourhood for extremely low wages to gain a living. In this context, seeking to understand past trends, recent developments and to evaluate the scope for optimal resource use at farm level are prerequisites to identify the most effective farm trajectories and intervention strategies. The above background motivated us to undertake this study on “**Understanding smallholder farming systems for food security in Burundi**".

This thesis provides one of the few recent comprehensive studies on Burundian agricultural systems. It studies the origin of the farming system and its efficiency levels. The study assesses both food security and livelihoods options in farming systems while accounting for risk and storage systems. For the case of Burundi, this PhD thesis builds a comprehensive and holistic view on the agricultural sector over time and how it could evolve for the future. The results should inspire policy makers to design sustainable strategies conducive to agricultural development suited to smallholder’s needs, background and desire.

1.3. Objectives and research questions

Burundi’s agriculture is unable to adequately feed the rapidly growing population mainly due to limited access to adequate resources. This study seeks to assess the potential sustainable production systems that could improve the households’ welfare on the small-scale farms. Hence we model the optimal resource use needed to secure sustainable livelihoods. The study aims at increasing knowledge of the country’s agrarian system and provides evidence on the optimal farm trajectories towards food security.

The specific objectives are, to:

- Increase understanding of past trends in agrarian changes of the rural areas of Burundi;
- Investigate the recent developments and efficiency (in crop and livestock-production) at farm level and their implication for the household living conditions; and,
- Investigate the optimum agricultural production plan able to increase returns to scarce factors and raise household food security levels.

To reach these objectives, a framework was developed to address the following research questions (RQs) related to agricultural sector of Burundi:

RQ1. What are the major challenges of small-scale farms in Burundi and which mechanisms have been adopted to address these?

RQ2. What are the current agricultural practices and their impact on factor productivity, and household welfare?

RQ3. What are the major determinants of livestock keeping on small-scale farms?

RQ4. Are there optimal farming systems that are technically feasible, capable to increase food security for the farm household?

RQ5. What are necessary conditions for farmers to change the farming practices as successful pathway out of poverty in the face of risk and limited options for food storage?

1.4. Study approach

1.4.1. Focus on small-scale agriculture

The goal of this study is to analyse the scope for farm households to meet their food needs through optimizing the traditional subsistence farming systems. Most of the approaches to household food security, above mentioned, highlighted the close relationship between food and livelihoods in the conceptualization of household welfare (Frankenberger and McCaston, 2000). Livelihoods combine a range of on-farm and off/non-farm activities. On-farm income is to some extent limited by the size of the farm. Furthermore, in agricultural based economies such as Burundi, off/non-farm income is highly dependent on agricultural activities. Off-farm activities are most often jobs on the farms of neighbours and workers get paid very low wages. Other job opportunities are quasi absent in rural Burundi. Hence this PhD thesis is focused on agricultural productivity growth with its prominent linkages effects on rural development.

The direct and indirect contributions of growth in small-scale farming to rural welfare have been confirmed by numerous studies. At the microeconomic level, agricultural production growth and the development of labour markets are major sources of income for poor households and therefore can improve livelihood conditions (Ellis, 2000). Production growth may lower food prices which has important implications for poverty reduction policies (Bresciani and Vladés, 2007). At macroeconomic level, rising agricultural output from the small-scale farming sector results in rural growth linkages' effects that spur growth of labour intensive non-farm activities in rural areas (Ellis and Biggs, 2001). The demand-driven growth linkages provide better income-earning opportunities for often vulnerable groups (Mellor, 1976; Robbins and Ferris, 2003; Hazell, 2005). Recent studies on Africa suggested that every dollar of increased agricultural income generates roughly an additional return of 30 to 50 cents in rural non-farm earnings (Haggblade et al., 2010). In addition, agricultural growth plays an important role in the structural transformation of a country's economy by creating savings and hence money that can be invested.

1.4.2. Development path

This study searches for development paths through which household resources, farm practices and activity choices may be optimised to achieve household food security and income in a context of subsistence farming in Burundi. The farm household is considered as an economic agent in both production and consumption, and is put at the centre of the analysis. The degree of household vulnerability to food insecurity depends on the livelihood capabilities which in turn depend on the operational context (Ellis, 2000; Dorward, 2014). The latter is made up of several enablers and constraints linked to environmental, demographic and institutional conditions that play a role in resource access, management and productivity patterns at the farm household level.

Demographic pressure decreased the size of individual landholdings. Land available per household in the study area has become very limited and plots are prone to further fragmentation. Access to information and technology is limited, adoption of new technology is scarce due to limited knowledge, and input use is limited due to high costs. Moreover, farmers face many institutional constraints which result in low yields and prevent producers from increasing productivity. Farmers may not be able to store the harvest or have limited access to transport means that bring produce to consumer markets. As a consequence, post-harvest losses are high and agricultural products are sold at low prices immediately after harvest. These factors have affected farmers' capability and willingness to invest in agriculture and lead to the adoption of subsistence behaviour through mixed cropping systems and extensive livestock keeping with subsequent impact on food security and household welfare.

Such decisions on household consumption and production strategies are often made simultaneously and are hence interlinked. Therefore modelling rural household behaviour in the context of market failures implies non-separability between production and consumption decisions (Janvry and Sadoulet, 2006; Schreinemachers and Berger, 2006). The lack of access to an insurance, credit, input and output markets induce households to manage their production decisions in such a way that it reduces consumption risk (Janvry and Sadoulet, 2006). Even, when risks of investment are high and the means to offset them absent, not investing is often seen as the most rational decision (Godfray et al., 2012).

These challenges of poverty and food insecurity require radical changes in the way food is produced, stored and consumed by the households. Future strategies should support more optimal and sustainable production systems that guarantee food security and income. Figure 1.1 depicts a framework showing how we assume that changes in agricultural resource use could affect livelihood patterns among small-scale farms. Increased productivity results in more food produced, increased farmers' income, increased rural wages, and probably reduced prices of food commodities.

The rural wage and reduced food prices offer possibilities for diversification of income sources to landless and nearly landless farmers. Increased income is spent or can be accumulated in assets such as land, livestock and cash savings, or investment in farm activity (seeds, fertilizers, equipment ...) or non-farm activities.

Important here are the household decision making structures including women empowerment, expenditure patterns, family size and education. Women empowerment and education are reported to have positive impact on birth control, household investments and income (Headey and Jayne, 2014; Kohler, 2012).

Finally, the accumulated assets and income can serve as stores of wealth for future investment, improve quality of life by increased spending which stimulate the non-farm sector growth. The non-farm growth would in turn absorb abundant labour and therefore decrease rural unemployment and increase labour market. The concepts in bold are those included in the study. We account for the contextual conditions, which impact on resource management. The optimization of resource management should increase land and labour productivity which in turn contributes to a better – more sustainable livelihood in terms of producer income. Indirectly this affects wage incomes and consumer prices. All these factors contribute to sustainable food security and poverty alleviation which in turn are important for economic growth.

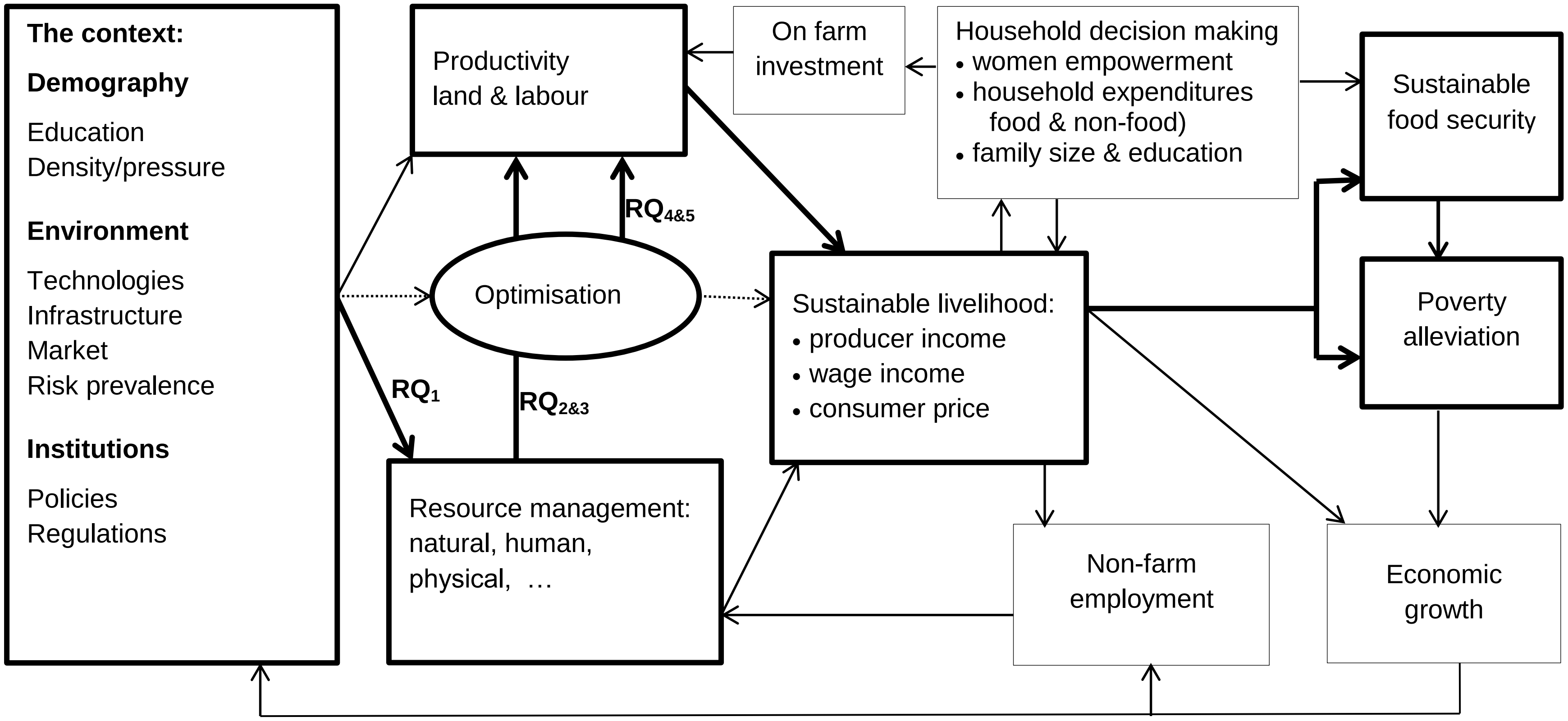

Figure 1.1: Study approach and research questions

As shown above, this thesis is concerned with the farming systems and how these could improve changes of land and labour productivity. Farmers could try to "hang in" and their households barely survive. They would continue to produce on the available land. If land fertility goes down, they suffer from landslides, adverse weather conditions or bad market prices, they may "fall down". However, in case they are able to improve land and labour productivity through the adaptation of their farming systems and market orientations, farming could provide a more sustainable livelihood, and farmer households could "step up". In case non-farm employment becomes available, farm households could "step out" (Dorward, 2014). A framework of the study is developed below (figure 1.2), and provides more details on the study approach.

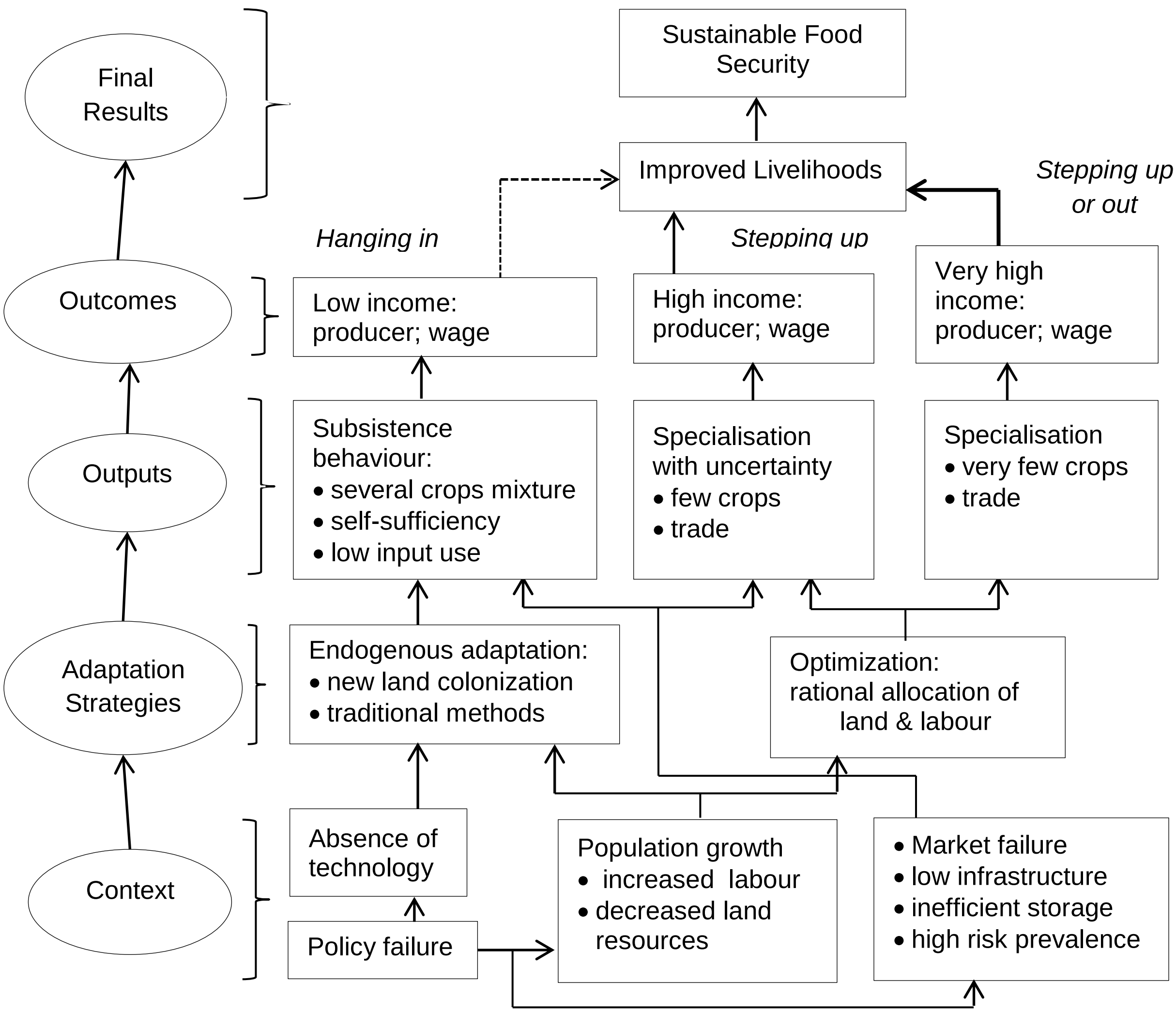

Figure 1.2: Framework of the study

In chapters 2, 3 and 4, the thesis analyses the context and the adaptation strategies. The chapters explain how the farming systems have evolved over time and discuss current productivity levels. Chapters 5 and 6 analyse how the productivity could be improved for sustainable livelihoods through optimisation.

1.5. Scope of the study and data

1.5.1. Overview of the study area

This research was carried out in the republic of Burundi. Known as "Land of a thousand hills" due to its landscape of unending succession of hills, Burundi is a landlocked country in the great lakes region of central-eastern Africa. With a size of 27 834 km^2, of which 25 650 km^2 is emerged land, the country counts 18 provinces[4] spread over 11 agro-ecological zones (fig 1.3) that differ in soil, relief, climate, flora and fauna (Bidou et al., 1991). The terrain is hilly, with extensive marshlands and generally fertile land. The country has a bimodal rainfall pattern with two main seasons, namely a rainy season (October-May) and a dry season (June-September). A short dry period of two weeks occurs between January and February. In general, the rainy season lasts about 8 months while the dry season lasts for 4 months. The rainfall varies from 2 000 mm at higher altitudes to 1 000 mm in the depressions and lowlands (MPDRN, 2006; MEEATU, 2011).

The agricultural calendar follows three cropping seasons per year. The first season (A), commonly known as 'Agatasi', occurs between October and January. The second (B) season is called 'Impeshi' and lasts for almost 4 months (February to May). A short dry period (with less frequent and intense precipitation) occurs between these two rainy seasons (mid-January to mid-February) allowing farmers to handle[5] agricultural produce from the first cropping season (A). The third cropping season (C) called 'Ici', occurs between June and September. In this dry period, farmers mainly grow vegetables, beans, maize, potatoes and off-season crops such as rice in wetlands and in river valleys.

[4] Before February 2015, Burundi had 17 provinces. The province of Rumonge was added to the list very recently.
[5] The only method traditionally used to lengthen shelf life is by drying the produce in the sun.

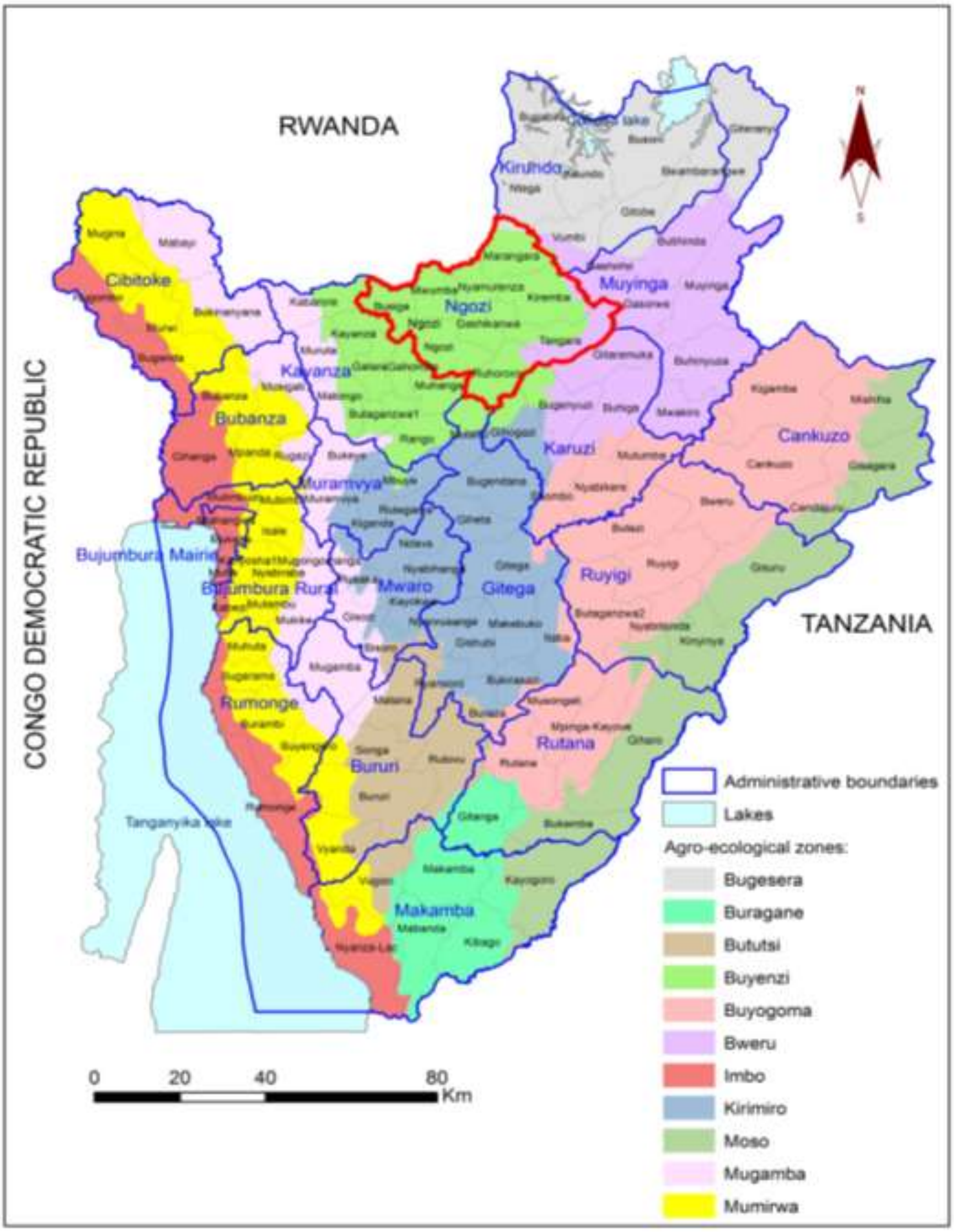

Figure 1.3: Agro ecological zones of Burundi

All these factors provide a good agro-ecosystem conducive to agricultural activities. But, land faces strong pressures for agricultural expansion and conflicts are frequent over the diminishing land resources for cultivation (Beck et al., 2010; Van Leeuwen, 2010). The third national demographic census of 2008 reported a population of 8 053 574 inhabitants with 289 inhabitants[6] per square kilometre, ranking Burundi among

[6] République du Burundi, 2010. Résultats définitifs du recensement général de la population et de l'habitat. Cabinet du Président, Décret présidentiel n°100/55 du 05 Avril 2010. République du Burundi, Bujumbura.

the most densely populated countries in Africa and in the world. The majority of the population live in rural areas (90%), of whom 70% lives on an income below the national poverty line (MINAGRIE, 2008).

As a resource-poor country with an underdeveloped manufacturing sector, the country's economy depends on the agricultural sector. Industry is limited to the processing of agricultural exports, mainly coffee and tea. The lack of adequate infrastructure and energy provision puts limit on industrial development. In 2006, the energy balance was such that 94.06% of the power supply was provided by biomass such as firewood, charcoal, peat and agricultural residues (MEEATU, 2011).

Thus, given the poor capacities in storage and processing facilities and techniques, many farmers have limited access to lucrative markets, which greatly contributes to the deepening poverty in rural areas (Baramburiye et al., 2013). There is a potential wealth in nickel (6% of the known world reserves) and other natural resources such as phosphates, vanadium, peat, and alluvial gold, and niobium and tantalum that are extracted on an artisanal scale. The country also has deposits of iron, limestone, uranium, titanium, carbonatites, and cassiterite under varying exploration and production conditions (Jeníček and Grofová, 2015).

1.5.2. Agriculture in a context of climatic changes

1.5.2.1. Agricultural sector in Burundi

With an urbanization rate close to 10%, almost 90% of the population lives in rural areas with agriculture as their main activity (MINAGRIE, 2008). Rural livelihoods are closely tied to agriculture as a source of food and income earnings (WFP, 2004). The sector encompasses 90% of the workforce through small-scale, subsistence-oriented family farming units, and contributes 95% to the food supply. The production system remains traditional with the use of family labour and few external inputs and heavily depending on rainfall patterns. Landholdings are typically small and the farming system is mainly focused on subsistence activities with only a limited surplus being marketed. The leading agricultural products can be classified into cash crops, food crops and horticultural produces (MINAGRIE, 2008).

An estimated 85% of the total cultivated surface is used for food crop production that together with the livestock keeping represent the main source of food and income for most households (D'Haese et al., 2010). Nearly all households grow a mix and diversity of food crops, sometimes associated with cash crops and some animals (Baghdadli et al., 2008). Animal production (milk, eggs, meat) is usually low or erratic (e.g. goats are slaughtered for particular celebrations), suggesting that livestock is mainly kept for manure, draught power, savings, security and social status (Cochet, 2004; D'Haese et al., 2010). However, the performance of these subsectors is very poor and imports of foodstuff are increasing steadily, exerting growing pressure on foreign currency reserves (PRSP, 2006). The country exports mainly coffee and tea followed by cotton. Coffee is the main source of foreign exchange and income – both for farmers and the government (Nkuruniza and Ngaruko, 2002) and 80% of export earnings come from the export of coffee (Baghdadli et al., 2008).

Agricultural production systems have evolved in response to the high population density and associated acute scarcity of agricultural land. In the past, adequate rainfall patterns and good soils had made Burundi self-sufficient in food production (Bergen, 1986). Nowadays, agricultural production is limited by the unavailability of high potential land and the progressive depletion of soil fertility in rural areas (Cochet, 2004). The high population density provoked a considerable increase in pressure on arable land which has gradually led to expansion of cultivated areas over marginal land, but also to a reduction in the average surface area per household and a situation of widespread under-employment in the countryside. This has forced farmers towards a progressive and continued intensification of cropping systems with two main components: (i) the multiplication of crop cycles and the spread of mixed or multiple cropping with the progressive disappearance of interspersed fallow periods, and (ii) the development of banana cultivation (Cochet, 2004) because of its prominent position in farming system and its multipurpose feature (Rishirumuhirwa & Roose, 1998).

Land fragmentation is very high which undermines productive capability of small-scale farms and overall food security (Verschelde et al., 2013). For the majority of the population, food insecurity has increased over the past two decades with per capita agricultural production declining by 24% since 1993 (WFP, 2016). Food production techniques remained traditional and farmers continued to produce mainly for subsistence purposes through mixed farming systems with a hand hoe as their main tool.

In 2010, the country's food deficit was estimated at 470 000 tons (cereal equivalent) per year with almost 75% of the population gripped by food insecurity (MINAGRIE, 2011a) and 58% of the population chronically malnourished. The nutritional balance has seriously deteriorated, particularly in most vulnerable groups. The overall energy requirement of the population is achieved at 75%. The deficit in food nutrients is more acute for proteins and lipids, only 40% and 22% respectively of people's daily needs of these nutrients is fulfilled (MINAGRIE, 2008). The recent Global Hunger Index report classified Burundi among the countries in an extremely alarming situation (IFPRI, 2014).

1.5.2.2. Agriculture and climatic changes

The adaptation of farming systems to demographic pressures and emerging needs has taken place at the expense of fallow land, pastures and woodlands, and has increased disturbances in fragile ecosystems such as wetlands (PRSP, 2006). The most important current environmental problems for Burundi are the (i) degradation and exhaustion of soils, (ii) degradation of forestry resources and (iii) human environmental degradation. The continuous impoverishment of soils has several causes. Most important causes are the rapid population growth that entails excessive pressure on the arable lands and natural resources, as well as reduced natural spaces (MEEATU, 2007). The land degradation results from the over-exploitation of the land, the persistence of poverty, insufficient financial resources for the conservation of nature and low environmental education (Bisore, 2006). The alluvial soils of the valleys and marshland that, in the past, were considered very fertile are currently poor. Several marshlands have been drained and are currently used to produce crops that used to grow on the hill side (MEEATU, 2011).

Natural forest areas have largely been converted into agricultural and other land uses, leaving a degraded landscape with a few spaces of scattered natural forests and artificial woodlots (Baramburiye et al., 2013). Natural vegetation is almost non-existent in many regions of the country (especially in the north and central regions) and free spaces are often covered by *Eragrostis sp*. as sign of deeply exhausted soils. Up to few decades ago, wetlands were covered by indigenous plant species (*Cypercus sp., Papyrus sp…*). Yet, due to the increased pressure on the marshland, the natural land cover was gradually replaced by rice, beans and vegetables. Gallery forests that covered the foothills gradually disappeared so that also the land could be used for food crops production (Niragira, 2011).

There is concern that precipitation patterns have changed and that rains have become increasingly erratic with increasing seasonal rainfall shortages. Since 1999, there is a strong variability in weather patterns. The climate is changing to longer dry season with rains ending early in April rather than May, and rains starting later in October instead of September (Baramburiye et al., 2013). The most vulnerable regions are located in the north eastern provinces and the Bugesera depression, a highly populated area with a long history of intermittent droughts.

Data from the past 60 years show an alternating cycle of excess and deficit in rainfall nearly every decade as well as an overall increase in the mean temperature (1-2.5°C). Severe floods occurred (e.g. in 2006-2007) as did severe droughts (e.g. in 1999-2000 and 2005) (MEEATU, 2007). Also recently, heavy floods and drought periods became more frequent in Burundi. In 2014, floods caused heavy causalities and landslides leaving 69 people dead and destroying more than 3 000 houses overnight (MINAGRIE, 2014). Projections for the period 2010-2050 indicate that inter annual fluctuations would continue and even amplify, but no clear trends of the increase or the decrease in precipitations is highlighted (MINAGRIE, 2014).

The frequent torrential rainfalls increase erosion and carry fertile soil, flood valleys and lowlands, and often destroy crops. The problem of erosion is now getting to alarming levels due to lack of water and soil conservation techniques, consequent to persistent traditional farming methods (MEEATU, 2009). The cultivation of steep slopes of this hilly land has increased erosion and the over-exploitation of land has affected the soil's reserves, leading to a general decline in soil fertility and yields. Excessive rainfall events increase also the presence of pests and diseases affecting food crops, livestock, and human lives[7]. Moreover, high temperatures are likely to increase evapotranspiration rates, to shape conditions for the proliferation of disease and vermin, which often affect the overall factors productivity (NCEA, 2015).

[7] The proliferation of Malaria is linked to heavy rains and flooding that increase the vegetation density, generally providing suitable breeding pools for mosquito larvae.

1.5.3. Data and sample

This PhD thesis uses primary data from five main sources (table 1.1):

1. Farm household data collected within the framework of the VLIR-UOS project (ZEIN2007PR336-69525) carried out in the northern region of Burundi. The project studied the dynamics of agricultural production and food security in the highly populated provinces of Burundi. Farm population of 90 collines (hills/villages)[8] of the Ngozi province (360 households) and 70 collines of the Muyinga province (280 households) were considered. In a first instance, a sample of 640 farm households were selected from 160 collines that were randomly selected during an earlier survey in 1996. The data used in this thesis was collected in 2007 in the Ngozi Province. The questionnaire consisted of household characteristics, farm data and detailed data on crop and livestock production. Crop data was collected at plot level.
2. Among the 360 farms households of the Ngozi Province, a sub-sample of 60 farms were selected and revisited several times[9] in 2010 to compile a detailed dataset used for the optimization models. A purposive sampling frame was used to ensure a more reliable and representative sample. The questionnaire had four main parts including both closed-ended and open-end questions. The first part was related to general household characteristics. The second part concerned farm characteristics including farm size, crops cultivated, and ownerships of the land, property right, and livestock keeping. The third part of the questionnaire considered farm output and inputs used, and ways of access to inputs. The last part included management including expenditures and income sources of the household and farmer's perception of the dynamics in farming activities over the past five years and their future intentions.

3. In 2012, the sample of farm households in Ngozi were revisited and interviewed in order to capture the evolution in some variables of interest over a period of 5 years. The questionnaire used was very similar to the one used in 2007 and questions related to market access and household compositions were added. A

[8] Colline is a basic administrative entity in Burundi. An administrative colline may consist of one or more hills. Each colline is headed by a "chef de colline".
[9] The information on selected plots required enumerators to revisit the farms for more details (on inputs) that were not provided during the first round survey. Farmers were visited at any time required.

total of 340 households could be retrieved from the 2007 sample and were interviewed. The other 20 households could not be interviewed because they were away or they were simply not available at home due to heavy work in marshlands (in dry season) outside their villages.

4. A fourth source of data was the agricultural household survey dataset derived from the National Bureau of Statistics. The survey known as ENAB is an agricultural survey conducted in 2011-2012 which focused on accurately measuring crop area and food production in 2560 farm households. It was the first nationally representative survey in Burundi since the 1980s and was carried out with the aim of updating the agricultural statistics and national accounts and revitalizes the statistical capacity of the national institute of statistics. Households were visited several times during the three cropping seasons. A close follow-up of farmers was made throughout the year in order to collect more detailed data on crops and labour at plot level, and the size of fields cropped. In addition, the survey collected some details on socio-economic household characteristics and inventoried the household's living conditions.

5. The Food and Agriculture Organization (FAO) country-level statistics were used to capture the evolution in production and input use. Despite the lack of accuracy as mainly generated through projections and estimations, these data were used as we lack better alternatives of panel dataset on agricultural production at farm level. Data on quantity in main crop production, area cropped and input used were taken from the FAO website[10] and used to compute the potential variation in yields.

The particular emphasis on the province of Ngozi is justified by both demographical and agricultural aspects. This province is among the most overpopulated provinces while it is one of the most important regions for agricultural production in Burundi. Thus, it provides a good sample for socioeconomic studies especially when the link between population growth and natural resources management needs to be considered.

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[10] http://faostat.fao.org/site/339/default.aspx (accessed on 30 may 2015)

Table 1.1: Overview of the data used for this PhD thesis

Dataset	Chap.	Location	Year	Purpose of data collection	N	Sampling design	Collected by
VLIR-UOS project	5,6	Provinces: Ngozi and Muyinga	2007	Agriculture production dynamics and food security in densely populated provinces of the northern region of Burundi	640	4 households randomly selected from 10 villages, in each of the 9 communes of the province. The villages were selected in 1996	University of Antwerp University of Burundi
VLIR-UOS project	5,6	Province Ngozi	2010	Agriculture production dynamics and food security in densely populated provinces of the northern region of Burundi	60	Purposive sample from the original 2007 dataset to make a more representative subsample of 60 households	Ghent University University of Burundi
VLIR-UOS project	5,6	Province Ngozi	2012	Agriculture production dynamics and food security in densely populated provinces of the northern region of Burundi	340	The sample farm (2007) was revisited to construct a panel dataset (20 households were missing)	Ghent University University of Burundi
ENAB	3,4	Countrywide survey	2011-2012 (cropping year)	Updating agricultural statistics and compile national accounts	2560	Representative of the country’s population and agro-ecological zones (stratification by provincial level, clustering at communal level)	ISTEBU, MINAGRIE
FAO Countrystat	2,6	Countrywide estimates	1960-2010	Time-series and cross sectional data relating to food and agriculture to give the major trends shaping global food and agriculture	—	Projections	FAO

1.6. Outlines of the thesis

This PhD research is conceived as a collection of articles. The different papers are related and structured to form a coherent study of the agricultural sector of Burundi. It is made up of two major parts and counts five chapters complemented by the introduction and the concluding chapter (figure 1.4).

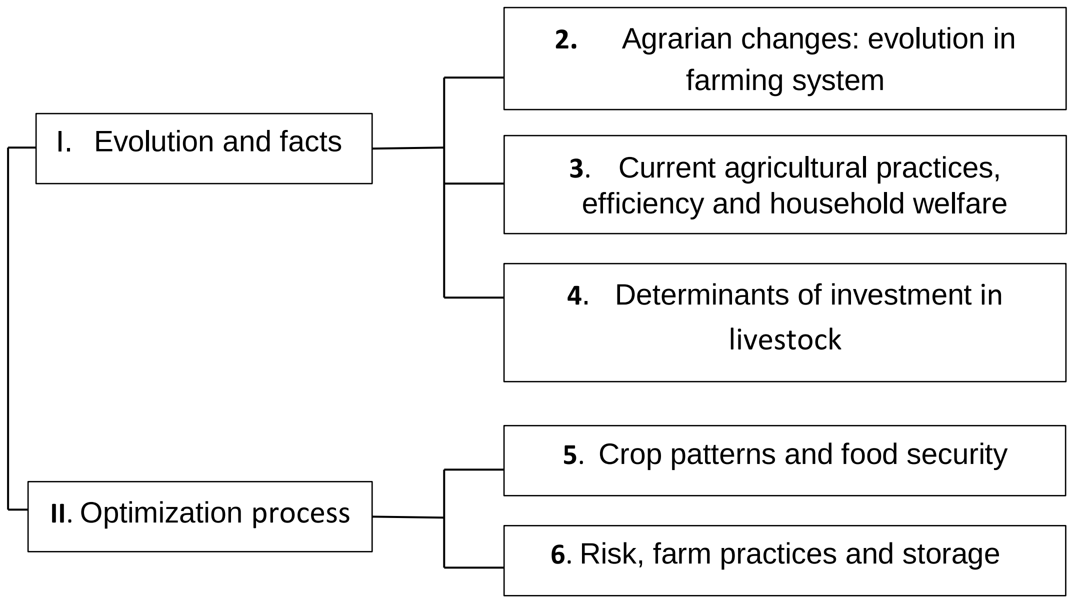

Figure 1.4: Outline of the thesis

The first part focuses on understanding the agricultural sector and farm practices as they evolved over time. This section shows that the agricultural sector went through several adaptation patterns as the land became scarcer due the demographic pressure (chapter 2). This chapter is based on review of literature. It is mainly descriptive and takes a historical approach. Chapter 3 deals with the efficiency of the current agriculture practices, and how these efficiency levels link to household poverty levels. This allowed us to test the impact of the commonly known premise of the Inverse Relationship between farm size and agricultural productivity on household living conditions. The analysis of this chapter uses a non-parametric Data Envelopment model to calculate efficiency scores amongst the ENAB sample. It tests the link between efficiency and poverty using an instrumental variable approach to control for endogeneity problems.

Chapters 2 and 3 challenge the idea of continuous adaptation among smallholder farms that dominated the neo Boserup School. Results show that despite their experience with induced intensification, the capacity of adaptation of traditional farms faces limitations due to the continuous population growth and pressure on land. Smallholder households have survived because they were able to intensify production, but they have become too small to be able to get out of poverty. They bounce against a productivity/viability limit that is probably not possible to cross anymore with the current farming system. The fourth chapter deals with livestock keeping. Generally, livestock keeping was among the imminent tools that helped to adapt farming systems especially through lateral transfer of fertility. With the decreasing extant of grazing land, the livestock sector faced difficulties which significantly affected the farmer's decision making on investing in the livestock. This chapter analyses the probability of livestock keeping against household's characteristics and location.

The second part of this thesis focuses on optimization processes in order to increase land and labour productivity in solving the problem of food insecurity and rural poverty. This part consists of two chapters: chapter 5 diagnoses crop patterns that could provide sufficient food to feed the family in terms of energy fat and protein. The chapter proposes crop combinations that could allow farm households to meet minimal food security needs while allowing trade between farmers in both inputs and outputs. The chapter confirms that it is still possible for households to overcome poverty through changes in agricultural practices and highlights some necessary conditions for the success in changes. This chapter is based on the data collected in Ngozi and the Muyinga province. An optimization model is calibrated using the detailed data collected amongst the 60 farmers. Chapter 6 includes risk attitude in farm practices and storage systems in the optimization model. In this chapter, the impact of risk on optimal agricultural practices and food security in subsistence oriented farming communities is analysed. The results show that risk is among the major factors threatening the agricultural productivity while highlighting the need for a reliable storage system to secure food availability at the household level.

1.7. Originality and novelty of the dissertation

This PhD aims to understand the options for optimising the farming systems of Burundi in order to supply food and income to farmers. The study provides a comprehensive and holistic view on the agricultural sector and shows how farming systems could evolve towards a more nutrition-sensitive agriculture. Studies that take a global approach are often lacking in existing literature. Agricultural studies focus mainly on production and productivity increases through improved agricultural practices. Agricultural economic studies focus on profit maximisation through increased production and trade, improved quality, better institutions, improved storage and efficient allocation of inputs, which should result in higher prices and more economic efficiency. Nutrition studies aim to improve the nutritional status focusing mainly on the provision of required micro and macronutrients (FAO and WHO, 2013). This study tried to link agriculture, agricultural economics and nutrition for subsistent, resource poor farm households using traditional farming systems constrained by their production environment and limited support systems.

To frame our study and to make the reader better understand the historical and political context of agriculture in Burundi, we introduce the analyses with a descriptive chapter on the farming systems. The novelty of this chapter is that it brings together different contextual aspects and literature. Next, the PhD explores the link between the inverse relationship of farm size and efficiency, and the need to secure sufficient quantities of food for the families in which they do not often succeed, in part because of the small size of the farms. The study on the inverse relationship may not be new or giving new insights. Yet, the dimension of minimal food needs is added to the discussion. A farmer may be efficient, but this may be relative to the inputs used. In absolute terms, production of the smallest farmers may not suffice to feed the family. This aspect has been largely overlooked in the inverse relationship literature. Moreover, the livestock sector in developing countries need empirical studies to guide both government and non-government interventions. While several restocking programmes focus on this sector in Burundi, studies on livestock are lacking. This PhD studies its historical role in the farming systems and describes how population density brings challenges on livestock rearing.

In addition, the study applied mathematical programming to diagnose crop choices toward positive nutrition outcomes within the agricultural production context. The model is adapted to the farming environment, taking into account the self-sufficiency behaviour of farmers (in both input and output). The model selected necessary crops to meet specific food intake requirements within the agriculture specific objectives. It also allowed for trade between the farm types. To the best of authors' knowledge, very few models have incorporated both risk in production and traditional storage in dynamic stochastic mathematical simulations.

1.8. Difficulties encountered during the study

The study encountered some difficulties in collecting the necessary information. First, documents that analyse the impact of past policies are lacking. We did not get sufficient documentation to conclude on the implementation level and in particular the impact of the different policies. Second, collecting reliable and representative farm and household data is challenging in environments as Burundi. We use two types of farm data; sets of data collected by own projects and data from an official country-wide survey. Both data sets may not be free of errors, of which we try to minimize the effect on conclusions. Calculating production figures is difficult because farmers may over- or under state figures on harvest and income while postharvest losses are difficult to estimate.

Thirdly, market and farm gate prices are difficult to get. Farm gate prices are absent because farmers sell only a small part of their produce (except for coffee, tea, cotton and bananas) on an erratic basis and not on a regular market. Hence prices collected from the farms may not represent the value they attach to their produce, neither the real price farmers would pay when buying the product. Market prices are therefore used as a proxy. Moreover, labour markets are thin. Most off farm work is done by family members and the extra labour is spent on other peoples' farms at very low wages. The wage level may hence not represent the true value of labour.

Chapter 2:

Historical changes in the traditional agrarian systems of Burundi: Endogenous drive to overcome food insecurity

Abstract

In Burundi, a succession of development policies designed to counter the Malthusian nightmare of a rapidly rising population and stagnant agricultural production has failed to attain their goals. The country is an agricultural based economy, yet its farmers struggle to get by. For more than a century it has been afflicted by a series of famines, caused by drought, pestilence or civil war. Food insecurity remains very high. In this chapter, we make a historical overview of the organisational and functional features of the agrarian system, and the adaptive changes in farming practices. This helped us to explore the relationships between the two and how the mechanisms and processes of agrarian change have affected agricultural production. We show how, despite policy failures and increased demographic pressure on land, traditional farm production systems have, over time, managed to adapt to new conditions and constraints. They have evolved in attempts to mitigate the impacts of the worsening production conditions, lack of economic opportunities, and political unrest. Yet, the current situation shows farmer's limitations to intensify agricultural production further unless policy support is provided. Policymakers need to promote local solutions that are aligned with the experiences, realities and aspirations of farming communities.

Key words: population growth, land expansion, farming systems, endogenous agriculture development, food security, Burundi.

This chapter is based on:

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Sanctus Niragira wrote the chapter and did the literature search. The co-authors (promoters) helped with revising the text and improving the structure.

2.1. Introduction

Burundian agriculture and its farmer households struggle to get by. Agriculture is the backbone of the economy and of people's livelihoods but land is scarce due to high demographic pressure while agricultural inputs are not accessible due to high costs and low incomes, technological innovation is limited and mechanization is almost non-existent. Cash crop production is limited to coffee, some tea and cotton. Many households are food insecure (Baghdadli et al., 2008; MINAGRIE, 2012). This makes one wonder how people survive. What happened – or not – to lead to this impasse? This chapter explores how traditional farm production systems in Burundi have adapted over time to changes in the country's ecological, social and political environment. It provides critical insights into the history of the agrarian systems and changes in the agrarian environment and policies that have resulted in today's level of agricultural intensification and poor socio-economic conditions.

The country has a long record of recurrent famines, civil strife, increasing population and decreasing land availability. The earliest recorded famines date back to 1880s. Famines hit the population again in 1904-05, 1908, 1917, 1925-27 and 1943-44. The World Food Programme (2016) [11] estimates that 60% of the population is currently malnourished and that only 28% can be considered food secure. Research and government reports alike emphasized the challenges of the rapid demographic growth and its subsequent effects on the country's resources, its management and development (Baghdadli et al., 2008; Ntampaka and Mansion, 2009; MINAGRIE, 2012; Minani et al., 2013). The first records of the early signs of the extensive demographic pressure date back to the 1960s. Administrative authority and development actors issued alerts that food production would not be able to sustain the country's high population growth. They estimated that there would be no more land available by 1978 (Ndimira, 1991). The dire rural situation is best depicted by the following figures: population increased by 278% during the last half century (1960 to 2010), the agricultural land was only extended by 142%, food production increased by 157% and the per capita food availability decreased by 41%[12]. According to the most recent estimates, about 70% of the population lives in poverty (MINAGRIE, 2012).

[11] https://www.wfp.org/countries/burundi (last accessed on 20 may 2016)
[12] Calculations based on FAO data/Burundi : **http://faostat.fao.org/site/339/default.aspx**

The civil war and socio-economic crisis of 1993-2000 is often reported to have hit the already struggling agricultural sector of Burundi (Baghdadli et al., 2008; FAO, 2008; Zoyem et al., 2008). Some studies argue that the competition over resources, especially land, has been an important cause of civil conflict and war in Burundi (ICG, 2003; Van Leeuwen, 2010; Samii, 2013). This would corroborate the arguments of Malthus (1798), that resources for subsistence cannot indefinitely sustain population growth. Malthus predicted that a persistently increasing pressure on resources is ultimately halted by *preventive checks* to population growth such as starvation, wars or epidemics (Leathers and Foster, 2009). Boserup (1965) countered the Malthusian view by showing that rising population density in rural areas can actually induce farmers to intensify agricultural production (Cochet, 2001; Angoran, 2004; Hatungimana, 2005).

Both these views can be used to explain what is happening in Burundi. Some farm households are indeed engaged in irreversible *asset eroding* strategies to meet short term family needs and are faced with decreasing and degrading production factors – thus limiting what they can produce to feed the growing population. Yet, at the same time farmers have been able to adapt their farming systems. Researchers do not agree on the magnitude of these different effects and some even totally refute the idea that population growth has already created a Malthusian trap in Burundi (Cochet, 2004).

The government's emphasis has been on reducing population pressure and supporting agricultural production systems albeit with limited outcomes so far. Policies in the 1950s sought to encourage people to migrate to the less populated lowlands. A birth control policy was drafted in the early 1980s (Barampanze and Ndikumana, 1994), but has not yet had an impact on population growth. In search for improved farming technologies, the national agricultural research institute of Burundi, ISABU[13], was created in June 1962 with the mandate to conduct agricultural research and extension activities in different agro-ecological zones.

Yet, despite the early warnings, development and policy initiatives, population growth is still high and landholdings are getting smaller (population growth rate is estimated at 2.4% annually while the landholding is of less than 1 hectare). Economic development is slow, and other sectors outside agriculture have failed to take-off.

[13] Before 1962, the agricultural research in Burundi and Rwanda was carried out by INEAC (in Congo-Belge)

Despite this, several authors have argued that the Burundian agricultural sector has made a slow but steady progress in food production and has been able to keep the country self-sufficient, at least in peaceful times up until the outbreak of the 1993 large-scale civil conflict (Angoran, 2004; Murison, 2004; Hatungimana, 2005). Yet, how does food insecurity, poverty, population pressure and endogenous agrarian change count up?

We can learn from the past about how processes of agrarian change have affected production (Mazoyer and Roudart, 2006) and understanding the agrarian system can help us to identify and propose effective and acceptable policy measures for the future (Turner and Brush, 1987; Saturnino and Borras, 2009). Yet, for Burundi, little is known about the policies that have been implemented in the past and how these affected farmers. As elsewhere, agrarian terrains are in state of constant change which requires rethinking on nature, scope, pace and direction of agrarian transformations to guide the above mentioned developmental policies (Saturnino and Borras, 2009) within a specific locational and historical context (Ruttan, 1982). However, the literature on the traditional agrarian systems in Burundi is scarce and is scattered over academic papers, books and unpublished grey literature written in various languages.

In this chapter we aim to address this void in the literature by presenting a comprehensive and critical study of the agrarian systems in Burundi. Building on literature and local knowledge, we provide a detailed account of how traditional agriculture has evolved over time, what may have triggered these changes and how they affected the smallholder farming population. The approach taken in this chapter is descriptive; its rationale is based on traditional farming systems research. Yet we argue that this chapter is needed to understand the analyses presented in the next chapters of the thesis. Furthermore, it helps to frame the policy options discussed throughout the dissertation. This chapter does not intend to be novel in methodology, but rather takes a reflective look at the past and present situation in farming systems of the country.

2.2. Study approach

This study is based on a critical review of the available literature. Table 2.1 gives an overview of the literature consulted. Literature on agrarian systems in Burundi was gathered from peer reviewed papers, books and unpublished reports from the Ministry of Agriculture and Livestock. References from the consulted documents allowed us to identify other important sources of information.

Table 2. 1. Overview of literature consulted

	Published in English			**Published in French**		
Focus area	**Reviewed papers**	**Books**	**Unpublished reports**	**Reviewed papers**	**Books**	**Unpublished reports**
Burundi	5	1	5	3	11	9
Africa and others	11	8	4	0	1	0

FAO data was used to assess the recent evolution in agricultural production, since official data from the country's statistical service is lacking. The first nationally representative agricultural survey since the 1980s was conducted in 2012: as such no panel dataset could be found to assess the evolution in food production. The FAO website[14] provides all the information on agricultural production per crop for every country. The quantities of crops produced, fertilizers used and area cropped from 1960 to 2010 were extracted, synthesized and used in this study. We used the food composition tables published by FAO "*Agriculture, food and nutrition for Africa: a resource book for teachers of agriculture*"[15]. The reference values were multiplied by the respective quantity produced for each crop (appendix 2.1 provides details on data extracted).

Please note that we followed the commonly used although simplified practice in literature to assume that calorific intake is the main determinant of physical health in assessing poverty thresholds in order to aggregate agriculture production. This helped to capture the evolution in food production over time (50 years).

[14] http://faostat.fao.org/site/339/default.aspx (last accessed on 30 may 2015)
[15] http://www.fao.org/docrep/W0078E/w0078e11.htm#P984 (last accessed on June 2016)

Instead of giving a chronological account of events and changes, the findings are organised thematically. It was not possible to organise this chapter chronologically because starting and end dates of different events were difficult to determine. A timeline is given in appendix (appendix 2.4).

2.3. Results

2.3.1. Food insecurity indicators

2.3.1.1. Famines

Burundi has recurrently faced periods of famines. The first officially reported famine occurred between 1892 and 1896. It was linked to several causes; mainly a severe drought occurred in 1889-1891, a rapid spread of smallpox (in 1892), outbreaks of rinderpest, foot and mouth disease and tripanosomiasis that destroyed half the cattle herds between 1891 and 1892. These epidemics affected the country at least until 1920. A second famine occurred in 1904-1905 opening a sequence of three more periods of food shortages that devastated the country in 1908-1909, then in 1915 and 1916-1917, and finally 1925 to 1927 (Thibon, 2002; Hatungimana, 2005). Despite preventive policies, a new period of famine called *Manori* started in 1943-1944. This famine claimed the lives of 8% of the population[16]. The historical sources mentioned three causes: a long period of drought, plant diseases and the heavy colonial burdens linked to second World War (Feltz and Bidou, 1994).

2.3.1.2. Rapid population growth

In the years following the big famines, population boomed, and then exploded in the 1950s (Cochet, 2004). The population density increased from 71 inhabitants per square kilometre in 1950 to 124 in 1965 (Barampanze and Ndikumana, 1994). This was mainly due to improved health care in the countryside and a continuous increase in food production that ended a long period of recurrent famines (Thibon, 2004). The administrative authority quickly recognised the adverse effect of the demographic pressure on livelihoods. It started to encourage migrations to less populated areas (1950s) as well as birth control (1983). Yet, despite the governmental preventive strategies, the population density increased to 206 inhabitants and 298 inhabitants

[16] According to the literature, it was reported that the population decreased by 8%, yet some of the people might have fled and remained outside the country.

per square kilometre in 1990 and 2008 respectively and has continued to increase (Barampanze and Ndikumana, 1994; MININTER, 2010) making Burundi one of the most densely populated countries in Africa (appendix 2.1).

The rapid population growth was also attributed to the traditional beliefs and social norms. Marriage is perceived as a social obligation that confers an individual's status in the community. In addition, the population has pro-natalist behaviour considering children as a family wealth that can perpetuate social norms and values. The burden of raising a child is believed to be partly compensated by the labour provided to the household in farming activities and other chores. Finally, like in most less-developed countries, children are potential security providers in absence of social security system (Headey and Jayne, 2014).

2.3.1.3. Changing agricultural production patterns

Burundi covers a wide agro-climatic diversity characterized by humid and tropical climate, tempered by altitude which allows the production of a range of crops. The country was self-sufficient in food production in the early 1990s (see appendix 2.1) (Angoran, 2004; Murison, 2004; Hatungimana, 2005). According to recent reports, almost 70% of the rural population lives under the national poverty line (Baghdadli et al., 2008; MINAGRIE, 2012). For 2010, a National Food Security Assessment reported a food deficit of 470 000 tons in cereal equivalent that had to be compensated for by food imports or food aid (MINAGRIE, 2011a).

The civil conflict (1993) had a large effect on agricultural production. Since its end in 2000 with the peace agreement, production of some food crops especially bananas, roots, tubers (appendix 2.3: fig 2.1) and cereals (appendix 2.3: fig 2.2) slowly recovered. Yet, pulses are less produced and were gradually replaced by root crops and tubers (appendix 2.3: fig 2.3) with a direct and negative impact on the diet. In the same period, banana production and consumption has increased significantly. In 2002, bananas contributed three times more to the agricultural GDP than coffee (MINAGRIE, 2011a). Bananas have tended to replace coffee production as a source of income, because coffee requires more land and inputs while contributing less on the household income (Cochet, 2004).

Modern input use which could contribute to increasing production is generally low and farmers prefer to grow mainly less demanding crops. Subsidized chemical fertilizers and pesticides were only provided for the production of coffee and other cash crops since the early 1960s. In the 1990s, several private initiatives started social and economic development programmes supplying fertilizers and credit in the highly populated areas of Burundi. Since 2012, the Government of Burundi has adopted a National Fertilizer Subsidy Programme which provides fertilizers to farmers at low prices[17] with the aim to increase agricultural productivity through greater input utilization in the country (MINAGRIE, 2014). Yet, only wealthier households can afford to buy fertilizers and or to take out loans to pay for these modern inputs.

2.3.2. Institutional environment

2.3.2.1. Access to land

In the past, farmers received rights to land upon clearing and using the land. All lands were formally held by the king and rights were attributed by the local chiefs to whoever was in need. The king (*Mwami)* of Burundi had the right to redistribute (*kugaba*) or to reclaim (*kunyaga*) the land. The princes (*Abaganwa*) or local chiefs assisted the king in their respective territories (Ntampaka and Mansion, 2009). The customary holder had the right to use his land, but it remained under the property of the family. Transfer of land between family members was determined by a patrilineal system. Therefore, full access to land was not granted to daughters to avoid the risk of the property being transferred to other families after marriages. A woman was granted a small share of land (*ikivi*), but the land returned to her family after her death. Seizure of land occurred when the farmer or any of his children wronged the king (*kumenja*). In this case, the family was deprived of the right to land and therefore was obliged to leave the territory (*kwangaza*).

Any landless farmer could apply for land from big landowners or local chiefs. In most cases, the beneficiaries of the land automatically became serfs (*abagererwa*) of the new master who had given them a means of survival and expected to be offered gifts (*ugushikana*) and a number of working days for various occasions in return (*gushengera*). This patronage system ended in 1976 and the right to land was granted to its users (Verhaegen and Dégand, 1993).

[17] With the national fertilizers subsidy scheme, farmers pay about 10% of the fertilizer market price

Today, inheritance is the main channel through which land goes from one user to another. This inheritance system has accelerated the fragmentation of landholdings as all male children are entitled to equal shares of their father's property. Most families have parcels that are scattered over different parts of the collines, sometime far from their villages. Recently, land sales have increased. Informal (sales and rental) rules have emerged to accommodate the growing land scarcity. Land has gradually become a commodity that can be marketed or rented to people outside the family lineage. Informal sale and rental agreements are signed (on small papers) before witnesses, and sometimes authenticated (sealed) by municipal authorities, especially when land is sold.

In 2011, the land tenure code was revised (the code was applied since 1986) in order to revitalize the agricultural sector with establishment of a genuine land market through greater respect of property rights (FAO, 2015). This is believed to allow land consolidation as farmers would be able to acquire or free land for farming activities (Lerman and Shagaida, 2007). Currently, there is an attempt to legalize land ownership through the establishment of a cadastral system in the countryside with the aim to improve land tenure security which could impact on technology adoption (Bidogeza et al., 2009) and productivity through access to institutional credit (Feder and Nishio, 1999). Moreover, inheritance patterns are evolving towards a greater consideration of rights of women to inherit land. Polygamy, often practiced in the past among wealthier families, is very rare today, which is also attributed to severe land scarcities. More wives imply more offspring and therefore low inheritance to their children.

Finally, it is worth noting that conflicts regarding property and user rights of land have increased in number and intensity over the years (Van Leeuwen, 2010). A commission was created in 2006 to deal with land and other wealth related conflicts (WorldBank, 2014).

2.3.2.2. Migration patterns

One of the main strategies to cope with spatial variability in natural and social resources in Burundi has been population relocation. Migrations, whether organised or not, have greatly contributed to decongesting the overpopulated highlands (Feltz and Bidou, 1994). The first round of migrations occurred in late 19th and early 20th

centuries, mainly due to famines. The first reaction of rural people was to search for safer regions for securing a food supply. Fathers and their sons went out over long distances to work for food. Women and children gathered any food they could find in their neighbourhoods. However, in case of strong and lasting famines, this occasional division of labour was jeopardized. Entire families fled to safer regions and sometimes never returned (Hatungimana, 2005). The second wave of migration occurred during the colonial era, in 1923-1924 and again in 1928. Migration to the British colonies, in quest of paid work, was very intense during the 1940s as people sought to avoid cash problems and possible physical punishment for failure to pay taxes (Thibon, 2004; Hatungimana, 2005).

The third and most important wave of migrations occurred during the early 1950s. Following the challenges faced by rural population in the densely populated highlands and central plateau of Burundi, the administrative authorities encouraged migrations into the lowlands. The policies aimed at rationalising agricultural production and at promoting interregional exchanges. The administration recommended each family to exploit at least 3 hectares of landholding and any citizen had the right to access some free arable land. This threshold was gradually revised downwards: 3 hectares in the 1950s to 2 hectares in the 1960s at independence and finally to 1.5 hectare per household in the 1970s.

The implementation of “Paysannats” programmes[18] in the plains of the western and eastern lowland was considered highly successful. The objective of these projects was to transform the traditional production system by introducing some industrial crops (cotton and rice), animal traction and agricultural mechanization. The migrants were initially reluctant to participate, as they were attached to the land of their ancestors, their family ties and their cultural roots. Despite these difficulties at the beginning of the programme, 9 000 families were relocated in the plain of the Rusizi-river in 1960 and 1 570 families in the eastern low lands of Kumoso. The Bugesera region in the north and Kumoso in the east had a lot of potential to support migrants. The Kumoso accommodated the Kirimiro and Bututsi landless population while Bugesera received Buyenzi migrants pushed out by the land scarcity. The migration continued after Burundi’s independence (1962) but in more organised and selective

[18] A policy attempting to foster “modern peasants”, called paysannats was implemented with the aim to establish the basis for future agricultural development by making peasants settle in fixed blocks and instructing them on new agricultural techniques.

way (Bidou et al., 1991). Later on, migration became more irregular and therefore very difficult to describe; often starting with individual seasonal mobility, with the family following on after some times.

Finally, it is worth mentioning that under the auspices of integrated rural development programmes, the government promoted villagisation and resettlement within the collines. Since the 1980s, the government of the Second Republic encouraged grouped settlements as an intervention towards development in rural communities as it would stimulate a more efficient land use (MDCOM, 2012). These programmes were intended to increase productivity through local cooperation and trade, participation in development activities, and finally the provision of basic services including schools and health care centres (Fransen and Kuschminder, 2014). The new settlement scheme intended also to strengthen agricultural extension services in densely populated villages rather than in the commonly scattered communities.

However, these programmes could not yield the expected results. They were highly criticized for their top-down approaches, their neglect of context-specificity, and the often forced nature of the relocation of people and land (Fransen and Kuschminder, 2014). Moreover, the problems this policy faced were multiple including the continuing socio-political conflicts that engulfed the country in the last decades (MDCOM, 2012). Today, the villagisation programme is applied when resettling displaced populations including the people who returned after having fled the country, international refugees, and demobilised ex-combatants in the *peace villages* under the commonly known *Rural Integrated Villages*. The objective is to promote reconciliation and co-habitation among the different groups of people (Fransen and Kuschminder, 2014).

2.3.2.3. Agricultural policies

In 1962, the national agricultural research institute (ISABU) took over the role of INEAC (Institut National pour l'Etude Agronomique du Congo-Belge; Rwanda-Urundi) assuming a long tradition of tropical agricultural research that was initiated in 1929 under the colonial authority at Gisozi. Its mandate was, and still is to develop and introduce new agricultural methods such as improved cultivation techniques (seedlings techniques, high yielding and resistant varieties), to promote the systematic application of fertilizer (manure, compost, mulching, or chemical fertilizers,…) and of erosion control mechanisms that were transmitted to farmers through extension services.

However, the deployment of extension services achieved minor increase in agricultural productivity in rural areas (Cochet, 2001). This is generally attributed to top-down approach that characterized the decision-making on the introduction of the new techniques. The extension service was indeed very authoritarian in imposing choices and technologies on farmers. Yet, these imposed new technologies were often not applied and farmers preferred to follow subsistence behaviour and resisted to the coercive policy environment (Nkurunziza and Ngaruko, 2005). In addition, several of the technologies that were promoted did not take into account the socio-economic conditions of the peasant farmers and were not immediately applicable to the smallholders (Ndimira, 1991). The extension service also lacked enough credibility and failed to gain the support from traditional farmers. The profitability of the new technologies was not guaranteed and the risk of market failure for both input supply and outputs was high (Verhaegen and Dégand, 1993). As a result, the majority of farmers only adopted technologies conducive to the preservation of basic nutritional, monetary and farm productivity levels (Verhaegen and Dégand, 1993).

Despite a political discourse that advocated giving absolute priority to agricultural production, the food crop sector was ignored (Ndimira, 1991). Attention and investment were mainly devoted to agro-industries and cash crops. Any increase in food production was obtained through the farmers' own initiative in adjusting land management and workforce allocation (Guichaoua, 1989). However, the farmers' ability to adapt to changing constraints and incentives has probably reached certain limits (Nkurunziza, 1991; Verhaegen and Dégand, 1993).

The prices of cash crops were set by the government, but food markets were not regulated. The government made several attempts to fix the prices of beans, rice and sorghum in 1978, but the intervention was quickly abandoned (Angoran, 2004). This price policy provoked distortions, and resulted into shortages of food on the market inducing a dramatic rise in food prices (Ndimira, 1991). Mechanisation was also proposed as a way of raising productivity. However, there was very little uptake due to significant biophysical constraints. These included the steeply sloping land that made the fields unsuitable for mechanization; farming system that were (and are) based on traditional mixed cropping (limiting the mechanical weeding or harvest) system and structural constraints due to the highly fragmented landholdings (Overbeeke et al., 1985).

Thus, many policy initiatives were not able to induce the hoped-for structural changes in agriculture. Many of these policies were initiated but then left unfinished or partially implemented (Angoran, 2004). Even the civil war and socio-economic crisis that engulfed the economy in its grips for almost a decade and which greatly undermined agricultural production and household resource bases (Beekman and Bulte, 2012), did not provide momentum for the much-needed policy reforms.

In more recent years, the Ministry of Agriculture and Livestock has developed a number of policy instruments set out in different strategic documents with the aim to mitigate agricultural sector vulnerability to shocks, to boost its profitability, and ultimately to sustain both food security and productive resources base (FAO, 2015).

A. The National Agriculture and Livestock Extension Programme (2005-2010)

The programme intended to boost the agricultural sector to meet its objectives, mainly to restore the country's food and nutritional balance, increase food security, household income and the contribution to the country's trade balance, and improve factor productivity in attempt to create incentives for market oriented agriculture. In the short and long run, the programme strategies were to: (i) reverse the downward trend in crop yields and livestock production, (ii) mobilise funds and revise the extension service practices, (iii) improve stewardship of resources and develop a sound pricing policy, (iv) increase land productivity for all agricultural commodities, (v) extend the market outlet for agricultural products, (vii) improve product quality in order to increase competitiveness on both regional and international markets, and (vii) rationally choose new opportunities for investment and create conditions for private investments.

B. The National Agricultural Strategy 2008-2015 and related Action Plan

The overall objective of the strategy and plan was to rehabilitate the production system and revitalize the agricultural sector in order to achieve (or surpass) the pre-1993 crisis levels of production, and leading the sector toward a market oriented agriculture with an annual growth rate of at least 6%. The policy initiated the following action plans, to: (i) diversify the sources of economic growth and initiate trade liberalization and privatization by improving the quality and competitiveness of production of agricultural commodities, (ii) ensure better control of water management and sustainable use of natural resources, (iii) ensure better availability of inputs for both agricultural and livestock sectors, (iv) seek for necessary means to solve land disputes, (v) strengthen agricultural research and development toward increased productivity, (vi) foster regional specialization of crops and livestock production according to the comparative advantages, (vii) ensure better processing and marketing of agricultural commodities in order to grasp the advantages of regional integration prospects, and (viii) mobilize funding and good coordination of actions.

C. The National Programme for Food Security (NPFS) 2009-2015;

The programme intended to restore the country's food self-sufficiency, improve the nutritional coverage of the population, reduce household vulnerability and rapidly mobilize effective emergency aid in case of disasters. The programme therefore proposed to fight against food insecurity with the aim to reduce hunger and malnutrition by at least 50% by 2015. The actions within this programme aimed to: (i) increase crop, animal and fish production through agricultural intensification with new technologies, adapted varieties and input supply, (ii) secure production through water management, soil fertility, environmental protection and conservation of natural resources, (iii) improve producers' income, especially income of women and young farmers, (iv) improve storage systems, marketing and processing of crops and animal products and fish, (v) improve the nutritional status of the population, (vi) to establish and strengthen the monitoring system, warning and rapid response to crises food in vulnerable areas, and (vii) strengthen the farmers' capacity and their support mechanisms.

In addition, the country has joined the Scaling Up Nutrition (SUN) movement in 2013, committing to tackle the alarming levels of malnutrition in the country. Subsequently, the Multi-sectorial Food and Nutritional Security Platform was established with the aim to promote the commitment and accountability among all national stakeholders (public, private and international community) (FAO, 2015).

D. The Farmer Field School (FFS)

Since 2008, the Ministry of Agriculture and Livestock adopted a Farmer Field School approach so as to enable transfer and ownership of agricultural innovations (FAO,2013a)[19]. In 2012, the global agriculture and food security programme highlighted the extension and the fostering of technical skills among farmers through establishment of the FFS and local service centres (MINAGRIE, 2012). This participatory training method is mainly supported by FAO and IFAD in several agricultural domains including seed production, protection of catchments, microfinances… (FIDA, 2014). Developed by FAO in the late 1980s, the FFS have had large successes in Asia and in Africa (Braun et al., 2006; Davis et al., 2010). The approach gives the possibility for farmers to learn, discuss and test agricultural strategies with a view to improving their food security and their livelihoods (FAO,2013a). They shape informal farmer learning which enhance lateral transfer of knowledge (Case, 1992).

E. The Comprehensive African Agriculture Development Programme (CAADP)

The CAADP was approved in 2003 in Maputo. It provides a general framework outlining the main priority areas of action for restoring agricultural growth, rural development and food security in Africa. It intends to implement the recommendations made during international conferences on food security, poverty reduction and sustainable use of natural resources. In Burundi, the strategic document for this program was approved in 2010. It is based on four major pillars: (i) extension of the area under sustainable land management and reliable water control systems, (ii) improving rural infrastructure and marketing capacities for improved market access, (iii) increasing food supply and reducing hunger and malnutrition and (iv) promoting agricultural research, extension service and adoption of new technologies for sustainable growth in production.

F. The Strategic Poverty Reduction Paper on Agriculture

The priority actions explained in this Strategic Poverty Reduction Paper were approved in 2011. It aims to increase food production and fight against food insecurity by establishing supporting infrastructure for production, promotion of traditional industries, import-export chains and non-traditional export sectors, improvement of entrepreneurship in the agricultural sector and the strengthening of

[19] FAO in action: http://www.fao.org/emergencies/fao-in-action/stories/stories-detail/en/c/175609/

state capacity. The policy is based on four pillars namely (i) sustainable growth of productive capital, (ii) professionalization of producers and promoting innovation, (iii) chain development and agribusiness support and (iv) institutional reforms and capacity building of farmer communities.

In addition, the Ministry of Agriculture and Livestock has developed a National Agricultural Investment Programme (NAIP), in order to operationalize these strategies, track investments in the agricultural sector and assess their impacts on rural populations and the government revenue (MINAGRIE, 2011b). Some of these are still being implemented, so it is too early to accurately evaluate them, but reports on the food security situation are still alarming and hence indicate that the measures have not (yet) had the intended results.

Notwithstanding the recent political commitment, the annual agricultural production growth of 2% (MINAGRIE, 2011a) is still low and the incidence of poverty remains high with 67% of the population living below the poverty line (MINAGRIE, 2014). The sustainable and effective implementations of the above mentioned policies remain a major challenge for Burundi. The institutional and human resource capacities are still limited. Detailed information on the implementation and outcomes of governmental nutrition-specific programmes is lacking (FAO, 2015).

It is worth mentioning that the agricultural sector is highly dependent on climatic conditions. The growing population has put increasing stress on the country's natural resources leading to low per capita production levels and an even increased vulnerability to climate change with low resilience in many areas of the country (Beck et al., 2010). Households adapted their livelihoods by extending agricultural activities on the protected areas, cultivating on steep slopes using unsustainable practices, and draining marshes for agricultural use (Baramburiye et al., 2013). The government of Burundi committed itself to the protection and management of the environment in its *2025 vision*[20] by promoting sustainable land use (MEEATU, 2013). Several conventions related to environmental and biological resource conservation were ratified. Moreover, texts governing the domestic law to counter adverse human effects on natural resources were promulgated. Yet, they could not yield the expected outcomes (Nzirikwa, 2005, Beck et al., 2010). An implementable land use planning or

[20] The government long-term framework for the country's comprehensive economic and social development was approved in 2011.

management system is still missing to properly coordinate development and conservation techniques as already noted by Beck et al. (2010).

Policy included a strategic and action plan towards environmental education and awareness (MEEATU, 2009). The government has set up a program for rational natural resource management and fight against climate change in 2013 (MEEATU, 2013) with the main objectives to: (i) ensure sustainable management of natural resources, (ii) promote ecotourism in the country's protected areas (parks, reserves,…), and (iii) develop an early warning system for the prevention of climatic risks. Yet, despite the drafting of these revised policies and codes relating to the environment, the implementing regulations, authorities, and monitoring systems are lacking. This may be due to an incomplete legal (regulatory) framework which renders the laws largely ineffective (Beck et al., 2010).

2.3.3. Endogenous agricultural intensification

Traditional societies have long used their endogenous capacity to innovate and agriculturally intensify. Farmers continuously search for ways to improve their farming strategies in order to cope with increasing land scarcity and socio-economic constraints (Guichaoua, 1989; Cochet, 2004). They developed strategies that allowed them to maintain higher productivity levels through labour intensive techniques, adoption of new crops, crop rotations with (or without) short fallow and various crop associations or apply erosion control mechanisms and soil fertility restoration methods (Barampanze and Ndikumana, 1994). In this section of the chapter, we try to understand the 'traditional' nature of the agricultural system, and try to learn from what is known on the agricultural systems from even before American crops were introduced in the central African region in late 18th century (Bahuchet and Philippson, 1998).

2.3.3.1. Early crops and shifting cultivation

Sorghum (*amasaka*: *Sorghum spp.*) and finger millet (*uburo*: *Eleusine coracana*) have long been the staple foods in Burundian diets (Cochet, 2004). Both grains were used as food, especially in the preparation of the staple paste ugali (*umutsima*) and beer (*impeke*). The two cereals are known as the oldest farming heritage and shaped the early phases of rural history. The first dominant farming system was shifting cultivation which turned gradually into rotational bush fallow in early settled agriculture. New plots were cleared and burned, then cultivated for several years before being left to fallow for several years allowing soil fertility recovery. After soil preparation (by hand) cereals were sown early in the rainy season and harvested at the beginning of the dry season.

Sorghum and finger millet served in dynasty and family cerebrations (n*ew year*). Sorghum was used in the annual ritual of *umuganuro*[21] that symbolised and legitimated royal authority in the kingdom of Burundi, and finger millet was commonly used in families, where the father wishes "a good year" to the family[22]. Both grains play a key role in the society, as they are ingredients in beer which was indispensable in all ceremonies in which families gathered for good or sad events or to shape social networks (Chrétien, 1982).

Beside sorghum and millet, other crops cultivated were legumes including beans of the vigna type (*inkore: Vigna unguiculata*), pigeon pea (*inkunde: Cajanus pigeon*) and bambara groundnut *(impande: Voandzeia Subterranea*). There were three important tubers: yam (*ibihama, ibisunzu*) including a variety that provides both underground and above ground tubers (*itugu: Dioscorea bulbifera*), taro (*amateke: Colocasia antiquorum*) and coleus tuber (*inumpu: Coleus dysentericus*). Indigenous vegetables included the African eggplant (*intore: Solanum esculentum*), bitter spinach (*insogi: Gynandropsis pentaphylla*), tetragone (*inyabutongo: Amaranthus*), amaranth (*imbwija: Amaranthus dubius*) and several kinds of *Cucurbataceae* that were planted near the family house (*bitter: imihiti and sweet: imyungu*). Whereas the sweet C*ucurbitacae* were cooked and consumed, the bitter varieties were used to make household utensils and containers (*igisabo*) for skimming milk. Other plants that characterised the Burundian countryside were indigenous trees that were often planted around the house and considered sacred, so they were rarely cut. These included *ficus* (*umuvumu*) the bark of which was used to make traditional clothes, *ibitongati* (*Dracaena steudneri)* of which ashes were used in malting sorghum for

[21] Every year a nationwide ritual was organised by the king to give the signal for the beginning of the agricultural year. Sorghum was used and symbolized the country's prosperity and successful social relations.
[22] A Burundi's ancient tradition, and even today in some regions, it was forbidden to eat the first finger millet meal of the year outside. It had to be offered in the household by the father or the eldest son (in the absence of the father, either due to death or absence on long term migration). Starting from the eldest, the father would say "take the "year" enjoy good health, and anyone who wishes you evil this year shall perish himself"

beer production, and *Erythrina* (*umurinzi: Erythrina abyssinica*) which was used mainly in ritual and religious practices.

Most farm work was done by the family labour, but clan members often provided extra hands when needed in the expectation that similar labour contributions would be made on their land *(ikibiri).* They were often offered an evening of drinking sorghum or finger millet beer afterward. Apart from sorghum and finger millet, all these crops were grown near the family compound in small amounts and fertilised using cow dung and household waste. Vegetables were either cultivated or gathered from wild areas and ashes served as a fertilizer in the grain fields (Cochet, 2001).

2.3.3.2. Exotic crops and changing land use patterns

The sorghum and finger millet cropping system changed after the introduction of crops of American origin (Cochet, 2001). In the late 18th century, crops of American origin were progressively disseminated in central Africa (beans: *Phaseolus vulgalis*, maize: *Zea mays*, sweet potato: *Ipomea batatas*, cassava: *Manihot esculenta* and potatoes: *Solanum tuberosum*). Banana (*Musa spp*) and modern taro (*Colocasia esculenta*) and peas (*pisum sativum*) of Asian origin were already grown in the region. Despite promising productivity levels, farmers in Burundi were slow to adopt these new crops in their farming systems. Farmers and their households were unfamiliar with the new food crops, and some food taboos delayed their integration in daily cuisine.

Gahama (2001) indicated that these crops were gradually adopted as distrust had finally diminished later during the colonial era in the 20th century. The colonial authority recommended peasant farmers to reduce sorghum and millet and to incorporate the new crops in their activities. The colonial authorities also wanted farmers to focus on food crop production rather than on sorghum and millet which was often used for beer production (Gahama, 2001). Moreover, due to their long cropping cycle, these grains allowed only one harvest per year. Later on, with the increasing competition for better-quality land, cultivation of sorghum and millet shifted from the more fertile lands to marginal areas and the yields of these grains declined. Finger millet was often used as an opening crop on newly cleared land.

Farmers organised crop production along well-delineated concentric circles with the family compound (Rugo) at the centre. The most intensive and therefore fertilised crops occupied the plots closest to the *Rugo*. The compound itself was fenced and several houses or rooms in the houses were used to dry grains, prepare food and for other household tasks. Banana was planted closest to the *Rugo*, and it was intensively fertilized with manure, ashes, plant residues and domestic wastes. While men were responsible for the bananas, women were allowed to grow taro and vegetables in the shade of the banana plantations. The next ring was characterised by a multi-cropping system including banana and two cycle crops, mainly beans intercropped with maize. This ring received less manure compare to the first ring. The third ring, mainly grassy plots, was not fertilized, and was used to produce less demanding crops such as sweet potato and cassava. Intercropping was no longer practiced on this ring with a relatively less fertile soil, which was left fallow for two or three years. The fourth ring was occupied by pastures and gallery forests between cultivated lands and the bottom valleys or marshlands. Colonial authorities also introduced coffee production in the early 20th century. Coffee plots were separate units and were always mulched (Rishirumuhirwa and Roose, 1998). Lands outside the family circles, often rather sloping, encompassed vast undivided grazing lands accessible to all families.

2.3.3.3. Early 20th century: famines and compulsory crops

In 1926, Cassava and sweet potato were decreed to be anti-famine crops as they could resist the seasonality feature while allowing gradual harvest in line with the household needs. The colonial authorities issued the obligation that each adult man had to plant 5 acres of anti-famine crops, a threshold area which was revised to 15 acres in 1931 of which at least 10 acres had to be planted with cassava. Any peasant who failed to do so was liable to a punishment of up to seven days imprisonment or a fine of two hundred Burundi francs (Gahama, 2001).

Rules on coffee plantations were issued in 1932. Farmers were forced to keep up to 54 coffee trees on fertilized land near the Rugo (Hatungimana, 2005). The policy aimed at commercializing agriculture so farmers would start to earn an income and be able to afford to pay taxes (Feltz and Bidou, 1994; Thibon, 2004; Hatungimana, 2005). The extension service regarding coffee production was particularly authoritarian and very closely supervised farmers. Many farmers were subject to fines for neglecting to mulch coffee plantations. This was even more severe when farmers dared to uproot unproductive coffee trees or plant other crops below the coffee plantations. The rigour on coffee cultivation continued after the independence (1962) until the eve of the socio-political crisis in 1993. At present, regulations on coffee plantations still exist but are moderately applied. Population pressure and land shortage have negatively affected the availability of mulching grass and many plantations are neglected or simply abandoned and sometimes mixed with food crops. The current liberalisation of the Burundi's coffee sector aims to improve its competitiveness on the international market.

2.3.3.4. Multiplication of crop cycles and mixed cropping systems

The short cropping cycle of the newly introduced "American" crops allowed farmers to grow food in different seasons of the cropping year. We can distinguish three cropping seasons mainly two rain seasons and one dry season (section 1.5.1). Cochet (2001) indicated that a double-cropping system was rare before the 1950s, except in regions where demographic pressure was already high. Most farmers preferred to leave their land fallow and have soil fertility recovered. Yet over time, fallow periods were reduced, and nowadays many plots are planted twice or sometimes three times a year.

Farmers were not very keen on cultivating the marshland because this involves heavy work[23] and they were thought of hosting ghosts. Later, people realized the importance of the wetlands in complementing the shrinking plots on hillsides. Wetlands are now used for permanent cultivation. After a bean cycle intercropped with maize in season C (dry season), farmers grow rice or sweet potatoes from December to June. On marshlands that are not suitable[24] for rice, potatoes are planted in December followed by vegetables in April, beans intercropped with maize and sometimes with cassava in July.

Over time, it has become more difficult to identify the earlier concentric circles in the farm plan and its succession of crops. The landscape has changed and it is now more difficult to clearly identify the different cropping systems. Most plots are intercropped except for plots with cash crops, rice in the marshlands and cassava on

[23] Crops on marshland were first enforced by the administration in 1924 as an alternative to hillside plots often subjected to heavy losses at time of drought.
[24] Only lowland plots with sufficient water availability can be used for irrigated rice production.

highly degraded lands[25] which are usually mono-cropped. Farmers are likely to plant up to five crops on a single plot in order to cope with potential risks and minimize yield variability in a more complex way. This practice protects them against risks of crop failures caused by adverse climatic conditions or pests. There is also an increasingly complex system of crop associations; cassava and sweet potato grow on the different plots with grains and pulses while banana trees are planted in combination with grains, legumes and tubers. It is very common to find beans, maize, sorghum, sweet potato and cassava with some fruit trees, and multipurpose trees on the same plot. Almost half of the plots visited during the National Agricultural Survey (2012) had at least four different crops (see appendix 2.3).

The association of crops has implications for food security and land cover. Beans, maize and sweet potatoes sown at the beginning of the rainy season do not mature simultaneously. Beans are harvested in December while the two other crops will be intercropped with sorghum in the second cropping season. Similarly, sweet potato is harvested in April before sorghum comes to maturity in July. The complex mixed cropping system implies that famers have to work their land more intensively as planting, maintenance and harvesting is spread out over time. The overlapping crop cycles therefore require almost continuous work on the plot, but this is relatively smoothed out through the year and some tasks are combined for all crops in the association (Cochet, 2001).

2.3.3.5. Multiple cropping and livestock patterns

Land use intensification created an increased need for soil fertilisation. Livestock has been increasingly integrated in the farm and represents both a form of capital accumulation and a source of manure. In the past, livestock was managed jointly; neighbouring cattle were herded together during the day (on undivided grazing lands) but kept in the fenced enclosure around the homestead (Rugo) at night. Calves were kept in the main house. This enabled the farmers to collect the dung to be used on the plots. Yet, fodder availability in the dry season limited the number of animals that could be kept. During this period, livestock was fed on crop residues (mainly sorghum straw). Fresh grass was available in the humid low lands, and some fresh grass was

[25] When farmers want to bring land back into production, the first crop they grow is cassava and fertilization starts after the cassava harvest.

available after the first rains following the tradition to set grassland on fire during the dry season (*umuyonga*). Transhumance was common in search for more grazing land in less populated regions of the country. Herders spent weeks away from home grazing their animals. The livestock was raised primarily as a wealth reserve to be used for payments of dowry, family emergencies, or ritual occasions and secondly for household consumption of blood (*ikiremve*), milk and meat.

However, with the increasing use of multi-cycle crops and disappearance of common grazing land located on the hillsides and along the rivers, livestock was, and is now, more often kept in compounds. Cattle are often fed on ‘cut and carry’ feeds from the fields[26]. Some farmers began to charge for access to postharvest remains and to rent out private grazing areas. Due to these feed constraints, cattle were progressively abandoned in favour of smaller animals, especially goats (appendix 2.4: figure 2.4). They are easier to maintain, and reproduce so fits better in small farms. As a result, the cattle numbers decreased substantially from the 1970s onwards, mainly due to the reduction and depletion of natural pastures (Hatungumukama, 2009). In addition, the livestock sector faced heavy losses the onset of the conflict in 1993, mainly due to theft and pillaging (Bundervoet, 2010). Since 2007, the government and NGOs have initiated restocking through solidarity chain programmes. These zero-grazed crossbreds or grade animals are fed on crop residues and fodder in the cowshed. This however limits the access of poor farmers with small landholdings to the programme.

2.3.3.6. Multiple cropping and soil fertility management

The intensive multiple cropping systems rapidly depleted the soils and there was insufficient manure, the most widely used fertiliser, to maintain soil fertility, which led to distant plots left unfertilised. As the free grazing areas became scarce, only wealthy households who could afford fodder and veterinary care were able to keep cattle. This led farmers to turn to alternative fertilisation systems. Banana groves gradually substituted livestock as a form of capital accumulation and source of fertilizer (Rishirumuhirwa and Roose, 1998). Throughout the country, almost every homestead planted a banana plot. As such, farms showed a centrifugal expansion of banana, gradually overlapping other peripheral crops and improved soil fertility

[26] This practice is also encouraged by policy as famers are sometimes fined for having grazed cows in public domains.

throughout the farm. Banana residues are used as mulch, to control runoff and erosion, and to improve soil chemical and physical properties.

In some regions, the old farming system with its concentric circles has totally disappeared. Farmers have also developed other methods to improve soil fertility through recycling biomass and composting techniques. The use of purchased fertilizers and pesticides remains limited due to limited purchasing power and limited market access. For some time, fertilizers and pesticides were provided by the government for coffee production but farmers often diverted it to food crops.

In today's farming systems, soil fertility on the plot is maintained by incorporation of crop residues at ploughing, the occasional application of manure in planting holes, crop rotation, and short fallows. Burning fallow and crop remains is no longer in use and all biomass is buried or gathered in pits for producing organic fertilizers. However, many of the poor farmers have insufficient land to practice crop rotation and fallow land is scarce.

2.3.4. Multiple cropping and environment degradation

As the description above shows, agricultural intensification went hand in hand with overall environmental degradation, including increased soil loss through erosion, decreasing soil fertility, and reduced biodiversity. Research shows that Burundi experienced one of the highest rates of deforestation (2-3%) between 1976 and 1985 (Allen and Barnes, 1985). In wetlands, rice, beans and vegetables cultivation gradually replaced autochthonous species (*Cypercus* and *papyrus*). Gallery forests which once dominated the foothills were gradually replaced by food crops and *Eragrostis olivacea* started to dominate most of uncultivated spaces; a sign of extremely exhausted soils. These lands are often planted with Eucalyptus. First introduced in Burundi during the colonial era, Eucalyptus has attracted farmers' attention as it is a multipurpose crop, acting as a prominent source of building timber, firewood and income for the households (from wood sales or converted into charcoal).

2.3.5. Who is/was able to act?

Malthusians are sceptical about the prospects of addressing the problems of population, resource access and food security. According to Malthus and his intellectual heirs, checks on population growth such as wars, famines are inevitable (Leathers and Foster, 2009), but this line of thought ignores the potential of production innovations (Thibon, 2002). This view was also criticised as legitimating government's search for bilateral and multilateral aid instead of seeking local and national answers (Cazenave-Piarrot, 2004; Thibon, 2004). In the 1960s, Boserup saw the potential of change rooted in local farmers themselves; she argued that traditional agricultural communities are continuously subjected to changes in agricultural technology, often induced by population pressure, and that this results in a progressive transformation towards more intensive cultivation techniques (Boserup, 1965). This view has in turn been criticized for not taking into account the negative aspects of intensification including environmental degradation (Lele and Stone, 1989). Equally, it is argued that improvements in production techniques can induce further population growth, simultaneously increasing the labour and food supply and food demand. Because of the diminishing conversion efficiency of production factors (labour and land) into food, such improvements may effectively cancel themselves out (Lipton, 1989) resulting in inevitable environmental degradation (Ehrlich, 1990; Carswell, 1997).

In reality, the model of "population growth's induced technological change" is unlikely to occur in places with very high population growth rates such as Burundi (Carswell, 1997). The argument is that population growth rates are so high that country's economy fails to support its population (Collier and Hoeffler, 1998; White, 2005; Kondylis, 2008). A number of studies (Pingali et al., 1987; Ruthenberg, 1980) have argued that endogenous technical change is not sufficiently strong to sustain steady increase in agricultural output. These authors argue that comprehensive and large-scale projects are needed and have to be initiated and supported by policy makers (Binswanger and Ruttan, 1978). However, government-led approaches in African agriculture have more often than not been financially unsustainable. They have collapsed and provoked macroeconomic crises in many countries. This has led to disenchantment in agricultural-led development (Nin-Pratt and McBride, 2014), something that has also occurred in Burundi, despite the renewed attention for agriculture sector since mid-2000s (Pingali, 2012).

International policies and programmes are generally built on the assumption of land scarcity and an abundance of labour and promote technology supply, intensive input use (Cleaver and Donovan, 1995; Morris et al., 2007), market orientated production and investments in infrastructure (Byerlee and Heisey, 1996). Yet, it has been argued that these international programmes tend to overlook the structural and agro-ecological characteristics of African agriculture, and do not promote sustainable agriculture (Nin-Pratt and McBride, 2014).

The question of who is/was able to act is particularly relevant for Burundi. As mentioned above, some are pessimistic about the future and foresee further food insecurity and civil unrest (Malthus, 1798). Others point to failures in policy attempts to influence population density and agricultural productivity. These failures can be traced back to a lack of awareness and recognition of the agro-ecological characteristics and potential. Drives to improve productivity, through technological changes, largely failed as they did not take smallholder preferences and their traditional farming systems into account. Yet, there have been visible changes in the farming systems, mostly attributable to endogenous changes (Boserup, 1965). Their relatively slow development is due to farmers themselves, who only change their farming systems in order to survive.

It is worth mentioning that while the lack of effective agricultural and environmental policies and especially their implementation posed particular challenges, the political instability halted sustainable production growth in all the sectors of the economy including agriculture. Since the independence, several episodes of civil war claimed more than 500 000 lives and caused about a million of refugees. The assassination of the independence leader Rwagasore in October 1961 destabilised the political situation in the country leading to vicious in-fighting between political elites, which eventually escalated into the 1972 massacre. The political tensions following the massacre further triggered the 1988 civil war in the north of Burundi. Finally, in 1993, another civil war broke out after the army overthrew the first democratically elected president (Nkurunziza and Ngaruko, 2005). This has greatly affected the implementation of different sets of policies and the population welfare deteriorated continuously as the country became dependant on food aid. The Global Hunger Index rose from 27.7 in 1981 to 32.3 in 1992, 39.7 in 1997 and finally to 42.7 in 2003 (Zoyem et al., 2008). Agricultural productivity decreased significantly, in part due to the prevailing conflicts and also due to land degradation and inefficient farming practices (Baramburiye et al., 2013).

2.4. Conclusion and policy implications

Burundi suffers from food insecurity and widespread poverty and population growth has been the main trigger for the intensification of farms. As the population grew, land resources became scarcer, land expansion increased and agricultural production was intensified. To some extent endogenous changes on the farms enabled farmers to survive and sustain themselves. The farming societies have evolved by adapting their livelihoods to the changing environment (cf Boserup). Yet, in contrast to many other areas in the world, this intensification has not come from the increased use of modern inputs, but more from traditional methods: spreading agricultural activities over virgin land including marginal land, by adopting new crops with a shorter cropping season to allow more cultivation cycles per year, reducing fallow periods, and adopting erosion control mechanisms and soil fertility restoration techniques. The use of livestock manure, complemented by recycling and possibly composting of banana residues and various other sources of organic matter has helped farmers to maintain crop yields that would otherwise have collapsed under permanent cultivation. Farmers have also adapted their livestock activities, responding to the limited availability of free grazing by making more and more use of crop residues, and cut and carry feeds.

Despite the endogenous capacity of Burundian traditional societies to evolve and adapt their livelihoods, the level of adaptation seems to have reached its limits. The ultimate disappearance of fallow, the drastic reduction of the extent in grazing pastures, the overexploitation of land, the decreased fertility and yields, deforestation, erosion resulting mass impoverishment of farmers and growing malnutrition show the limitations of farmers' capabilities. The more intensive land use has caused serious problems for both the ecosystems and diets. Soil conservation has become critical as farmers see their land fertility declining over time. Moreover, the on-going substitution of legumes by root and tubers crops in the cropping systems is compromising the population nutritional balance.

A sustainable increase in agricultural productivity seems unlikely unless policy assistance is accessible for both technology and production. However, decision makers need to consider the (historical) background in farmers' practices and local institutions. There is a need for policymakers to promote local solutions that are in line with experiences of local people, and are aligned with their perception of the problems, their expectations and initiatives and local embedded institutions, instead of setting up top-down and authoritarian policies. It is impossible to get the farming population to change their traditional production techniques without acknowledging and valuing the prevailing agricultural system. Agricultural extension services could adopt more participatory approaches in order to improve technology adoption among farmers. Another key policy area is making land better available through reducing land fragmentation. Part of the solution could be to stimulate settlement in villages or to encourage land consolidation between heirs or through land market development.

Chapter 3:

Farm size and productivity, exploring smallholder farmers' welfare in Burundi

Abstract

This chapter presents an economic analysis of small-scale production efficiency and household welfare in Burundi. We used recent advances in data envelopment analysis (robust DEA) to generate standard and bootstrap-bias-corrected technical efficiency scores for a nationwide sample of farms in Burundi. Next the correlation between these efficiency scores and poverty levels was checked. Finally, an instrumental variable approach was used to assess the link between household welfare and farm productivity. Results show that smaller farms are more efficient compared to the larger farms. Yet, given their small size, this efficiency level is not sufficient to raise the farm income above the poverty line which raises concerns about their viability. Most of the farms are too small and agriculture can no longer provide a realistic livelihood for the household to earn a living. Their households depend mainly on a casual labour income. As a consequence, most of the land-constrained household are poor and food insecure despite their high productivity levels. As such, it is hard to appreciate how the inverse relationship between farm size and land productivity can strengthen nearly landless households or how livelihoods can be sustained. Both consumption and income appear as increasing functions of the size of the landholdings. We argue that fundamental changes in the farming systems and agricultural policy are necessary to increase the scope for sustainable smallholder-led agricultural intensification. This could boost the potential for agriculture to play its role and have positive spill-over effects on the growth in other sectors.

Key words: smallholders, farms, efficiency, food security, welfare, Burundi.

Paper in preparation by Sanctus Niragira. The initial structure and research questions were developed in collaboration with the promoters. Data was gathered by Sanctus Niragira and Sam Desiere. Analysis was done by Sanctus Niragira in collaboration with Jan Brusselaers.

3.1. Introduction

The potential of smallholder agriculture to create employment in rural areas, to generate income, and to contribute to household food security has been well documented in different developing countries (Hedden-Dunkhorst and Mollel, 1999; Mellor, 2014). Since 1964, when Schultz formulated the "poor-but-efficient" hypothesis, smallholder farmers attracted the attention of researchers, donors and decision makers alike. By agreeing that small-scale farmers are more rational, compared to the large landowners in allocating their scarce resources, improving the livelihoods of these households becomes a central aim of agriculture-led development. An impressive body of literature confirms that small-scale farms are efficient by showing an inverse relationship between farm size and yield (Wiggins et al., 2010; Verschelde et al., 2012). Better efficiency on small-scale farms is partly attributed to the abundant family labour per unit of land. Family workers are typically more motivated than hired workers and provide self-supervised high quality labour (Lipton, 2010). In addition, small farms achieve higher productivity with lower capital input compared to large farms, which is very important in countries where land and capital are scarce relatively to labour (Hazell, 2005) and markets for credit and inputs are imperfect.

Empirical evidence suggests that support to small farms should not only be motivated by efficiency reasons but also because family farms are needed to maintain stability in the community, to secure sustainability of agricultural production and to stimulate local rural economic growth. Productive activities on small-scale farms as well as their labour mobilization, consumption patterns, ecological knowledge and common interests in long-term maintenance of the farm as a resource, contribute significantly to a stable and lasting local economy (Rosset, 1999). Smallholder farms contribute to reducing unemployment, provide a more equitable distribution of income and generate an effective demand for products and services from other sectors of the economy (Bravo-ureta and Pinheiro, 1997). By spending substantial shares of the extra income on locally produced non-agricultural goods and services, they contribute to markets and production of often labour-intensive goods (Mellor, 1976; Robbins and Ferris, 2003; Mellor, 2014).

In turn, these demand-driven growth linkages provide better income-earning opportunities for the most vulnerable groups including nearly landless farmers and landless workers. Hence, both direct and indirect effects arising from supporting small farms contribute to the overall reduction in rural poverty and food insecurity (Hedden-Dunkhorst and Mollel, 1999; Hazell, 2005) as these households account for large shares of the rural poor (WorldBank, 2007). Moreover, growth in the smallholder farm sector adds to a more vibrant rural non-farm economy which in turn could constrain the rural-urban migration (Hazell, 2005). However, the viability of smallholder farms today is greatly challenged. They are confronted with trade-distorting agricultural policies and the shift toward increasingly integrated and consumer driven markets as part of market liberalization and globalization (Kirsten and Sartorius, 2002; Narayanam and Gulati, 2002; Hazell, 2005). Also access to sufficient land is a great concern (Jayne et al., 2003).

In many poorer countries, the continuous spatial subdivision of landholdings has reached levels where a growing number of subsistence farms are unable to achieve their primary goal to secure the families' food and income (Glover and Kusterer, 1990). Hence, a pertinent question is if and how farm size affects the ability of the farmers to provide a decent living to the household and further ensure communities' long-term economic sustainability? According to Hazell, the minimum acceptable size of a farm depends on the possibility in complementing income from farm activities with non-farm income (Hazell, 2005). At a certain level of farm size division, farms could get so small that production becomes too low to warrant their farming activity. Non-farm income is then needed to survive, but non-farm income earning opportunities may be very scarce especially in the rural areas. Jayne et al. (2003) emphasised the growing number of landless and nearly landless farms leading ultimately to a rapid exodus from the countryside (Jayne et al., 2003) despite the low accommodation capacity and high rates of unemployment in African cities.

Against this background, this study assesses the link between farm size, productivity and household welfare in the context of highly fragmented landholdings of Burundi. Demographic pressure has caused shortages of agricultural lands. In addition, the intensive cultivation led to serious soil erosion and fertility problems (Oketch and Polzer, 2002), and therefore putting limits on the scope of sustainable intensification. Yet, the agricultural sector is considered to be the backbone of the country's economy and its problems hence call for comprehensive public interventions (MINAGRIE, 2011b).

A study by Verschelde (2013) in two Northern provinces of Burundi found an inverse relationship between farm size and land productivity while showing a strong correlation between farm size and household food security (Verschelde et al., 2013). This inverse relationship has been confirmed for other smallholder farming systems too. The findings may not come as surprise if one assumes the limits of scale economies due to limited mechanisation, input use and market. Yet, how small, a small farm is allowed to be as to secure household survival. For numerous households, farm income is not sufficient to properly remunerate the farmer's work nor to support household food and non-food needs (MINAGRIE, 2011b). Therefore, even though smaller farms are considered more productive, the key question for the farm family is in the end whether the total income generated and food produced allows them to feed their families and to cross the poverty line.

Higher farm productivity may allow an exit from poverty, if the size of production and the income generated is sufficiently large; or in other words if the farms are of a minimal size (Valdés and Foster, 2010). Access to land is generally regarded as a key issue for sustainable livelihoods in Burundi (Pedro, 2011). Scholars view access to land as a significant determinant of food security, vulnerability to risks and shocks, and income potential (Ricker-Gilbert et al., 2014). A particular question is also how efficiency levels influence welfare given a certain farming system and land area. This relationship may differ from the one between land area and efficiency. This basically answers the question whether it is possible for a household to gain welfare through improving the farming system's efficiency given the land it has available.

The link between the inverse relationship of farm size and efficiency, and a discussion on minimum scale to secure sufficient quantities of food for the family, is not often made. We want to close this gap in literature. This study makes at least two contributions to literature. First it analyses the production levels and efficiency of production in terms of energy and macronutrient levels. The production and income recalculated in food availability and accessibility allow to investigate farm production from a nutrition-sensitive agriculture perspective. We calculate the relationship between farm size, efficiency levels, production size, income and food security. Second, we add a question of minimum scale to the inverse relationship literature. As far as we know this has been overlooked in literature so far.

We use a dataset of information collected by the Ministry of Agriculture from farms across Burundi. We apply a Data Envelopment Analyses (bootstrapped to increase robustness of the results) to calculate efficiencies which are then compared to absolute levels of production and income. We estimate how increase in efficiency, given the land area, can influence farm household's welfare levels. The key welfare variable for this study is farm income per adult equivalent. Despite that income is considered less desirable in measuring consumption-based welfare, it is generally accepted as a key indicator of household economic activity and welfare (Jayne et al.,2003).

3.2. Study methodology

3.2.1. Data

This study uses data from a recent agricultural survey available from the National Statistical Bureau of Burundi (ISTEEBU). The nationally representative survey was conducted in the 16 provinces of the country on a sample of 2560 farm households during the cropping year 2011-2012. In each of the 16 provinces, 20 collines (administrative entities) were randomly selected and in each colline, 8 farm households were randomly chosen to participate in the survey. The main purpose of the survey was to update agricultural statistics in the country. The survey included 14 sections with questions related to farm production, household characteristics, income generating activities and livestock keeping. Households were visited several times during all three agricultural seasons. The data on agriculture was complemented by data on living-conditions collected by the World Bank on the same farm household sample. For some variables, we noticed measurement and encoding errors which prevented identification and therefore merging of the datasets[27]. Farm households which could not be matched were removed from the dataset, resulting in a sample of 2130 farm households. Note that the province of Bujumbura *mairie* (which is the single most important urban area in the country) was not considered in the survey due to the relatively minor role it plays in agricultural production of the country.

[27] A partial checking of the database was done. As result one part of the data was removed as we could not manage to correct all the errors.

3.2.2. Variables included in the study

Not all available data were used in this study. Only variables related to household composition, farm size, agricultural investments and annual production were considered. Household composition is given in number of adult equivalents taking into account the household structure. The Adult Equivalents are created to normalize the nutritional needs of different family members in a household based on age and gender (see Buse and Salathe, 1978; Weisell and Dop, 2012). Pregnancy and breastfeeding were not included in the study due to lack of related information in the dataset. With regard to farm production, we valued food crops production at their market prices, irrespective of whether crops were sold, consumed by the household or exchanged through social networks[28]. The quantity of each crop was multiplied by an average market price[29] of the respective crop because individual farm-gate prices were missing. They are highly volatile while only very limited amounts of produce are sold. We consider that this price represents the real amount of money that farmers would have to pay to acquire the products on the market. Annual production was also valued in terms of calorie and food macronutrients (proteins and fat contents) in order to aggregate the production in a single unit that can be compared with the household food needs. Production quantity of each crop was multiplied by respective approximate content in calories, proteins and fat issued by FAO[30]. The production of banana was taken separately because banana can be considered a semi-cash crop as it is mostly used to produce the locally well-known and highly marketed banana wine/beer (Niragira et al., 2015). Cash crops are coffee, tea and cotton, and related income and non-farm income were reported by farmers during the interviews.

Land size, labour and cost of purchased inputs (agricultural expenditures) were included as production factors. For land, the total farm area that was used for growing crops in the three cropping seasons of the 2011-2012 agricultural year was calculated. The impact of land fragmentation was assessed because a single farm in Burundi consists of numerous spatially separated parcels. Whereas some authors consider land fragmentation as an obstacle that causes inefficiencies in production

[28] Previous studies highlighted that 72% of food production were consumed by the household while 28% were either sold to the market or exchanged through social network.
[29]Information on average price is found at the national statistics Bureau (Annuaire statistique 2013).
[30] Proximate composition of foods ***http://www.fao.org/docrep/W0078E/w0078e11.htm#P9840_707166*** (last accessed on 20 May 2016)

and hence reduces income of farmers, others view it as an advantage for farmers to mitigate risk and optimise the cropping activities calendar (Demetriou, 2014). Land fragmentation was captured by Simmons index which is the sum of different plot areas squared divided by the square of total cropping area $\sum S_i^2 / (\sum S_i)^2$; with S_i: area of plot i). This index varies between zero and one, with the higher values indicating lower fragmentation (Demetriou, 2014).

Two different sources of labour were considered, namely family labour measured as the number of adult family workers, and hired labour expressed in labour expenditure. Although the former is an imperfect proxy of the effective time spent by family workers on the farm household, it was used as we lacked more detailed data. Most of farm work is done by family members. Due to the absence of an alternative labour market to agriculture, overemployment on own farms is very common. One may assume that the marginal productivity is almost zero in such case which makes it difficult to calculate the opportunity cost for labour. The extra labour is sometimes hired, but paid very low wages. Hence, the true value of the labour is very difficult to quantify and the wage levels are used as proxies.

Purchased inputs concerned expenditures for seeds and chemicals. Generally, seeds and seedlings used in agricultural production in Burundi are mostly local varieties taken from previous harvests. Yet, farmers often complement the seed stock with purchases or simply buy all the seeds if the quantity (previously) harvested was not sufficiently enough to deduct the seeds. Farmers may also choose to buy improved seeds to enhance productivity. Farmers buy fertilizers and pesticides even though at less extent.

3.2.3. Analytical framework

The model presented in this chapter is based on a Data Envelopment Analysis that generates efficiency scores for each farm in the sample related to the best performing peer farm. These efficiency scores are then compared to the poverty levels by farm size. We improve the traditional DEA and poverty measures in three ways: First, we used robust DEA model to generate standard and bootstrap-bias-corrected technical efficiency scores among farms. We used an approach for bootstrapping proposed by Simar and Wilson (2000) which simulates the effect of noise in the data on efficiency evaluation. Given the stochastic nature of the agricultural production and the possible occurrence of outliers, this more robust modelling approach significantly improves the estimation of predicted behaviour of scarce resource use in different policy contexts or in different production activities.

Second, the P-alpha measure of poverty, developed in 1984 by Foster, Greer and Thorbecke, was used to define the poverty levels (poverty incidence, gaps and severity) among farm households. We used a poverty threshold estimated for Burundi by Bundervoet (2006) as the poverty line. Based on a consumption bundle deemed adequate to satisfy basic needs, the food poverty line was estimated at 14.95 USD[31] per adult equivalent per month to which a minimum amount of 3.3 USD per month for non-farm needs was added. This sums up to 18.25 USD per adult equivalent (Bundervoet, 2006a). With an exchange rate of 1 238 BIF[32] to the USD, the overall poverty line is defined at 22 593.5 BIF per adult equivalent per month or 271 122 BIF (219 USD) per adult equivalent per year.

Third, a regression analysis was implemented to assess the driving factors of household welfare measured as household income per adult equivalent. An Instrumental Variable (IV) regression approach was used to deal with reversed causality between farm efficiency and household welfare causing problems of endogeneity. This IV approach is used for confounding control (Greenland, 2000). The principle is that variables correlated with some outcomes through their effect on other variables, are explicitly excluded from some equations and included in others (Angrist et al., 1996) in a system of equation known as structural equations models.

3.2.3.1. Efficiency analysis

We used a non-parametric procedure to estimate the farms' production frontier. Non-parametric approaches are sometimes preferred over parametric methods because the latter requires assumptions such on the mathematical specification of the functional form of the production (Abdulai and Huffman, 2000). DEA methods have gained greater momentum after the pioneering work by Charnes et al. (1978) for a constant return to scale (CRS) version of DEA, which was later extended by Banker et al. (1984) to a variable return to scale (VRS) DEA framework. The individual technical efficiency scores are calculated using mathematical programming

[31] The food poverty line was defined based on a food basket of 2500 kcal/day

[32] The exchange rate from the Interbank Burundi (s.a) of 1238 at the time of the survey was used : www.interbankbdi.com

techniques where the solutions satisfy inequality constraints of all decision making units involved.

The CRS restriction assumes that all farms in the analysis are performing at an optimal scale. However, technical efficiency scores reported under CRS are biased by scale efficiencies. The variable return to scale (VRS) implies that each unit is compared to a 'peer group' consisting of a linear combination of efficient production units with similar size (Murillo-Zamorano, 2004). This study uses a VRS specification.

Mathematically, the model is represented as follows (Simar and Wilson, 2008), given column vectors of p inputs (denoted by $x \in \mathbb{R}_+^p$) and of q outputs (denoted by $y \in \mathbb{R}_+^q$), the production set of physically attainable points (x, y) is given by:

$$\Psi = [(x, y) \in \mathbb{R}_+^{p+q} | x \text{ can produce } y)] \qquad (1)$$

This can be described as either an input-oriented set (minimizing the proportional input variables while remaining within the envelopment space) defined as $\forall\ y \in \Psi$,

$$X(y) = [(x \in \mathbb{R}_+^p | (x, y) \in \Psi] \qquad (2)$$

Or an output oriented set (maximizing the proportional increase in the output vector) defined as $\forall\ y \in \Psi$,

$$Y(x) = [(y \in \mathbb{R}_+^q | (x, y) \in \Psi] \qquad (3)$$

The choice of any particular orientation only has a minor influence upon the reported efficiency scores (Coelli and Perelman, 1996). The radial (input-oriented) efficiency boundary (efficient frontier) is then defined by:

$$\partial X(y) = [x | x \in X(y), \theta x \notin X(y)\ \forall\ 0 < \theta < 1] \qquad (4)$$

The Farell input measure of efficiency for a production unit working at level (x_0, y_0) is defined as:

$$\theta(x_0, y_0) = \inf[\theta | x_0 \in X(y_0)] \qquad (5)$$

$$= \inf[\theta | (\theta x_0, y_0) \in \Psi]$$

And given an output level y, and an input mix (a direction) expressed by the vector x, the efficiency level of inputs is determined by: $x^{\partial}(y) = \theta(x, y)x$, which is the projection of (x, y) on the efficient boundary $\partial\Psi$, along the ray x and orthogonal to the vector y.

The same algorithm can be applied to the output space where the output boundary $\partial Y(x)$ is defined for all $x \in \Psi$; as:

$$\partial Y(x) = [y | y \in Y(x), \lambda y \notin Y(x)\ \forall\ \lambda > 1] \qquad (6)$$

Then the Farell output measure of efficiency for a production unit working at level (x_0, y_0) is defined as:

$$\lambda\left(x_{0,} y_0\right) = \sup[\lambda\, |(x_0, \lambda\, y_0) \in \Psi] \qquad (7)$$

The efficient level of output, for the input level x and for the direction of the output vector determined by y is given by $y^{\partial}(x) = \lambda\,(x, y)y$.

Note that the frontier Ψ is unique; $\partial X(x)$ and $\partial Y(y)$ are two different ways of describing it (Cazals et al., 2002; Simar and Wilson, 2008).

3.2.3.2. Robust optimization

All deviations from the frontier are considered as inefficiencies in the standard DEA which makes the approach unable to accommodate measurement errors and it is extremely sensitive to outliers (Cazals et al., 2002; Veettil et al., 2012). To overcome those problems, researchers started to incorporate stochastic considerations into DEA models (Simar and Wilson, 1998; Simar and Wilson, 2000; Simar and Wilson, 2008; Wu and Olson, 2008; Bruni et al., 2009; Wu and Lee, 2010). The bootstrapping approach was first introduced to the standard DEA model by Simar (1992). Henceforth, the stochastic programming based on robust optimization became a common approach to handle uncertainty and is preferred due to its applicability (Gharakhani et al., 2011). Based on statistically well-defined models, the method allows for robust estimation of the production frontier as well as of the corresponding efficiency scores (Murillo-Zamorano, 2004; Mugera and Ojede, 2011). Bootstrapping investigates the reliability of the data by creating a pseudo-replicate data set using Monte Carlo approximation, which provides a better estimation of parameters of the interest. The bootstrap distribution will mimic the standard unknown sampling distribution of the estimators of interest resulting in changes in the ranking of bias-corrected efficiency scores from the standard efficiency scores. The DEA bootstrapping process is well documented in Simar and Wilson (2000; 2008).

The robust DEA model was used to estimate input-oriented measures of technical efficiency with variable return to scale. The production activities are disaggregated into following inputs: area cropped, agriculture investment (expenditure on seeds, labour, fertilizers and pesticides), and labour expressed in number of adult persons (active) in the household; and three outputs: food production (calories), total banana production (kg) and cash crop incomes (section 3.2.2 provides more details on the inputs and outputs).

3.2.3.3. Household poverty assessments

To evaluate poverty levels among farm households, we used the P-alpha measure of poverty or the poverty gap index first developed by Foster et al. (1984). The index is based on the normalised income gap and a predetermined poverty line. With $y = (y_1, y_2, \dots, y_n)$ a vector of household (individual) incomes and $z > 0$ the poverty line, the expression $g_i, = z - y_i$ indicates the income shortfall of the i^{th} household. The number of poor households (income $< z$) is $q = q(y, z)$ while $n = n(y)$ is the total number of households. The poverty measure P is given by the following expression (Foster et al., 1984):

$$P(y, z) = \frac{1}{nz^2} \sum_{i=1}^{q} g_i^2 \qquad (9)$$

With $H = \frac{q}{n}$ the headcount ratio, $I = \sum_{i=1}^{q} g_i^2/(qz)$ the income-gap ratio, the squared coefficient of variation C_p^2 measures inequality and is defined as:

$$C_p^2 = \sum_i^q (\bar{y} - y_i)^2 / q\bar{y}_p^2, \text{ where } \bar{y}_p = \sum_i^q \frac{y_i}{q}, \text{ then } P(y; z) = H[I^2 + (1 - I)^2 C_p^2] \qquad (10)$$

C_p^2 is obtained when *n* and $\bar{y}$ are substituted for *q* and *z* in the definition of *P*.

For households whose income is below the poverty line, poverty measures can be calculated from the following general equation (Foster et al., 1984):

$$P_\alpha = \frac{1}{n} \sum_{i=1}^{q} \left(\frac{z - y_i}{z}\right)^\alpha \qquad (11)$$

The quantity in parentheses is the proportional shortfall of expenditure or income to the poverty line for households living below that line. The parameter α can be viewed as a measure of poverty aversion: a larger α gives greater emphasis to the poorest households in the community. For $\alpha = 0$, the measure P_0 is simply the headcount ratio H, where there is no aversion to poverty. When $\alpha = 1$, P_1 gives the depth of poverty or poverty gap ($H.I$). By setting $\alpha = 2$, the measure of P is obtained, which is commonly known as the poverty severity (Foster et al., 1984; Foster et al., 2010; Asogwa et al., 2012).

3.3. Results and discussion

3.3.1. Descriptive statistics on farm household

The sample of 2130 farm households retained for the study was divided into four land quartiles in order to illustrate the possible relationship between landholding on the one hand and household characteristics, farm stewardship and productivity, and households' living conditions on the other hand. We first give an overview of the basic characteristics captured by the data (table 3.1). The standard deviations are given in parentheses and significant results from comparisons are indicated by letters *abcd* (superscripts) to highlight quartile of farms which differs from the selected one (a, b, c and d stand for Quartile I, Quartile II, Quartile III and Quartile IV respectively).

Table 3.1: Basic household characteristics (n=2130; sd. in parentheses)

	Overall mean	Farm size categories				F-test
		Quartile I	Quartile II	Quartile III	Quartile IV	
Age of the head household (years)	43.47 (15.56)	42.90 (14.76)	43.35 (15.54)	44.22 (16.09)	43.39 (15.85)	0.667
Household size (number of persons)	5.26 (2.35)	4.51^{bcd} (2.08)	5.08^{acd} (2.30)	5.45^{abd} (2.30)	5.97^{abc} (2.40)	38.827***
Farm household workers (number)	2.47 (1.20)	2.10^{cd} (0.80)	2.34^{cd} (1.079)	2.56^{abd} (1.28)	2.86^{abc} (1.39)	40.243***
Dependency ratio (%)	51.31 (30.36)	52.07 (30.81)	50.44 (29.04)	50.84 (32.39)	51.88 (29.14)	0.362
Household adult equivalents	4.21 (1.96)	3.47^{bcd} (1.59)	4.04^{acd} (1. 87)	4.37^{abd} (1.95)	4.97^{abc} (2.09)	58.668***
						χ^2-test
Gender household head (% male)	78.03	76.2	73.1	80.9	80.8	13.254**

Symbols indicate significant differences at ***: p-value ≤ 0.01, **: p-value ≤0.05, *: p-value ≤ 0.10

The average age of the household head was 42 years with minor variations over the quartiles. Households were mainly headed by men and the average household size was 5 persons per household. Two to three members worked on the farm. The number of active persons provides a good indication of the labour availability in the farms since the family labour is likely to be the largest labour source for many rural households. To assess the household needs, the household size was converted into adult equivalent units based on the number of persons, their age and gender. On average households counted 4.21 adult equivalents, with the largest households found amongst the largest landowners (table 3.2).

Table 3.2 introduces basic statistics on the farming practices by land quartile. We consider area used for crop production which is the total amount of land that a household cultivated during rainy and dry seasons in the corresponding year. Fallow land and marginal land used for grazing animals or reforestation were excluded from the analysis. Results in table 3.2 reveal that households depend on less than one hectare of land (0.71 ha on average) for agricultural production.

Table 3.2: Agricultural investment and production techniques (n=2130; sd. in parentheses)

	Overall mean	Farm size categories				F-test
		Quartile I	Quartile II	Quartile III	Quartile IV	
Agricultural land (hectare)	0.71 (0.58)	0.19[bcd] (0.06)	0.41[acd] (0.06)	0.70[abd] (0.10)	1.51[abc] (0.63)	1690.56***
Seed expenditure (USD)	23.39 (35.57)	14.63[cd] (24.38)	20.57[cd] (24.80)	25.40[abd] (33.91)	32.95[abc] (50.26)	26.173***
Labour expenditure (USD)	26.23 (26.22)	9.33[bcd] (24.37)	18.39[acd] (38.06)	28.44[abd] (46.61)	48.78[abc] (71.57)	65.440***
Expenditure on chemicals (USD)	10.57 (25.22)	5.92[bcd] (20.94)	10.13[ac] (21.92)	12.95[ab] (26.00)	13.29[a] (30.29)	9.859***
						χ^2-test
Extension training (%yes)	10.00	6.90	10.30	8.10	14.60	20.497***
Anti-erosion methods (%yes)	38.40	30.40	38.70	43.50	41.00	18.572***
Access to credit (% yes)	5.30	4.90	5.60	4.70	5.80	0.977
Membership agro-cooperative (% yes)	13.80	13.10	13.90	14.30	13.70	0.312

Symbols indicate significant differences at ***: p-value ≤ 0.01, **: p-value ≤0.05, *: p-value ≤ 0.10

Clearly, Burundian farmers are poor, they use very little inputs for a subsistence production on a highly fragmented (average number of plots: 6, range from 1 to 26) landholding. The basic input for agricultural production is land of which the size is limited due to an ever-increasing population. The distribution of land over the sample is rather unequal which results in a high number of very small-scale farms. An estimated 47% of the households in the sample had access to less than 0.5 hectare of agricultural land. Investments in agricultural production (agricultural expenditures) seem to be closely correlated with farm size with larger farms allocating more resources and spending more on inputs, but the overall levels of agricultural expenditure remain very low. The average yearly expenditure on seeds, labour and chemicals which included both fertilizers and pesticides amounted to 23.39, 26.23 and 10.57 USD respectively.

Smallholder farmers also lack access to extension and research services, as well as access to credit. Only 5% of the sample reported to have received credit during the cropping year of the survey. Despite the fact that farmers consistently reported a need for credit, microcredit rarely reached them. Commercial banks are reluctant to lend to farmers due to a lack of collateral. Agricultural cooperative, which could improve the access to credit (World Bank, 2007) are not well developed neither. Only a small number of farmers interviewed were member of cooperative. In addition, despite the new institutional engagement of the government to expand the extension service, few farmers were aware of it. Since 2005, 2803 extension agents received training and were sent to every *colline* which brings them in walking distances of most farmers. Yet, only 10% of the farmers' population interviewed indicated to have received agricultural training during the cropping year 2011-2012 while almost one third had applied erosion control on their fields. Technology transfer and adoption are still problematic in the country due to weak linkages between research services and extension. In addition, the extension agents are often poorly trained and less motivated (FAO, 2015). This is confirmed for other African countries where it was shown that the traditional communication approach following research had low impact on technology adoption of the users (Tizikara et al., 2007).

3.3.2. Household income and food production

The agro-ecological diversity of the country allows for a great variety of crops to be grown and farms mix several crops on their plots. Of the fifty-three crops reported in the survey, the shares in overall production (per land quartile) of ten most important crops are reported here (fig 3.1). Crops like wheat, banana, beans, potatoes and peanut were mainly produced on larger farms while small landowners had larger shares in rice production, peas and cassava. However, these results need to be interpreted carefully because some crops such as rice are mainly grown in the agro-ecological zones with high population density and hence small landholdings. Likewise, wheat is grown in the highland regions where population density is still low.

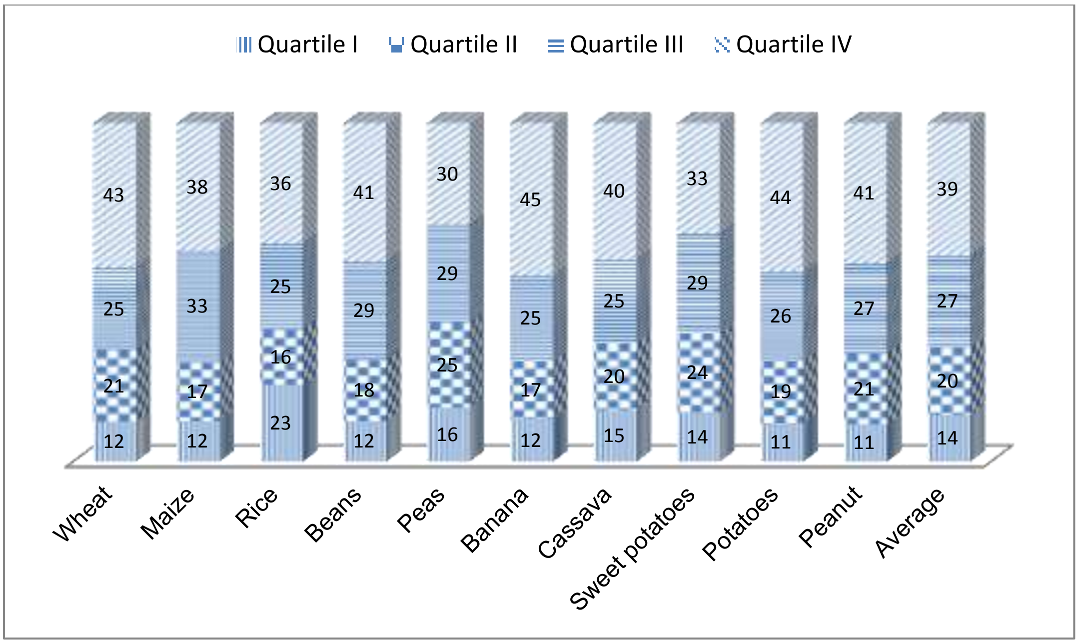

Fig. 3.1: Farm quartiles and their respective shares in overall production per crop (%)

Globally, the farms in the two quartiles with the smallest landholdings produced together less (34%) than the farms in the fourth quartile (39%). The contribution to the overall production of the third land quartile is low compared to the fourth quartile but significantly higher than the contribution of the second quartile (20%). The first quartile contributes very little to the total food production (14%).

The annual household income (table 3.3), measured as a sum of the market value of food crops, the cash crop revenue and the non-farm income, is very low. On average household income is estimated at 650.63 USD per year. This should cover both food and non-food needs of the family (5 to 6 persons on average). The value of net crop and farm income (gross income minus expenditures on input) per hectare, a measure of partial land productivity, decreases with increasing land size. Whereas land productivity is higher for smallholders, the labour productivity (farm income per unit of labour) is higher for larger landholdings. These findings might be influenced by the cost of hired labour which is more temporary and hard to capture in terms of farm labourers.

Table 3.3: Household income per year (n=2130; sd. in parentheses)

Farm income (USD)	Overall mean	Farm size categories				F-test
		Quartile I	Quartile II	Quartile III	Quartile IV	
Market value food crops (USD)	551.99 (535.41)	271.17[bcd] (312.36)	435.82[acd] (402.89)	615.58[abd] (533.08)	885.27[abc] (629.41)	156.788***
Cash crop income (USD)	16.04 (47.17)	9.37[d] (37.96)	15.10[d] (45.88)	14.90[d] (40.54)	24.81[abc] (59.97)	9.996***
Non-farm (including off-farm) income (USD/year)	82.60 (244.91)	99.99 (290.98)	80.85 (253.47)	74.60 (203.46)	74.95 (222.56)	1.268**
Annual farm household income (USD/year)	650.63 (595.69)	380.53[bcd] (426.55)	531.77[acd] (479.65)	705.09[abd] (585.28)	985.03[abc] (681.44)	117.669***
Share of non-farm (off-farm) income (%)	29.69 (24.93)	44.08[bcd] (28.93)	29.59[ad] (23.47)	23.99[a] (19.52)	18.50[ab] (18.50)	40.757***
Land productivity (USD/ha)	1043.73 (1331.31)	1598.19[bcd] (2190.19)	1064.97[ad] (997.76)	889.63[ad] (753.75)	621.87[abc] (474.00)	54.962***
Labour productivity (USD/worker)	283.33 (276.70)	193.22[bcd] (216.97)	250.17[acd] (244.10)	308.43[abd] (278.20)	381.68[abc] (321.09)	48.266***

Symbols indicate significant differences at ***: p-value ≤ 0.01, **: p-value ≤0.05, *: p-value ≤ 0.10

Some studies link low income levels to a vicious circle of over-exploitation of land leading to continuous nutrient mining and loss of soil organic matter, and further reductions in the returns to fertilizer use (IMF, 2014). Burundi is one of countries with the lowest levels of fertilizer use in Africa as on average only 7.4 kg of fertiliser are applied per hectare of arable land (Worldbank, 2013)[33]. This is confirmed by the results in table 3.2 that on average, only 10.57 USD are spent on fertilizers and pesticides. With this amount of money, a farmer can afford to buy only 8.1 kg of fertilizers (if the price of 1.3 USD/kg is assumed, subsidies not included)[34].

Farmers survive mainly on their agricultural produce but also on work for wage and self-employment activities throughout the year. The market value of production (food crops and cash crops) increases with farm size whereas non-farm/off farm income is important for household with small farms. Large numbers of small farms seem to be too small to provide a subsistence living. Roughly 36% of the surveyed households had one or more members engaged in non-farm employment. An average household gets 30% of its income from non-farm earnings. This ranges from 19% in large farms (fourth quartile) to 44% in nearly landless farms (first quartile). They try to diversify

[33] http://data.worldbank.org/indicator/AG.CON.FERT.ZS (last accessed on 13 June 2016)
[34] Information from the regional agricultural office (Karuzi) on prices (in 2012) of fertilisers before the subsidy programme which is currently applied on fertiliser sector in Burundi (since august 2012).

the household's livelihoods in order to increase income security, food security and risk coping ability. Yet, non-farm income and employment opportunities seemed insufficient to adequately compensate for the low farm income. Local labour markets are not well developed, and only occasional ill-paid off- and non-farm employment is not able to improve the food security situation of the households.

3.4. Assessment of food security indicators

3.4.1. Food availability from own production

Table 3.4 presents figures on food production (expressed in calorie, proteins and total fat production) per adult equivalent. This food production represents the food available from all the food crops produced during the cropping year without accounting for sales and losses. It may hence be considered as the upper-bound of food available through subsistence farming. The table gives the means, standard deviations, medians and percentage of households who meet the minimum requirements as prescribed by WHO. As mentioned above, farm production is much larger amongst the relatively large farms compared to the group of the smallest farms.

Furthermore, the mean values presented mask a high level of heterogeneity within cluster. Within-group inequality is shown by the high levels of standard deviations and the much lower values for medians compared to the means. The results suggest that 62% of the sample farms produced enough food to fulfil the household calorie needs, 49% managed to meet the proteins recommendations while only 11.50% could meet the fat intake needs. This also implies that many farms do not provide sufficient food to feed their family, i.e. 40% when calculated in terms of calories, 50% in terms of proteins, and 88% in terms of total fat.

It is very important to highlight that energy requirements presented as such remain theoretical. They have little practical value until they can be related to foods which provide the energy to meet the requirements, and the food nutrients (FAO, 2002). This is emphasised in the next section on food accessibility.

Table 3.4: Food production in calories, proteins and fat by farm size quartile (medians in curly brace, sd. in brackets, % fulfillment in square brackets)

	Reference values[α]	Overall/ average	farm size categories				F-test
			Quartile I	Quartile II	Quartile III	Quartile IV	
Calories (kcal/Adult Equivalent /day)	2895	5393 {2839} (7497) [62.00]	3499[bcd] {1683} (6067) [44.50]	4681[ad] {2547} (5841) [57.90]	5640[ad] {2854} (7697) [66.50]	7751[abc] {4881} (7751) [79.20]	32.050***
Proteins (g/Adult Equivalent /day)	55	85.21 {53.70} (105.0) [49.30]	58.41[cd] {29.07} (114.4) [44.50]	74.22[d] {46.20} (82.44) [57.90]	90.05[ad] {59.62} (98.48) [53.60]	118.15[abc] {85.47} (112.4) [71.30]	32.755***
Total fat (g/Adult Equivalent /day)	48	24.14 {12.41} (42.60) [11.50]	14.45[cd] {6.09} (35.22) [5.80]	22.05[d] {10.55} (37.66) [8.80]	26.53[ad] {14.03} (50.02) [12.40]	33.54[ab] {19.70} (43.75) [18.80]	19.325***

α: the reference values are drawn from the WHO[35];

Symbols indicate significant differences at ***: p-value ≤ 0.01, **: p-value ≤0.05, *: p-value ≤ 0.10

The inequality within the groups of farms per quartile is also visible in figure 3.2 which shows the boxplots. The boxplots indicate that production figures measured for some households are excessively high. These farms could be considered outliers. Yet when checked for other variables, these farms do not show outstanding values for other farm characteristics. It is hence questionable if we should delete these farms from the data set. They were deliberately kept in the analysis as they contain valuable information for the study.

It is worth mentioning that these results need to be interpreted with care. First, the study did not incorporate the nutrients from products of animal origin due to their erratic character in the diet (Speedy, 2003). Second, the production data include bananas used for local beer brewing purpose; these might bias the results in terms of energy and food nutrients calculation because bananas account for 29% of total cultivated area and 44% of the total value of the country's crop production (FAO 2010; MINAGRIE, 2011b). Third, the quantities of produce were computed immediately after the harvest. The post-harvest losses could not be accounted for.

[35] http://www.fao.org/docrep/w0073e/w0073e08.htm#P9793_1161767 (ibid.)

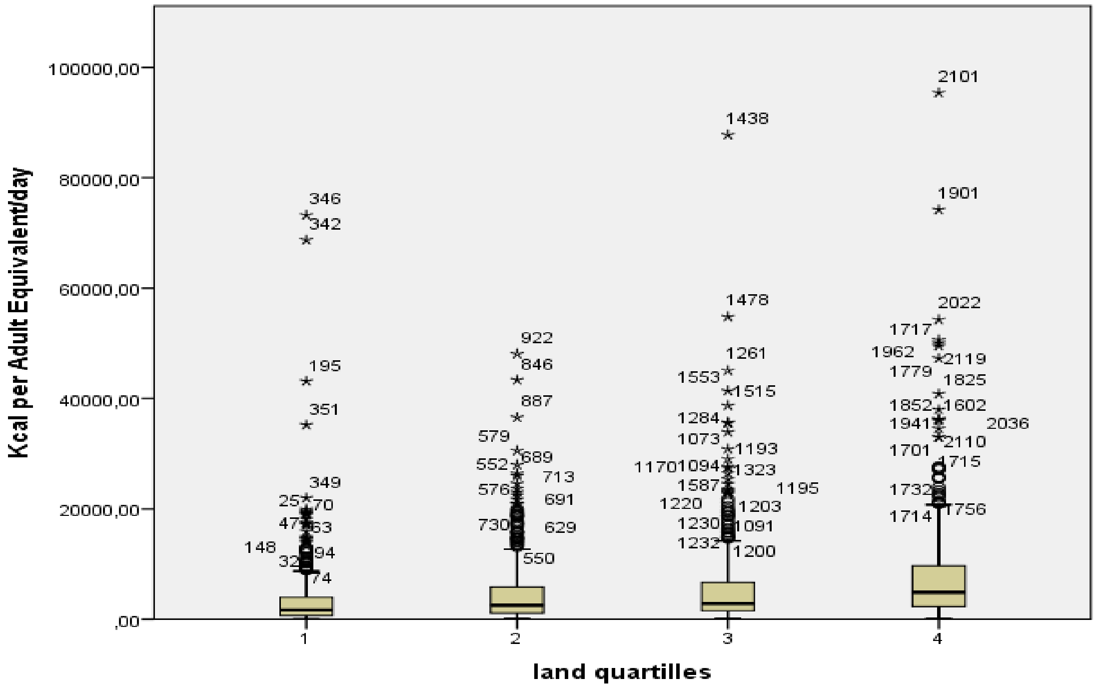

Figure 3.2: Distribution of production figures in caloric content by land quartile

The outliers of the production figures could be due to measurement errors, or a truly large production of high caloric foodstuffs. Yet, it may also be due to the family sizes. Many of the outlying farms had small family sizes which affect the per capita food calculations. Figure 3.3 gives the box plots for a subsample of the farms when 10% of the highest producing farms were excluded (appendix 3.1 provides the mean, median and standard deviation by land quartile).

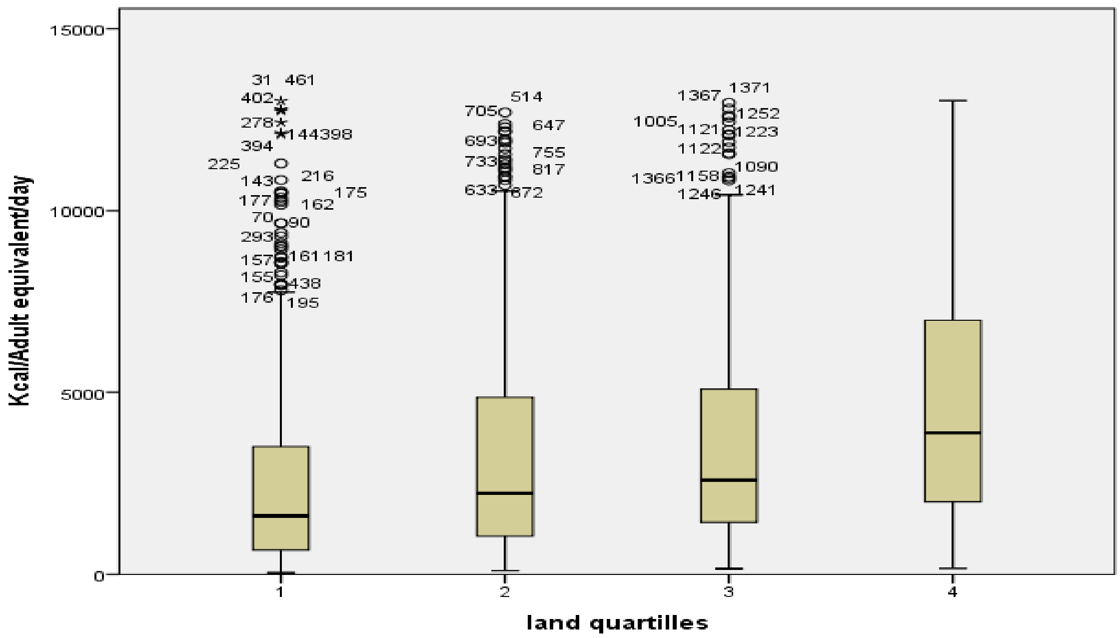

Figure 3.3: Distribution of production figures in caloric content by land quartile for a subsample excluding the top 10% of the sample

3.4.2. Food accessibility

In this section, we try to calculate the food accessibility of the farm households by estimating what the households could buy in terms of calories and macronutrients if they would have to spend all income to food. Income is considered as the sum of market value of farm production (food and cash crops) and off-farm income. Bundervoet (2006a) used the local and actually observed rural household behaviour to determine a consumption bundle deemed adequate to satisfy basic consumption needs. The reference food basket was expressed in terms of calories and ultimately assigned a monetary value.

The food poverty line was calculated at 14.95 USD/month (0.498 USD/day) to cover 2500 kcal per adult equivalent (daily) (see above), which enabled us to calculate the calories that each farm household in the sample could buy with its total income (table 3.5). The food security situation of the farmers in the sample calculated as such is even worse than what was presented based on food production. Only 32% of the sample households had enough income to cover the caloric needs of the household. Standard deviations are high, pointing to the inequalities in the sample discussed above.

Table 3.5: Food access and poverty indicators by farm size categories(sd. in brackets and percentage fulfilment of minimum levels in square brackets)

	Overall mean	Farm size categories				F-test
		Quartile I	Quartile II	Quartile III	Quartile IV	
Energy$^{\alpha}$ (kcal/adult equivalent/day)	2474 (2636) [32.40]	1842^{cd} (2984) [19.70]	2226^{cd} (2197) [28.00]	2654^{abc} (2473) [35.20]	3172^{abc} (2678) [46.90]	25.959***
Protein density of the production (mg/kcal)	25.36 (13.17)	26.14 (15.54)	25.44 (13.05)	25.26 (11.96)	24.58 (13.17)	1.269
Fat density of the production (mg/kcal)	6.91 (8.31)	6.07^{b} (7.74)	7.46^{a} (9.29)	7.15 (8.42)	6.97 (7.65)	2.768**
Income$^{\beta}$ (USD/adult equivalent/year)	177.54 (189.18) [25.20]	132.20^{cd} (214.15) [16.90]	159.80^{cd} (157.69) [20.70]	190.47^{abd} (174.89) [27.40]	227.69^{abc} (192.23) [35.60]	25.959***

Symbols indicate significant differences at ***: p-value ≤ 0.01, **: p-value ≤0.05, *: p-value ≤ 0.10

α: the reference value is the food poverty line (2500kcal per adult equivalent a day =14.95USD/30days)
β: the reference value is the overall poverty line (18.25 USD/month x 12 months =219 USD/year)

The food nutrient density was calculated by dividing the food nutrients (proteins and fat) by the total calories. Expressed in terms of milligrams per kcal, the densities in proteins and fat give an indication of the nutritional value of the production with regards to food nutrient contents (appendix 3.2 provides some examples of nutrient densities in some crops). The calorie content alone does not sufficiently reflect the nutritional value of the diets (FAO, 2002). Therefore, enough calories do not guarantee the nutritional sound composition of diets (Pinstrup-Andersen, 2009).

Overall results show that the diets accessible to the households in the sample are poor in nutrient contents with 25.36 and 6.91 milligrams (per kcal) of proteins and fat respectively. This was also shown by the protein and fat content of the food produced on the farm (Table 3.4). High value food crops have been gradually substituted in farming systems with less demanding crops which tend to have low nutritional quality. While tubers and roots crops cultivation increased again after a drop in production in the early 1990, cereals and pulses are less and less cultivated which has a significant and negative impact on the diet.

3.5. Efficiency and poverty in smallholder farms

3.5.1. Efficiency levels

This section presents the results of the farm efficiency analysis. The mean efficiency score was 0.53 for the standard DEA and 0.49 for bias-corrected-scores. A t-test was used to compare the standard and bias-corrected scores. A significant difference between them at 95% confidence interval (8.417***) was found, which indicates that the sample distribution was slightly influenced by stochastic effects. The distribution over the sample of farms organised by land deciles showed similar trends for both standard and bias-corrected efficiency scores (table 3.6).

The rest of this chapter uses the bias-corrected-efficiency scores. The results corroborate the low productivity findings which were also addressed in a recent report of the International Monetary Funds (IMF, 2014). The study highlighted an important need to improve the farming systems of Burundi. Profit maximisation models would yield higher efficiency scores (Mugera and Ojede, 2011).

The following graphs illustrate the distribution of the efficiency scores by the factors affecting productivity at farm level. The efficiency scores are largely influenced by the number of adult people working on the farm (fig 3.4).

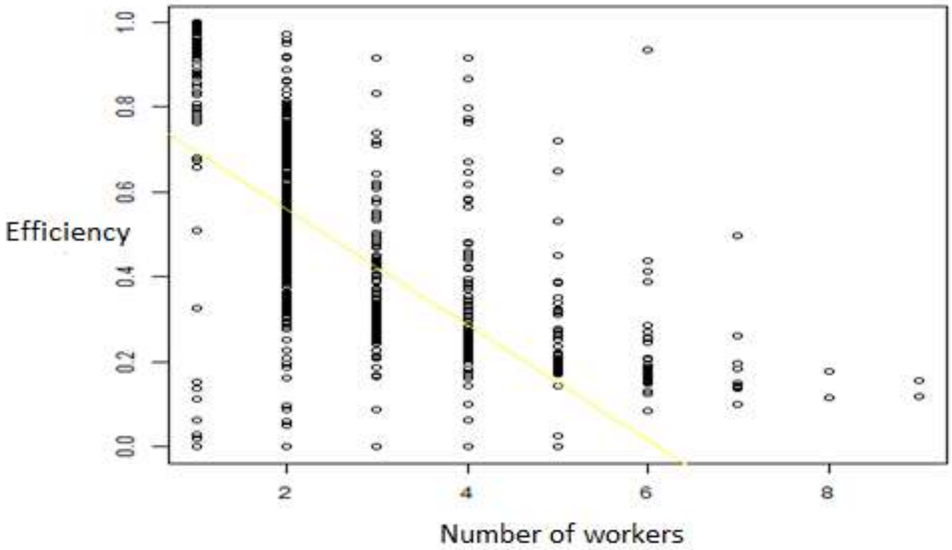

Figure 3.4: Household labour and farm efficiency

The highest efficiency levels were found among households with fewer adults and active people in the household. Labour productivity was low when the number of workers was high while the land to be cultivated was relatively small. This reflects the high level of underemployment in the study area reported in previous studies (Cochet, 2001; Baghdadli et al., 2008; Niragira, 2011).

Likewise, the distribution of efficiency scores shows a decreasing trend as the farm size increases. Figure 3.5 shows how efficiency levels of small farms result in different frontiers due to the variable return to scale assumption implying that each unit is compared to a ‘peer group’. The general trend is that the level of efficiency is higher for farms with small landholdings (fig 3.5). Figure 3.6 shows the efficiency scores plotted against the cumulative percentages of farm households for each land quartile. High efficiency levels were found in the land quartiles of the smallest farms.

These results suggest an Inverse Relationship between farm size and productivity often highlighted in literature (Schultz, 1964; Lipton, 2010, Wiggins et al., 2010; Verschelde et al., 2013). IR has been explained by imperfect factor markets leading to suboptimal resource allocation at the farm level (Feder, 1985). Labour market imperfection is often cited as a cause of low productivity on large farms due to supervision cost of hired labour. Also methodological issues are raised (Verschelde et al; 2013).

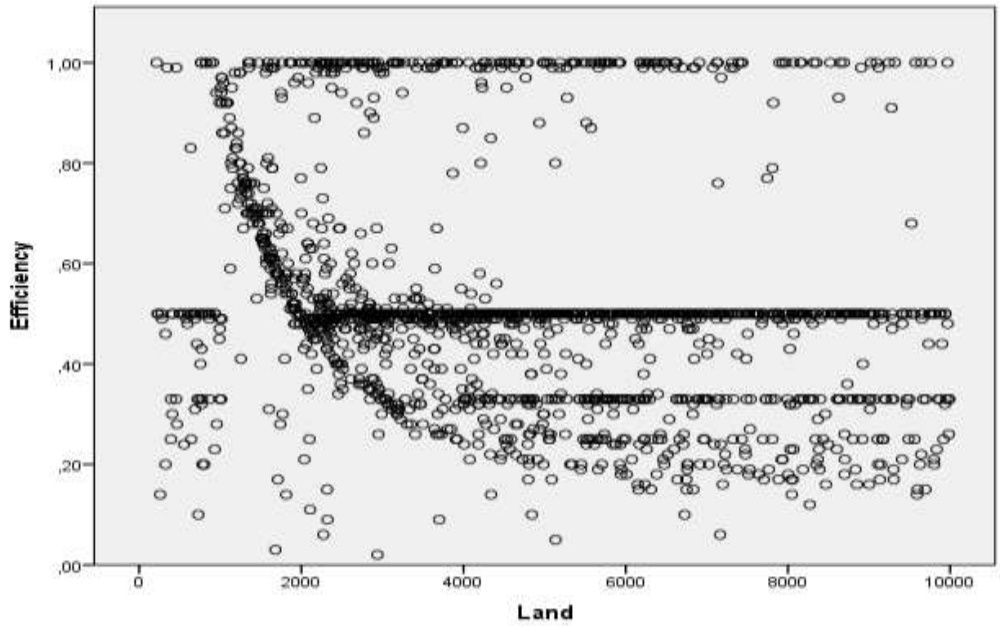

Figure 3.5: Farm size (m²) and efficiency levels in small-scale farms

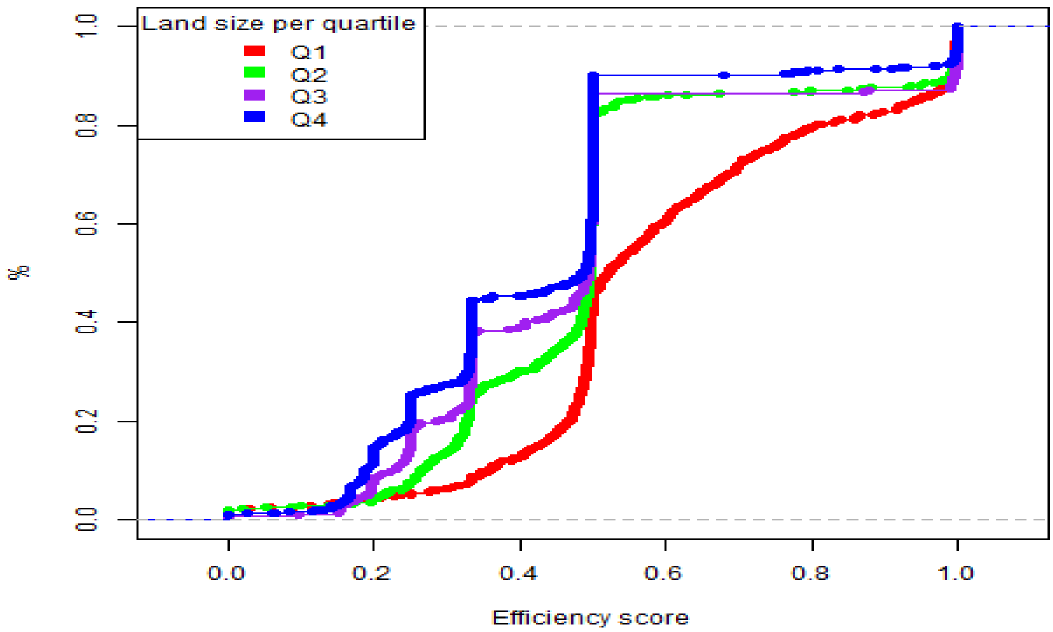

Figure 3.6: Cumulative percentages of households and efficiency scores

Another reason often put forward in literature is that IR emerges from other variables often omitted from the analysis (Benjamin, 1994). In the case of Burundi, land fragmentation is high with an average Simmons index of 0.21. Farmers own many parcels (6 plots on average) spatially dispersed all over village areas, in neighbouring villages and in distant villages. Due to the distance from the farmstead to the plot, parcels at greater distance are cultivated less intensively. Poor infrastructure, potential theft and the cost linked to the implementation of soil conservation work result into farmer's low motivation to invest in distant plots (Demetriou, 2014). This entails differences in land quality and therefore differences in soil productivity which clearly could affect the farm's output levels (Sen, 1975). Numerous empirical studies also confirmed that soil quality affects the IR between farm size and productivity (Benjamin, 1995; Lamb, 2003; 2007; Barrett et al., 2010). Including these variables in the efficiency analysis did not cancel the IR in an earlier study on Burundi (Verschelde et al., 2013).

3.5.2. Distribution of efficiency score by landholding

Table 3.6 compares the efficiency score over the categories of farms grouped in land deciles. The use of land deciles intended to give a more detailed view on the distribution of efficiency scores across sizes of landholdings. They range from 0.41 in the largest decile and 0.63 in the lowest decile showing that small landholdings are farmed more efficiently. A one way ANOVA yielded an F-statistic equals to 20.776***, indicating that there are statistically significant differences between the land deciles in the mean efficiency scores. Yet these results cannot show which of the specific groups differ significantly. The results of a Tukey post-hoc test in SPSS is shown in table 3.6. The post-hoc test identified six groups of farm deciles with significant differences in efficiency at 95% confidence interval. The four highest deciles (7 264 - 20 902 m² of land) had little differences in mean efficiency scores. Also the two lowest deciles (1171-2191 m²) seem not to differ much in terms of efficiency scores. Yet, deciles of smaller farms had a higher mean efficiency score than the mean of the deciles of the larger farms

Table 3.6: Tukey range test in efficiency scores by land decile

Land deciles	Area cultivated (m²)	Homogenous groups (mean efficiency scores)					
		Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
X	20 902	0.41					
IX	12 228	0.43	0.43				
VIII	9 143	0.43	0.43	0.43			
VII	7 264	0.46	0.46	0.46			
VI	5 924		0.48	0.48	0.48		
V	4 847		0.48	0.48	0.48		
IV	3 925			0.50	0.50		
III	2 954				0.54	0.54	
II	2 191					0.57	0.57
I	1 171						0.63

3.5.3. Household poverty levels

The poverty head count index in the sample is 0.75. This result is in line with the International Monetary Funds' estimates that 80% of the farming population lives below the poverty line (IMF, 2014). This suggests that only 25% of the farming population had income levels that succeeded to meet household food and non-food needs. The poverty gap and severity were on average estimated at 0.40 and 0.26 respectively, but, vary from 0.57 to 0.20 for the poverty gap and 0.42 to 0.10 for the poverty severity from the lowest to highest land decile (table 3.7). The group of farms with the smallest size were worse off in terms of income.

3.5.4. Farm productivity and household welfare

This section compares the farm productivity and household welfare indicators. Table 3.7 suggest that land ownership had a positive impact on household welfare while affecting the efficiency negatively. Off-farm income was important for the smallest farms and its importance decreased as landholding size increased. This is confirmed for other low income African countries (Jayne et al., 2003). The land-constrained households have little choice but to practice unsustainable farming methods, and this is undermining current and future land productivity. They are more likely to engage in off-farm work but their labour productivity is typically lower than that of large farms.

Table 3.7: Farm efficiency and household poverty

Land deciles (m²)	Share of agricultural income	Standard Efficiency scores	Corrected Efficiency scores	Poverty indicators		
				Poverty Incidence	Poverty gap	Poverty severity
1 171	0.45	0.62	0.63	0.86	0.57	0.42
2 191	0.62	0.60	0.57	0.84	0.56	0.41
2 954	0.66	0.56	0.54	0.80	0.47	0.33
3 925	0.71	0.54	0.50	0.75	0.42	0.27
4 847	0.74	0.53	0.48	0.80	0.44	0.29
5 924	0.74	0.50	0.48	0.74	0.38	0.23
7 264	0.77	0.51	0.46	0.72	0.36	0.22
9 143	0.78	0.47	0.43	0.71	0.34	0.20
12 228	0.80	0.47	0.43	0.66	0.29	0.16
20 902	0.84	0.46	0.41	0.58	0.20	0.10
7 055	**0.70**	**0.53**	**0.49**	**0.75**	**0.40**	**0.26**

While non-farm employment is believed to be a potential avenue to overcome land constraints among households, the underemployed workforce is typically engaged in the country's large informal sector where the level of payment is very low. Hence, the majority of the more diversified households are poor with the highest rate of household under the poverty line. It is hard then to appreciate how the inverse relationship between farm size and land productivity can strengthen nearly landless households under these conditions or how livelihoods can be sustained and allow them to cross the poverty line.

3.5.5. Factors influencing the household welfare

The results presented in table 3.7 give an indication that landholding has a positive impact on household welfare while being negatively correlated with the farm efficiency. Yet, what happens if efficiency increases for a given land area? Will it increase welfare? An econometric model including other household and farm characteristics as explanatory variables is necessary to gauge the causality between farm efficiency and household's welfare. The variables included are: efficiency, age and gender of the household head, education, active people in the household, participation in producer cooperatives, access to credit, farm size and land fragmentation indicator (Simmons index), and agricultural expenditures. Variables like age and gender of the household head, education, participation in producer cooperatives, and access to credit did not yield a significant effect on the household welfare and were not included in the final model.

The variable efficiency could potentially be considered as endogenous because the dependent variable income is indirectly used to calculate the efficiency levels. Hence three instrumental variables are selected for a 2-stage least squares approach. The variables land, agricultural expenditures and active people can serve as instruments for the efficiency. Both agricultural investments and land can be considered as perfectly suitable instrumental variables but enter also in the main equation of the linear regression model. This is not the case for the number of active people because we assume that the redundant availability of labour does have a direct link with income or welfare.

Table 3.8 presents the outcomes of the explanatory variables for a farmer's welfare, taking into account the endogeneity for variable efficiency and using number of active people as an instrument. The dependent variable is income per adult equivalent (BIF/adult equivalent) as an indicator of the household welfare. These results demonstrate how efficiency positively impacts farmers' welfare. Hence, keeping all other variables (including for example land) constant, a farmer can increase household welfare by improving productivity. Investment and land ownership positively impact a farmer's welfare. Land concentration seems to negatively impact welfare. This can be due to the fact that wealthy farmers buy more land which increases their number of plots. Note however that also for these variables some endogeneity or simultaneity problems might arise.

Table 3.8: 2SLS estimates for explaining household welfare (dependant variable: income per adult equivalent)

Variables	Coefficient estimate	t-test	VIF
Intercept	6.61e+04	3.22**	
Agricultural expenditures	3.16 e-01	5.74***	1.12
Efficiency scores	2.49 e+05	7.89***	1.06
Simmons index	-2.17 e+05	-6.12***	1.04
Land available	7.62 e+00	8.43***	1.17
Residual standard error	226488.304		
Root MSE	226488.304		
Multiple R-squared	0.067		
Adjusted R-squared	0.065		

Symbols indicate significant differences at ***: p-value ≤ 0.01, **: p-value ≤0.05, *: p-value ≤ 0.10

Table 3.8 gives also the Variable Inflation Factor (VIF) which is used to test for potential multicollinearity. The VIF provides an indication of how much the variance of the estimated coefficients is inflated when multicollinearity exists. Value exceeding 4 warrant further investigation, while values above 10 indicate serious multicollinearity requiring correction[36]. In our model all VIFs calculated fall below the cut-off values.

3.6. Conclusions and policy implications

This study analysed the efficiency and poverty levels of small-scale farms of Burundi. Despite the significant efficiency in smallholder agriculture, findings raise concerns about the viability of these very small-scale farms in the densely populated areas of the country. Given the rapid population growth, shrinking farm sizes, and declining soil fertility, it has become very difficult to ensure household food security. Most households have such small landholdings that agriculture may not be a realistic possibility for earning a living even if efficiency is high.

This situation is expected to worsen with the continuing land subdivision due to the inheritance system. As a consequence, poorest household mainly depend on casual labour income in order to survive. Both consumption and income appear as increasing functions of landholdings. Yet the scope for expanding agricultural land is

[36] https://onlinecourses.science.psu.edu/stat501/node/347 (last accessed on 10th November, 2016)

very limited in Burundi, putting limits on the ability to generate sufficient economic livelihood among households.

Under the current farm practices, smaller farms are more efficient but given their small size, this efficiency level is insufficient to raise them above the poverty line. Without fundamental changes in agricultural policies and farming systems, Burundi has little scope for sustainable smallholder-led agricultural intensification. In the absence of non-farm income, the source of rising local incomes would come from supporting agricultural growth among the small but sustainable farmers (especially farms able to invest in soil fertility restoration) and thereby catalysing a more successful economic transformation. This highlights a great need for policies that stimulate agricultural investment such as credit access, improved markets for agricultural products and more effective extension services. Moreover, land markets could allow households to buy and sell land. This would facilitate to free lands for other farmers.

Sustainable rural employment is critical to encourage the nearly landless farmers leave farming activities (or to free labour from the farms) which may benefit those who might remain on farm operations as well. The transfer of the workforce to other sectors would make agriculture more viable for at least three reasons: first, it would free up agricultural land. Second, it would allow more investment in agriculture via transfer of investment or remittances. Finally, it would improve the market for those farmers who stay in agriculture. This could boost the potential for agriculture to play its role. It would create possibilities to generate scale economies and have positive spill-over effects on the growth of other sectors. This chapter does not suggest abandoning policies directed to very small farms in agriculture, but cautions that policy in the field of rural development should be rethought for designing successful poverty reduction strategies.

Chapter 4:

Cow or Goat? Population pressure and livestock keeping in Burundi

Abstract

Livestock contributes significantly to livelihoods in developing countries. While used for wealth accumulation, livestock keeping is the imminent ways for lateral transfer of fertility in the farms. However, with the shrinking grazing land, the livestock sector is facing several challenges especially cattle due to its high demand of forage. Yet, most academic studies focus on dairy cattle and neglect that many smallholder farmers in mixed-cropping systems prefer goats, sheep, pigs or poultry over cattle. Using a unique dataset from a national representative agricultural survey in Burundi, we estimate the determinants of livestock keeping with a multivariate probit model. We find that wealthier households keep more livestock, but population density and access to markets are also key determinants. Moreover, even the wealthiest households switch from cattle to smaller animals in densely populated regions, where pressure on land is high and access to pastures limited. This has important policy implications since it questions the emphasis of most development programs by NGOs and governments in Sub-Saharan Africa which promote dairy cattle.

Keywords: livestock, cattle, smallholders, agricultural policy, Burundi

This Chapter is based on:

Desiere, S., **Niragira, S**., D'Haese, M., 2015. Cow or Goat? Population pressure and livestock Keeping in Burundi. Agrekon 54 (3) 23-42.

The initial idea to study livestock in Burundi came from Sanctus Niragira. The structure and research questions were developed in collaboration with Sam Desiere and the promoter. Data was gathered by Sanctus Niragira and Sam Desiere. Analysis was done (using Stata package) by Sam Desiere and the literature search was done by the two first authors. The promoter helped with revising the text.

4.1. Introduction

Livestock contributes significantly to the livelihoods of many smallholder farmers in developing countries. The benefits of livestock in these agrarian societies are well-known and diverse. Besides the production of eggs, milk and meat, livestock plays an important role as a saving, financing and insurance device, provides manure and draught power and is kept to display status (Moll, 2005, Randolph et al., 2007, Herrero et al., 2009). Many studies have emphasized the important role of livestock as a way to accumulate wealth and to insure against risk in societies characterized by imperfect credit markets (Dercon, 1998, Doran et al., 1979, Turner and Williams, 2002).

In socio-economic literature on livestock-keeping, a majority of the papers focus on cattle. This is understandable when studying pastoralist societies, where cattle are indeed the main source of wealth and income. Yet, even studies in regions characterized by mixed farming systems, which are the predominant systems in Sub-Saharan Africa, focus mainly on (dairy) cattle and tend to neglect the role of smaller animals (Dolberg, 2001, De Vries, 2008, Lammers et al., 2009). This bias towards cattle also exists in government and NGO policies which often set up cattle donation or crossbreeding programs, but rarely facilitate small stock-keeping. Moreover, many studies and policies (implicitly) assume that cattle-rearing is more profitable than keeping smaller animals.

A similar assumption is conveyed in the concept of the livestock ladder. This concept assumes that households start by investing in small stock and gradually, as they gain income, invest in cattle (Todd, 1998, Perry, 2002, Maass et al., 2013). In other words, the only reason why farmers do not invest in cattle would be that they do not have the required lump sum needed to cover the initial investment. In terms of policies, and if being cash-strapped is indeed the main reason for low levels of investment in livestock, setting up a micro-credit programme would be the most appropriate development strategy. Yet, rational households are likely to consider the profitability of their investment in livestock before actually making an investment. The expected return on livestock will depend on local, environmental conditions such as population density, rainfall and market access. For instance, goats are less demanding in terms of forage than cattle because they efficiently digest roughage and can survive on marginal lands (Devendra, 2007).

Households might prefer to keep goats instead of cattle in densely populated regions, where pressure on land is high and access to forage limited. On the other hand, browsing and grazing of sheep and goats is less easily managed than grazing by cattle and this may cause damage to cropland in densely populated regions and thus entail a loss of food production. In addition, smaller animals are more prone to theft which is also more likely in densely populated regions. In sum, the effect of population density on the choice of investing in either large or small stock is ambiguous and requires empirical research. Market access is expected to play a key role, as livestock, and especially cattle, is mainly reared to sell on local markets. A study in Ethiopia, for instance, found that 75% of cattle production occurred within a distance of 5 hours of travel time to the main markets, while sheep and goat production seemed less centred around the main markets (Tilahun and Schmidt, 2012).

In this chapter, we argue that households, even if they have the necessary means to invest in cattle, consider the profitability of the investment before investing. Based on a unique dataset of Burundi, we show that besides wealth, population density and market access are important determinants in the choice between investing in cattle or small livestock such as sheep, goats, poultry or guinea pigs. This finding has important policy implications. It questions current rural development strategies which focus, almost blindly, on dairy cattle. The finding also suggests that keeping smaller animals, which are more suited to local, adverse conditions, might be more cost-effective in densely populated regions in Sub-Saharan Africa in general, and particularly in Burundi.

In the next section we briefly describe the role of livestock in the agricultural system of Burundi. We then describe our dataset, discuss its weaknesses and strengths and provide more details on secondary datasets of rainfall and population densities that played a key role in our study. Before presenting the results, the empirical strategy based on a multivariate probit model will be discussed. In the conclusion we highlight some important policy recommendations.

4.2. Livestock in Burundi

Cattle-keeping has been an important socio-economic activity in Burundi for a long time. In pre-colonial times, various tribes and kingdoms defined themselves on the basis of their herds of Ankole cattle, which symbolized power and wealth (Ndumu et al., 2008). In more recent times, cattle have remained an important symbol to distinguish Tutsi and Hutu. Tutsi were believed to be wealthier pastoralists, who migrated with their herds to Burundi from the north in the fifteenth and sixteenth century, while Hutu were seen as poorer farmers, probably from central Africa (Uvin, 1999, Maguire, 1995). Goats, sheep, pigs, poultry, rabbits and guinea pigs were introduced later. Their ease of care, size, and fast reproduction, along with the decreasing availability of fodder and grazing lands have made them the most important animals on small farms. Additionally, small livestock are easily marketed and can provide meat for household consumption whenever needed (Hatungumukama et al., 2007a).

Cattle populations in Burundi are mainly dominated by pure breeds of Ankole/Zebu cattle or cross-breeds from the following seven breeds: Ankole, Ayrshire, Brown Swiss, Friesian, Guersey, Montbeliard and Sahiwal (Hatungumukama et al., 2007a). The Ankole breed represents more than 90% of the cattle population of Burundi, but it remains difficult to determine the degree of cross-breeding (Ndumu et al., 2008). Traditionally, the Ankole breed was considered as sacred and cows were kept for milk production, but rarely for their meat (Wurzinger et al., 2006). The Ankole breed evolved through natural selection and it adapted to withstand and reproduce under stressful conditions. Ankole cattle are known to be tolerant to ticks and are known to have significant resistance against East Coast fever (theileriosis). Moreover, the breed can withstand severe drought and can survive on low-quality feed (Ndumu et al., 2008). Yet, milk productivity (1.8 to 2.75 l/day) is low (Grimaud et al., 2007, Hatungumukama et al., 2007b).

Cattle play an important economic and social role in Burundian society. Milk and meat are an important part of the Burundian diet but are not produced in sufficient quantities. Therefore, milk and meat is almost exclusively consumed by the wealthiest households. The skins are used to manufacture leather goods and the horns are used to make traditional musical instruments *(Idonongo).* Livestock is also considered as the most efficient tool for transferring and renewing fertility on the doubled-cropped plots, in the absence of expensive chemical fertilizers (Cochet, 1996). Typically, half of the manure is recovered using nocturnal animal holding when dung is collected each morning and transported directly to the cultivated plots. Manure from stables is transported and ploughed into the fields. In addition, cattle are the principal form of capital accumulation and they are generally only sold to cover larger expenses (Cochet, 2004). For instance, cattle are often sold in September when school fees need to be paid. Cattle also provide social prestige to the farmer. The prestige of farmers with a large herd stemmed from its dominant power in the relationship established with poor farmers with little or no livestock who were obliged to exchange their labour for cows (*ubugabire*) and/or other livestock related products such as dung and milk. Finally, cattle also play an important cultural role through the practice of bride wealth. However, the customs of gifts between families is currently being abandoned due to decreasing number of animals.

Reduction, degradation and overexploitation of natural pastures are major constraints for cattle rearing in Burundi (Hatungumukama et al., 2007a). In densely populated areas, natural communal pastures have almost completely disappeared. In other areas, pastures gradually shifted to more marginalized land with poor soils. At the same time, zero-grazing systems remain the exception in Burundi. Rational management of pastures, forage installation and use of agricultural residues helps farmers to some extent to overcome the deficit of animal feed. Particularly during the dry season from July to August, when feed is a critical constraint, fodder conservation through silage and hay is applied (Maass et al., 2012). However, the biomass needed for this purposes is also often used as organic fertilizer. For instance, stems of cereal and banana leaves are used for mulching coffee, crop residues from legumes are buried during ploughing or composted to fertilize the fields. Meanwhile, the low revenue of smallholder farmers curbs their access to commercial feed concentrates. Most livestock is left to graze on poor pastures and receive limited supplementation or other treatment.

The reduction in availability of feed has greatly reduced cattle stock in the last decades. Compere and Huhn (1975) identified 756,000 cattle in 1968, while it decreased to 479,000 in 1987 and 346,341 in 1996 (MINAGRIE, 1997). The decline of cattle from 1970 to 1990 was due to the reduction and loss of natural pastures as a result of the human population growth. Consequently cattle production has been progressively abandoned in favour of small stock which are better adapted to the available forage (Hatungumukama et al., 2007a). The civil war, which started in 1993, accelerated the decrease of Burundi's dairy cattle population. Many animals were sold and slaughtered indiscriminately due to the insecurity, theft and pillage of livestock which was rife at the time. Some farmers also migrated with their herds to neighbouring countries (Bundervoet, 2006b). Recently, new livestock rehabilitation programs are trying to revitalize the sector by reversing the trends in herd ownership among households. The Government of Burundi, through its Poverty Reduction Strategic Paper (2005-2010) and the conclusions of the forum on Agriculture and Livestock in 2007 developed a framework for rapid livestock recovery which involved several stakeholders (FAO, IFAD, World Bank, European Union, Catholic Relief Services, World Vision, CARE….). The animals concerned by the restocking programs are: cattle, goats, pigs and occasionally sheep, poultry and rabbits (Sindayigaya, 2014). In 2012, IFAD initiated a method of categorization households in order to identify the beneficiaries according to their vulnerability. Only farmers with more than 0.5 ha of land could benefit from cattle donation or breeding programs (FIDA, 2014). Yet most of the interventions (donation and breeding) were mainly geared to dairy cattle. There was no specific target set for small livestock (e.g. MINAGRIE, 2011a).

The availability of data on the livestock sector is still very limited in Burundi. Few studies have been conducted on livestock selling prices, marketing channels, consumers, as well as different factors influencing the livestock sector markets. In general, the marketing system is complex involving farmers, traders, wholesalers, butchers and retailers. Livestock products are found at many local markets and specific livestock markets are organized for the sale of animals. These livestock markets are held at specific times in every province and sellers must travel long distances to get to these markets. Most markets are held once a week and differ in the animals that are traded. In contrast with cattle, small stock is also often traded within the village.

It is against this background that this chapter examines the conditions under which households prefer small livestock over cattle. We investigate the determinants of investing in livestock and hypothesize that local, environmental constraints such as rainfall, population density and market access will play a role. As explained above, high population densities, in some areas above 600 persons/km², are particularly challenging for livestock keeping in Burundi.

4.3. Material and methods

4.3.1. Empirical framework

A household in Burundi can choose to invest in different groups of animals. Three groups of livestock are distinguished: cattle (TLU[37]= 0.70), sheep, goats and pigs (TLU below 0.2) and small livestock such as chicken, rabbit, guinea pigs and ducks (TLU=0.01). These investment choices are not mutually exclusive: households are likely to keep more than one type of livestock. This choice will depend on both the profitability of the investment and households' wealth. Consequently, we hypothesize that even if a household is sufficiently wealthy to acquire livestock, it will only do so if this is also a profitable investment. Hence, our model consists of three binary choices, y_{ij} (investment in cattle; investment in sheep, goats and pigs; investment in other small livestock) which are determined by the local environment, E_i, and by households' wealth, X_i.

$$y_{ij} = 1 \; if \; \alpha E_i + \beta X_i + \epsilon_{ij} > 0 \; (j = 1,2,3)$$
$$0, otherwise$$

Where i indicates the household, j the choice variable and $(\epsilon_1 \epsilon_2 \epsilon_3)$ represent the distribution of the errors and follows the trivariate standard normal distribution, $N(0, \Sigma)$, where Σ is the covariance of the error terms.

It is likely that the errors are correlated because of omitted or unobservable variables that contribute to explaining several investment choices (Assa et al., 2014). For instance, a household that is faced with an unexpected adverse shock might decide to sell all its livestock. Consequently, estimating the three equation separately with probit or logit models would result in inefficient estimators, because these estimations would not exploit the interdependency between the equations. Therefore, the three equations will be estimated simultaneously with a multivariate probit model. In many respects, this approach is similar to the well-known Seemingly Unrelated Regression (SUR) models, with the only difference that the dependent variable is not continuous

3 [37] Tropical Livestock Units: Cattle=0.7; Sheep/goats=0.1; Pigs=0.2; Small livestock=0.01

but binary (Greene, 2003). However, the estimation is computationally complex and requires multidimensional integration. We will follow the approach proposed by Cappellari and Jenkins (2003), based on the popular GHK simulator, which has been implemented in Stata by the same authors.

A multivariate probit model only allows the modelling of the three binary choices related to investment in livestock, but does not take into consideration that a household can decide to buy several cows, goats or chicken. At first, this could be considered a weakness of our approach, but as we will see in the descriptive analysis, few households keep more than one cow, and even the number of goats and chicken is fairly limited. In addition, our estimations will be less susceptible to measurement error because it is unlikely that the households did not correctly report keeping livestock, whereas the number of animals kept might be prone to measurement error, particularly for the number of smaller animals. As a robustness check, the analyses were repeated with hurdle models which also take into consideration the number of animals kept by the household. These count models consists of two parts: the first part explains the decision to invest in livestock using a logit or probit model, while the second part explains the number of animals kept by the households using a binomial count model (Loeys et al., 2012). The results were consistent with those from the multivariate probit model.

In order to evaluate the importance of the profitability on the decision to invest in livestock, we need variables that determine the profitability of cattle rearing in a particular context, but that cannot directly be controlled by the household. We consider population density, rainfall in the dry season and access to markets as exogenous variables that influence the profitability of cattle rearing. A higher population density increases the pressure on land and therefore reduces the access to communal land that is available for grazing and fodder production. Malnourished animals are likely to be less profitable because of lower production of eggs and milk, slow weight gain, a slower rate of reproduction and a higher risk of premature death. Relative to other types of livestock, cattle are especially vulnerable to adverse local conditions (Devendra, 2007). Consequently, a higher population density should reduce the probability of investing in livestock, particularly for cattle. Similarly, in regions characterized by low rainfall or recurrent periods of droughts, we also expect less livestock relative to regions with sufficient rainfall. Since cattle are primarily raised to be sold, access to markets is expected to raise the profitability of a cattle enterprise. We will use two proxies for market access: whether the nearest provincial road is more than 5 km away from the nearest village and the distance of the household's farm to the capital.

Burundi consists of 11 agro-ecological zones, ranging from plains to mountains (MINAGRIE, 2013). Differences between these regions might partially explain the profitability of livestock rearing and we therefore included regional dummies in the model. Hence, we examined whether differences in population density, rainfall and distance to the capital within a region influence livestock keeping.

We expect wealthier households to keep more livestock in general, and cattle in particular, for two reasons. First, because nearly all households are credit constrained in Burundi[38], only richer households will be able to make the lumpy investment required to buy cattle (Dercon and Krishnan, 1996). Second, richer households are more likely to need a saving device because they are more likely to regularly make profits and they have few other possibilities to invest besides livestock. Land markets, for instance, are poorly developed and buying, selling or leasing of land is the exception and cannot be considered as an alternative to investing in cattle. We will use land as the main proxy for wealth, because land is the most important asset in Burundi, strongly related to assets and is mostly inherited from father to son. Moreover, cultivated land has been carefully measured with GPS and is therefore likely to be less prone to measurement error than total agricultural production, which would have been another obvious choice as a proxy for wealth. The main disadvantage of this proxy is the fact that land might also have a direct impact on the profitability of cattle rearing because households with more land might use it for grazing or to produce fodder.

It is, however, difficult to come up with a good proxy for wealth that is at the same time uncorrelated with the profitability of livestock keeping. As a second indicator of wealth, we include a variable that indicates whether the households bought fertilizer in the previous year. Fertilizers are rather expensive in Burundi and only richer households therefore have access to it (MINAGRIE, 2013). As a third indicator of wealth we include a variable that indicates whether the household head is a woman.

[38] Less than 10% of the households in our sample reported having taken a loan in the three years prior to the survey.

Female household heads are generally widows and considerably poorer because of the absence of a male breadwinner. Finally, two more household characteristics are also included in the regression: the age of the household head and the size of the household.

4.3.2. Data

We use data from a national representative agricultural survey of 2560 households conducted in 2011/2012 by the statistical office of Burundi and the Ministry of Agriculture, and financially supported by the Belgian Technical Cooperation and the World Bank. This was the first, nationally representative agricultural survey in Burundi since the 1980's. The main purpose of the survey was to update agricultural statistics and to provide reliable production numbers at provincial level (section 3.2.1 provides more details on sample and data).

With regards to livestock, detailed information was collected on the number of animals kept, sold, bought and consumed during the previous year. Unfortunately, no information was collected on the production of milk and eggs, nor on the inputs required to feed the animals or on expenses for veterinary services. Total farm size, which will be our main proxy of wealth, has been measured precisely with GPS. Eight observations were discarded due to missing variables.

This dataset was complemented by secondary sources about population density and rainfall. A national population census was conducted in 2008 by the Government of Burundi, which enables to calculate population density at communal level (MININTER, 2010). A commune in Burundi is an administrative unit that consists of several collines, which are the lowest administrative unit. The disaggregation of population density at communal levels allows us to examine whether differences in population densities within regions partially explain investment decisions in livestock of the household.

We used rainfall data from the WorldClim project, which makes global climate data freely available from their website (Hijmans et al., 2005). The estimates are derived from an interpolation of average monthly weather data from weather stations and have a spatial resolution of 0.86 km^2. We used one variable of this dataset: average precipitation in the driest quarter. As households were geo-referenced in the dataset, we could link the weather data with the households.

4.4. Results

4.4.1. Descriptive statistics

Table 4.1 shows the total number of animals kept at the time of the interview. Goats were clearly the most popular form of livestock, followed by chickens, guinea pigs and cattle. In general, very few animals were consumed by the household. For instance, none of the households reported having slaughtered and consumed a cow in the previous year and only 10% of the total stock of guinea pigs was slaughtered. However, the death rate of most animals was rather high and households might have consumed these animals, yet no evidence can be given. The number of animals sold was larger than the number which was consumed, which confirms that livestock is primarily considered an investment and not intended for own consumption. The two most important reasons for selling livestock that were mentioned during the interviews were the urgent need to take care of a family member and to buy food in times of shortages. This confirms the hypotheses that cattle are an instrument for saving and insuring. Very few animals were given away as a gift, which might indicate that livestock plays a less important ceremonial role in Burundi than in the past. Trade in livestock seems to be relatively exceptional for most animals. Only between 5% and 10% of total stock had changed hands in the previous year.

Table 4.1: Livestock in Burundi

	Number of animals	Bought (%)	Born (%)	Received Gift (%)	Sold (%)	Consumed (%)	Gift (%)	Stolen (%)	Dead (%)	Price (sd)
Cattle	1099	10.9	8.8	1.1	4.1	0.0	1.3	0.9	2.4	293 (152)
Sheep, goats, pigs										
Goats	4251	8.6	22.3	2.1	6.1	0.4	0.5	0.4	7.6	28 (11)
Sheep	703	12.5	22.6	1.3	5.3	0.6	0.6	1.0	6.7	30 (8)
Pigs	649	25.6	27.9	0.3	22.5	0.2	0.6	0.0	11.6	45 (46)
Other small livestock										
Chicken	4124	10.9	51.0	2.2	7.6	3.8	0.6	2.8	29.9	6(7)
Guinea pigs	1846	11.8	39.0	1.8	14.9	9.8	1.8	2.0	25.0	1 (1)
Rabbits	652	19.0	46.0	2.6	14.3	6.0	1.7	0.9	30.2	5 (11)
Ducks	114	3.5	36.0	0.9	2.6	0.9	0.0	0.0	5.3	4 (.)
Other poultry	83	10.8	31.3	2.4	9.6	3.6	0.0	3.6	22.9	1.5 (0)

Table 4.1 also shows the average price of livestock that households received when selling. Note that these prices are somewhat imprecisely estimated because only few

animals were sold albeit that these prices were confirmed by key-informants. Cattle were more than eight times as expensive as sheep, goats and pigs which were nearly five times more expensive than chicken or rabbits. The average price was 293 000 BIF ($188) per cow, which is a considerable amount relative to GDP per person which is estimated around $600 per capita at purchasing powers parities (IMF, 2015).

In the next analyses we will group livestock in three categories: cattle, sheep/goats/pigs and other small livestock (which includes poultry, rabbits and guinea pigs). This simplifies the analyses, but is also in line with recommendations of the FAO which attribute similar weights to these animals when calculating Tropical Livestock Units (Chilonda and Otte, 2006). In addition, as Table 4.1 shows, livestock included in each of these categories received a similar market price.

The distribution of livestock for successive quartiles of farm size is shown in table 4.2. The median farm size was 0.51 ha and the average farm size of the 25% poorest households (first quartile) is less than 0.2 ha. This is extremely small by global standards, but in line with neighbouring countries such as Rwanda (Ali and Deininger, 2014). It confirms the extremely high pressure on land. As expected, the likelihood of keeping livestock clearly increases with farm size. The second category of animals, and in particular goats, were the most widespread type of livestock and are kept by more than 50% of the households, followed by other small livestock and cattle. The number of animals kept, conditional on keeping livestock, also increased with farm size. Hence, richer households are not only more likely to keep livestock, but also to keep more animals than poorer households. However, even the wealthiest households had relatively few animals. For instance, the richest households with cattle kept, on average, less than 3 animals. Even the number of animals in the category of other small livestock was limited: households that kept small livestock (mostly poultry and guinea pigs) had on average between 5 and 8 animals.

Table 4.2: Distribution of livestock for successive quartiles of farm size

Successive quartiles of farm size	Farms size (ha)[2]	TLU	Cattle		Sheep, goats & pigs		Other small livestock	
			%	Animals[1]	%	Animals[1]	%	Animals[1]
1 – smallest	0.16	0.24	8.5	1.37	41.4	2.87	26.7	5.32
2	0.38	0.40	16.8	1.63	53.5	3.14	31.5	5.93
3	0.71	0.63	21.6	2.28	58.6	3.76	39.7	7.38
4 - largest	2.74	0.92	26.5	2.95	67.9	4.61	50.5	7.80

[1] Animals gives the mean number of animals conditional on keeping this type of livestock. Given the large number of households without livestock, the sample means are considerably lower.
[2] 13 farms are larger than 10ha, which biases average farm size in the 4th quartile. Median farm size in this quartile is 1.58ha.

4.4.2. Multivariate probit model

The results of the multivariate probit model explain households' decisions to invest in cattle, sheep, goats and pigs and other small livestock (table 4.3). As explained in the methodology, we make a distinction between variables that are used as a proxy for wealth and variables that determine the profitability of the investment. Interpreting the estimated coefficient of multivariate probit models is not always straightforward. Hence, to facilitate their interpretation and gauge the impact of the explanatory variables on investment in livestock, the model was used to predict probabilities of keeping livestock as a function of variables of interests (figures 4.1 to 4.3).

Table 4.3: Multivariate probit model explaining investment in cattle, sheep, goats & pigs and other small livestock

	Cattle	Sheep, goats and pigs	Other small livestock
Production environment			
Population density (persons/km²)	-0.00102***	0.000630**	0.000868***
Rainfall in driest quarter (mm)	0.0114***	-0.00108	0.00409*
Market access			
Distance to capital (km)	-0.00949***	-0.00184	0.00265**
Nearest provincial at more than 5 km (yes=1; no=0)	-0.401*	0.0221	0.0727
Wealth			
Farm size: second quartile	0.450***	0.254***	0.112
Farm size: third quartile	0.585***	0.328***	0.294***
Farm size: fourth quartile	0.849***	0.525***	0.543***
Female headed household (yes=1; no=0)	-0.331***	-0.196***	-0.0849
Access to fertilizers (yes=1; no=0)	0.193**	0.251***	0.157**
Household characteristics			
Age	0.000173	0.0144	0.000125
Age squared	-0.000012	-0.000125	-0.000023
Household size	0.0886***	0.0779***	0.0668***
Constant	-1.04**	-0.653**	-1.24***
Correlation between error terms	Rho1	Rho2	
Rho 2	0.0474		
Rho 3	0.116***	0.309***	

Symbols indicate significant differences at ***: p-value ≤ 0.01, **: p-value ≤0.05, *: p-value ≤ 0.10

Regional dummies were included, but are not reported.

Overall, the model confirms that wealthier households were more likely to keep livestock: households with more land or with access to fertilizers were more likely to keep livestock, whereas female headed households were less likely to own livestock. The probability of keeping livestock increased nearly linearly with wealth, as measured by total landholdings of the households (figure 3.1). For instance, less than 10% of the households in the first quartile (0.16 ha of land) kept cattle, while more than 20% of the households in the fourth quartile (2.74 ha of land) did so. Yet, besides wealth, there are other factors that explain livestock investment.

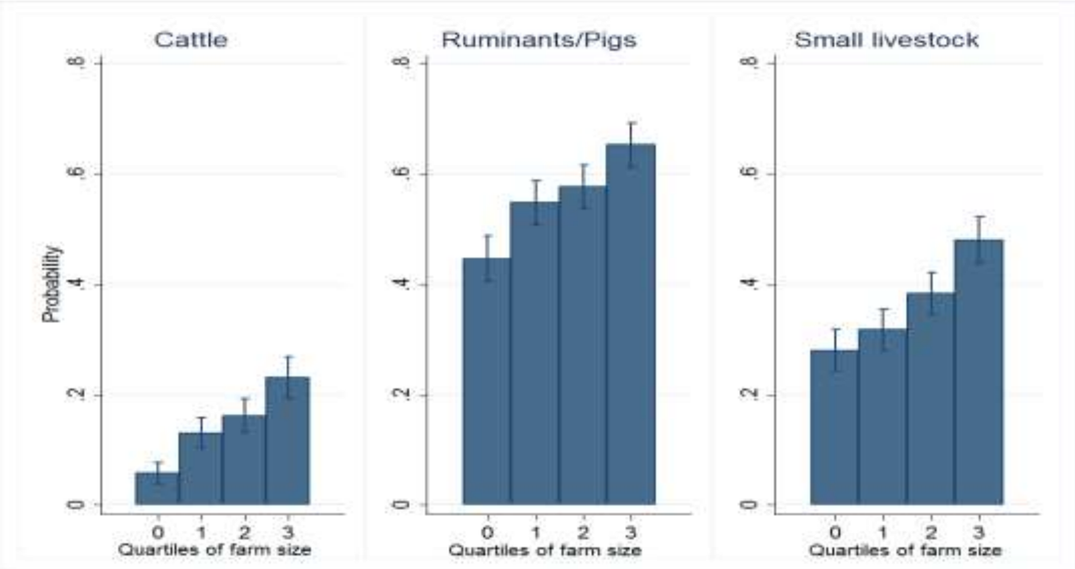

Figure 4.1: The predicted probability (with 95% CI) of investment in livestock in function of successive quartiles of farm size

The multivariate probit model shows that population density plays an important role in the choice of investing in livestock (figure 4.2). In villages characterized by high population density, households were significantly less likely to keep cattle. The probability of keeping cattle is 17% if the population density is 300 persons/km², but decreases to 6% if the population density increases to 600 persons/km². This suggests that households are concerned about the return on their investment and do not only buy cattle if they have the required means to do so. Surprisingly, the probability of investing in other types of animals increases significantly with population density. This suggests that households with sufficient capital still want to invest in livestock, but prefer to invest in smaller animals rather than cattle if population density is high. We assume this is because investing in cattle is not sufficiently profitable or too risky in these areas due to shortages of grazing land. It is indeed well-known that cattle are more vulnerable to feeds of poor quality relative to goats and other small livestock (Devendra, 1999). Hence, these animals can be considered a substitute for cattle in densely populated regions.

Average rainfall in the driest quarter of the year is positively correlated with the likelihood of keeping cattle and, to a lesser extent, with keeping other small livestock. It does, however, not explain investment in sheep, goats and pigs. The probability of keeping cattle, for instance, increases from 10% in regions with an average rainfall in the dry season of 25 mm to 25% in regions with an average rainfall in the dry season of 65 mm (results not shown). With a similar increase in rainfall, the probability of keeping other small livestock increases from 33% to 42%. It may be that limited rainfall in the dry season reduces the availability of feed and is therefore a critical constraint in livestock rearing (Bidou et al., 1991)[39].

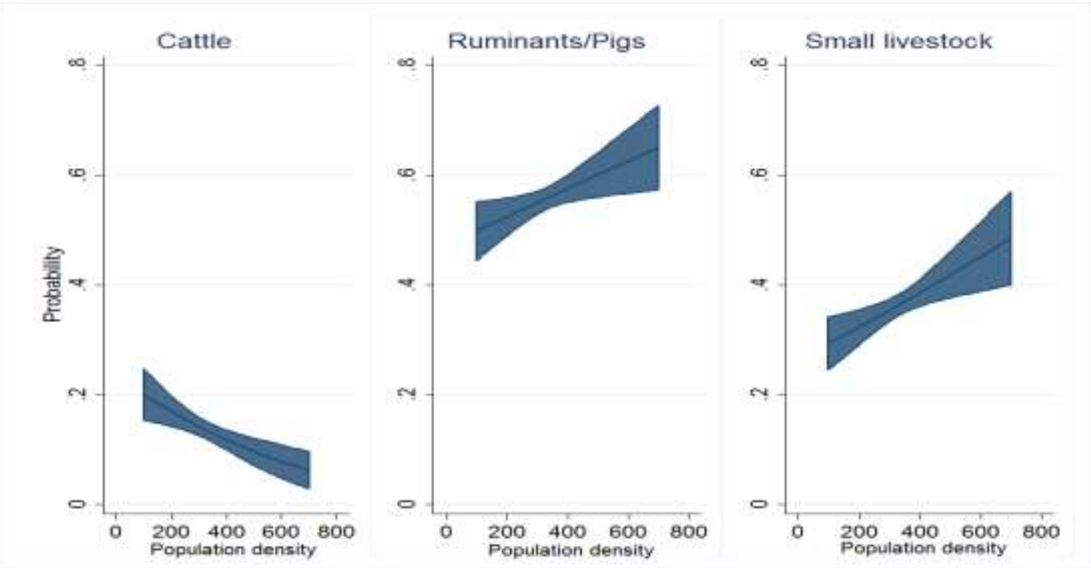

Figure 4.2: The probability of investing in livestock (with 95% CI) in function of population density

The model also suggests that market access contributes to explaining investment in livestock. The distance of the household to the regional capital shows a large and significant negative correlation with keeping cattle, and a smaller positive correlation with keeping other small livestock. Figure 4.3 shows that the probability of keeping cattle decreases from 20% to less than 3% when the distance to the capital increases from 50 to 150 km. This is a very large correlation given that few households sold their cattle directly in the capital, but rather sold it on local markets to intermediaries. In our view, the correlation is too large to attribute it completely to the beneficial impact of better market access given the market structure in Burundi. Part of the effect might be attributed to the fact that cattle rearing is very common around the capital because of excellent agro-ecological conditions for cattle rearing. Although regional dummies are included in the model, these might not completely capture the concentration of cattle around the capital.

To test whether the effect of the distance is non-linear, we also included the squared distance in the multivariate probit model, but the estimated coefficient was small and insignificant. A second potential explanation is the civil war that ravaged Burundi from

[39] Average annual rainfall was not significantly correlated with livestock keeping.

1993 to 2002. However, it is well-documented that the civil war was more severe in the region around the capital (Bundervoet, 2006, Voors et al., 2012) than in other provinces. Consequently, if recovery of the civil war would still play a role we would expect less livestock around the capital than in the provinces further away from the capital. This is clearly contradicted by our results. The third, and most likely, explanation is the strong positive correlation between access to Bujumbura and access to regional towns. As such, we cannot determine whether access to a regional town has a more pronounced effect on livestock keeping than access to Bujumbura. It can only be concluded that market access is likely to influence the investment decision of farmers. The second proxy for market access, which refers to whether the closest provincial road is situated at more than 5 km from the village confirms that market access is an important aspect in the decision to invest in livestock. Households with good access to a provincial road are more likely to keep cattle.

The multivariate probit model estimates the correlation between the error terms of the three investment decisions. As expected, the three error terms are positively correlated, although correlation between the error terms of the first (cattle) and second (sheep, goats and pigs) category of animals is small and insignificant. This confirms that a multivariate probit model is more appropriate than estimating the three investment decisions separately with probit models. The positive correlations also show that a household with one type of livestock is also more likely to keep another type of livestock. Remarkably, the correlation of the error terms between investing in sheep, goats and pigs or other small livestock is significantly higher than the correlation between the other error components. This might suggest that investing in sheep, goats and pigs is a close substitute to investing in other small livestock, while investing in cattle is mainly driven by other factors.

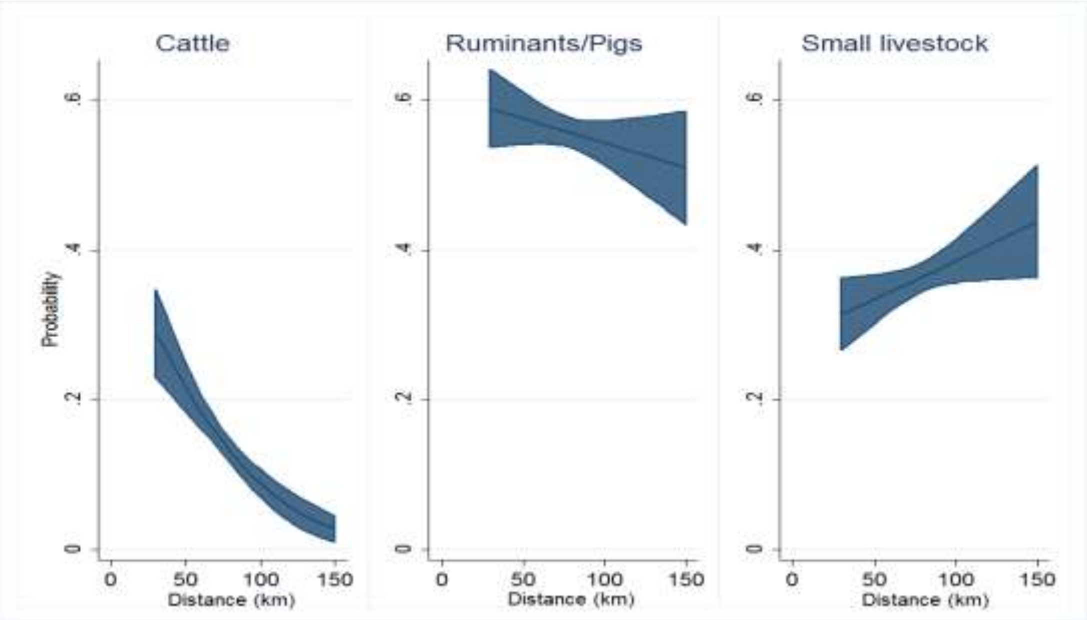

Figure 4.3: The probability of investing in livestock (with 95% CI) in function of the distance to the capital

4.5. Conclusion

This study explains that not only wealth in terms of land matters for cattle rearing in Burundi. Even relatively wealthy farmers in densely populated regions are unlikely to keep cattle and switch to smaller animals such as sheep, goats, pigs or smaller livestock, which are less vulnerable to feed shortages and feed of a poorer quality. Similarly, poor market access also reduces investment in cattle, which are primarily reared to be sold on the market. Consequently, the concept of the livestock ladder has to be refined. The poorest households indeed invest rather in small stock than cattle, but wealthier households only shift to cattle if the expected return on this investment is sufficiently large. The conditions that influence the expected returns include population density, rainfall and market access.

Our results have important policy implications. While we could not directly calculate the return on investment in livestock, it seems that cattle are not always the most productive investment when compared with small livestock, particularly in densely populated regions. At the same time, policy makers in Burundi, and in Sub-Saharan Africa in general, are primarily concerned with developing the dairy sector and seem to neglect other forms of livestock. For instance, the investment plan for the agricultural sector 2012-2017 in Burundi aims to distribute 200,000 cows to smallholder farmers, but does not set targets for any other type of livestock

(MINAGRIE, 2011a, MINAGRIE, 2014). Some NGOs interventions are oriented toward small stocks. Yet since this was not clearly highlighted in the government plans, the achievements in regards were very limited. Given the role smaller animals can play in poverty and food insecurity alleviation, the fact that these animals might be better adapted to local conditions and their lower cost relative to cattle, might make it worthwhile for both the government of Burundi and NGOs to rethink their strategy towards the livestock sector and to focus more on smaller animals. Although a policy shift from promoting cattle to promoting smaller animals seems justifiable, more studies are required that examine technical and economic aspects of keeping smaller animals in Burundi such as sheep and goat management to avoid damage to cropland, disease management and nutritional evaluations.

Chapter 5:
Food for survival: diagnosing crop patterns to secure lower threshold food security levels in farm households of Burundi

Abstract

Burundi is one of the poorest countries and comes last in the Global Food Index (2013). While a large majority of its population depends on agriculture, most smallholder families do not produce enough to support their own families. This study aims at estimating the optimal crop mix and resources needed to at least procure the family with enough food in terms of energy, fats and protein supply. We used mathematical programming to obtain the optimal crop mix that could maximize output given the constraints in production factor endowments and the need to feed the household. Model predictions are compared with data collected during a revisit of the area in 2012. Results showed that by producing fewer crops in which farms have comparative advantages and trading, large and medium farms get better off and are willing to hire in extra hours to complement family labour. Predictions of crops to be planted coincided to a high degree with what farmers planted two years after our survey on newly acquired plots. Despite the rampant land scarcity, the results show that it is still possible for households to find optimal crop combinations that could meet minimal food security requirements while generating a certain level of income, except for nearly landless households. The later farm group would benefit from the increased off-farm employment opportunities.

Key words: food insecurity, resource allocation, specialization, small farms, production model, Burundi

This chapter is based on:

Niragira, S., D'Haese, M., D'Haese, L., Ndimubandi, J., Desiere, S., Buysse, J., 2015. Food for Survival:Diagnosing Crop Patterns to Secure Lower Threshold Food Security Levels in Farm Households of Burundi. Food and Nutrition Bulletin 36, 196-210.

The leading author coordinated the data collection by the enumerators of the University of Burundi in the framework of a VLIR-UOS project. He did the literature search, conceptualised the model with the help of Professor Jeroen Buysse, and wrote the chapter. The co-authors (promotors, colleague and project coordinators) helped with revising the text and improving the structure.

5.1. Introduction

The way agriculture can contribute to food security is well-established, whereas recent renewed attention is given to the role of agriculture for nutrition; e.g. by (Haddad, 2013) and (Turner et al., 2013). A key role for agriculture is to provide nutritious food to the households that produce it (Haddad, 2013). Agricultural growth is expected to contribute to food and nutrition security, both directly (e.g. auto-consumption) and indirectly (e.g. income generation) (Haddad, 2013); and such agricultural growth is to be expected from increased farm productivity through technology adoption and improved access to inputs, inclusion in food value chains and conducive policy environments (Haddad, 2013; Turner et al., 2013; WorldBank, 2007). Yet, many poor African rural households are still facing food insecurity. Paradoxically, poor African rural livelihoods, often heavily depending on subsistence farming, seem unable to cover their own minimum food needs (Cunguara & Darnhofer, 2011; Fulginiti et al., 2004; Savadogo et al., 1998). Dominant production systems in the poorest areas are still characterized by low input use, mixed cropping and extensive livestock keeping with a high degree of self-reliance. Besides problems of land-scarcity and soil degradation, smallholder farmers operate in an environment of incomplete and poorly functioning markets for everything from labour, land, credit, commodities, risk and information (Timmer, 1997) while support policies are limited (Adesina, 2010). This explains at least partly the persistent low crop productivity, food insecurity, hunger and malnutrition among poor African agricultural-based communities (Nkala et al., 2011).

The obvious question is then what would be needed to realize what Haddad calls 'the elusive potential of agriculture for nutrition' (Haddad, 2013) - and food security? Haddad calls for the development of diagnostic tools that enable identification of leverage points on issues such as crop choices, investment areas, agricultural extension and access to inputs and markets (Haddad, 2013). Turner et al. (2013) advance research gaps in terms of methodologies and metrics in agriculture-nutrition research, and express concerns over the limited research on agricultural policy and governance issues. In this chapter we try to address – or at least touch upon - these issues. We propose a mathematical model to predict which cropping patterns may be most appropriate to provide food security to distinct groups of farmers in the poor rural areas of northern Burundi. Perhaps we do not fully answer Haddad's question because we are more concerned with the provision of minimal amounts of food to feed a household and secure its macro-nutrition composition rather than with the availability of micro-nutrients. Yet, given the dire food insecure situation of poor Burundian households, we think such an initial approach is valuable.

While food demand in Burundi continuously increases as a result of population growth, declining land availability and increasing rural poverty hamper further production growth and agricultural development. Over the years and reinforced by the political crises, food insecurity and poverty have worsened. Burundi has a sad record of coming last in the IFPRI ranking of the Global Hunger Index of 2013. Yet, an estimated 90% of Burundians depend on agriculture for their livelihoods; but farms are small, mainly using mixed cropping systems, supplemented with few livestock and secondary commercial banana, coffee and tea production.

This chapter aims at analysing the optimal crop mix and resource use that maximize crop output which should be large enough to cover household food needs (in terms of calorie, and macro-nutrient availability). Mathematical programming is used to calculate the optimal crop mix that could maximize output given the constraints in production factor endowments and the need to feed the household. Furthermore, the models also account for possible trade of resources between farmers. We attempt to show that changes in crop choices may contribute to improved food self-sufficiency, but also that relative resource constraints strongly determine the optimal crop combination. A comparison of the results between farms with different endowment levels allows us to check how such resource constraints influence optimal crop mixes.

We use detailed farm level data that has been collected in the north of Burundi in 2007, 2010 and 2012. A typology of four farm types is based on the 2007 data. A subsample was revisited in 2010 and 2012. The mathematical model is calibrated with the 2010 data. The predictions made by the model are compared with crop production trends recorded by the 2012 data. Since no specific policy towards crop specialization has been implemented since 2007, the trends in crop production measured between the two records are a result of population pressure, changes in land tenure and market forces (e.g. recent liberalization of the coffee market).

Mathematical models have been used for years to analyse optimization processes at a micro-economic level (Kaimonwitz & Angelsen, 1998). The models are embedded in the land rent theory of Von Thünen and Ricardo, and depart from the premise that all parcels of land, given their attributes and location, are used in the way that earns the highest rent (Lambin et al., 2000). The key argument of specialization goes back to Ricardo's claims for labour division, comparative advantages and trade. Yet poor infrastructure, high transport costs and the bulky nature and perishability of many of Africa's staple food crops put limits on crop specialization, intra-regional trade and large scale exchanges (Adesina, 2010). Given the poor resource base of farmers we deal with in this study, we believe the greatest scope lies in domestic markets and efforts should be geared towards improving intra-rural systems of distribution.

We believe this study is original for at least three reasons. First, the mathematical programme is used as a diagnostic tool to predict what crop choices could secure production that covers minimal nutrition requirements in terms of caloric content and macronutrients, and which at the same time fits realities in subsistence production systems. It also allows for trade between the farm types. Secondly, this chapter distinguishes farm types identified by cluster analysis. While all farmers in the study area are considered smallholder farmers, relatively small differences in endowment levels have an important effect on crop choice, production and productivity. Hence, development paths need to be identified by farm type (Verschelde et al., 2013). Finally, as the research area was recently revisited, we are able to check whether the outcome of the model correctly predicts the changes in crop production.

5.2. Study background and methods

5.2.1. Household food security situation

Low agricultural returns have seriously affected farmers' ability and motivation to invest in their farms. The capacity of land and labour to supply food in sufficient amount has been compromised, imports of food are increasing steadily and the country is depending heavily on aid from bilateral and multilateral donors. Subsistence crop production has grown more slowly than the population while export crop production has fallen (Banderembako, 2006; MINAGRIE, 2008). Per capita agricultural productivity has been declining for years with obvious implications on food and nutrition security. Studies point to high poverty levels with 70% of the population living below the national poverty line and 63% of them gripped in a severe food insecurity situation (Ahishakiye, 2011; Baghdadli et al., 2008). Options for rural employment (which should create job opportunities that could absorb the excess of rural labour) are often limited to informal labour exchange between farms during critical periods. It is against this background that we study the potential for optimizing farm production systems.

5.2.2. Sampling procedure and data collection

Household data on farm activities was gathered in three survey rounds in 2007, 2010 and 2012 in Ngozi. In 2007, 640 households were interviewed in Ngozi and the neighbouring province, Muyinga. In each village or commune (9 in Ngozi and 7 in Muyinga) of each province, 10 collines or hills were sampled on which four households were randomly selected. This sampling procedure tried to capture the variability of the farms across the provinces. However, due to some irregularities[40] in the data, 6 % (39 households) of the households were removed from the sample and the remaining households were clustered in four farm types. Across these types, a sample of 60 farms was purposely chosen to be interviewed in 2010. The 2010 survey collected more detailed information on production and input use compared to the 2007 survey data. In 2012, 340 of households interviewed in 2007 in Ngozi were revisited (section 1.5.3). This resulted in a panel dataset that is used to validate the predictions of the model.

The rationale behind selecting the area for the study was suggested by both demographical and agricultural features of the region. Ngozi ranks among the most overpopulated provinces of Burundi with an average population density of 462 inhabitants per square kilometre. In addition, the province ranks 4th out of 17 provinces of Burundi in terms of agricultural production (MPDRN, 2006). Moreover, the agro-ecological conditions allow a wide range of crop combinations and human settlements. This is said to be one of the reasons for the high population density observed in the region. The soil quality (mainly ferrisols), the water availability and the diversified tropical climate, moderated by altitude, offer favourable physical conditions for intensive and diversified agriculture (MPDRN, 2006).

[40] The survey was done with the head of the household in order to collect more accurate information. In some households where the head was absent, the spouse could be interviewed. Yet some of them could not provide information on the household income because they ignored the earnings of the household members, or the sources of inputs and the household expenditures.

The interviews were done in Kirundi by a team of researchers of the University of Burundi. The questionnaire inquired on household, farm and farming system characteristics. The farm input and output data covered one production year, which consisted of three cropping; seasons 2009C, 2010A and 2010B. The questionnaire also included questions on expenditure on different farm inputs and various additional household expenses.

5.2.3. Farm typology and data

The first step of the study consisted of running a cluster analysis on the original (2007) dataset (appendix 5.1). The aim of the analysis was to construct a farm typology that could serve as a sampling frame for the 2010 data. The typology was based on variables that are indicative of agricultural trajectories and the strategies employed by farmers in sustaining household survival, which are, at the same time, linked to farm characteristics (available land per capita, labour availability, share of cash crops, food crops and banana in total output, livestock and share of non-farm earnings). Next, a subsample of farm households was selected to be interviewed in 2010 and as such to obtain a smaller data set of 60 farm households on which further analysis were performed. In a third step, the validity of the model was checked with the outcomes of a panel data set (2007-2012) with 340 observations that provides a detailed overview of the evolution of the production for the main crops.

Typically, production systems and livelihood strategies of rural households in less favoured areas are characterised by a wide diversity in terms of resource endowments, activity choices and the prevailing conditions for engagement in market exchanges (Pender & Ruben, 2004). It is unusual to find two absolutely identical agricultural production units. Therefore, the ideal development strategy would be to distinguish between all individuals and to find a unique solution for each of them which is obviously unaffordable (Köbrich & Khan, 2003; Manyong et al., 1987); nor will one-fits-all policies provide an adequate solution in a situation of great diversity (Pender & Ruben, 2004). To deal with this marked diversity in possible development paths followed by different farms, it is worthwhile to categorize the sector into subsets showing a maximum amount of heterogeneity between the farm types, while obtaining maximum homogeneity within particular categories (Köbrich & Khan, 2003). A good farm typology accounts for the success of research operations and planning of rural development (Manyong et al., 1987) by increasing the general applicability of recommended solutions generated by mathematical programming models (Köbrich & Khan, 2003). However, for such models to be effective as a diagnostic tool, they have to be constructed for 'truly' typical or representative situations (Köbrich & Khan, 2003).

Havard et al. (2002) suggest two variants of agricultural development typology, namely (a) a typology that is structure-based, using available production factors on the farms to distinguish the groups, and (b) a functional typology that considers the process of production and the farmer's decision making. We used proxies for both in our cluster analysis. The variables considered in the study for classification are resource endowments (land, labour, livestock), agricultural practices (share of cash crops, food crops and banana) and household income diversification (non-agricultural income). Banana is considered as a semi-cash crop as it is important for both household food supply and income earnings the whole year round.

5.2.4. Modelling framework

Mathematical Programming (MP) has become an important and widely used tool for analysis in agriculture and economics. The basic motivation for using programming models in agricultural economic analysis is straightforward; because the fundamental economic problem is how to make the best use of limited resources (Buysse et al., 2007). These models have been successfully used to improve the planning of agricultural systems (see e.g. Glen and Tipper (2001)).

The models in this study maximize the annual farm output (three cropping seasons: A,B & C) (expressed in monetary terms). They take into account limited production factors at farmer's disposal (land, labour and capital or the amount of money annually invested in agricultural production) and the availability of the sufficient energy and main macronutrients for the household throughout the year. The data of 60 farmers across the four farm types were used as input for the Mathematical Programming. Farm output is measured by the sum of the market value of all crops produced. Farm production for each food crop is multiplied by the average market price of the respective crop.

Though we are aware of the livelihood diversity of farm households in the study area, for simplicity, activities in the model are limited to crop production. Fifteen crops are identified as major crops able to provide more than 80% of the household food supply; these are banana (*Musa spp*.), sweet potatoes (*Ipomoea batatas*), cassava/manioc (*Manihot spp*), avocado (*Persea americana*), beans (*Phaseolus vulgaris*), potatoes (*Solanum tuberosum*), rice (*Oryza sativa*), maize (*Zeya mays*), sorghum (*Sorghum bicolour*), colocase/taro (*Colocasia esculenta*), groundnut (*Arachis hypogaea*), peas (*Pisum sativum*), soya beans (*Glycin max*), tobacco (*Nicotiana tabacum*) and coffee (*Coffea spp*). However avocado was dropped from the list to eliminate bias as the crop is perennial and does not require regular maintenance. The model can be summarised below:

$$Max\ Z_l = \sum_{jk} P_j x_{jkl} \qquad (1)$$

Subjected to:

$$\sum_j I_{ijk} x_{jkl} \le Q_{ikl} \qquad (2)$$

(for all i = 1,…,n; all k= 1,2,3; and l = 1,2,3,4)

$$\sum_{jk} N_{jh}\, x_{jkl} \ge F_{hl} \qquad (3)$$

$$\sum_j N_{jh}\, x_{jkl} \ge S_{hkl} \qquad (4)$$

$$\sum_{jl} I_{ijk}\, x_{jkl} \le \sum_l Q_{ikl} \qquad \forall\ i = land \qquad (5)$$

$x_j \ge 0$ (for all *j* = 1,...,m)

$x_j$being the level of farm activity *j*, *m* the number of activities, *k* seasons, *n* the number of constraints, *h* the types of food caloric content (kcal) and food nutrients (proteins and fatty acids), *l* the number of farm categories (more details can be found in table 5.1).

The model was initially applied to three scenarios of which two yielded feasible results. The first scenario (*market oriented*) assumes agricultural inputs (land, labour and capital) to be the only limiting factors and thus shaping the farmer's decision making (equation 2). Under this scenario, it is assumed that farmers maximize the value of their output subject to their resource constraints. The second scenario (*subsistence oriented*) includes a constraint that production needs to have the minimum requirements of the households in terms of energy and macronutrients (equation 3). The food calorie and nutrient contents (proteins and fatty acids) of all crops are multiplied by their respective quantity produced, and compared to the household food intake needs set as a constraint because the main goal of the farms is to satisfy the family consumption in subsistence agriculture. A third scenario tried to capture seasonality (equation 4). It tests the seasonal interdependency in providing sufficient production necessary to sustain the household food availability. Yet, as will be explained later, the models were infeasible.

For each scenario, an additional run is performed to assess the impact (on the farm output) of exchanges in production factors between farms, mainly lands (equation 5). The model is applied to representative farms of the four different farm types identified. Four representative farms were purposely selected from each farm type cluster based on the quantity and quality of available information; mainly farms closer to the average in terms of the variables of interest of the farm types were chosen.

This model obviously has its limitations. First, the variables considered in the farm typology are mainly resource endowments, agricultural practices and household income diversification. Other typologies may be developed. Second, we preferred to work with a real farm data and not with an average farm per farm type (although the farm with the data closest to the average for each type was selected). We believe the production/input balances are more accurate in such an approach. Models with average data may give different results. Thirdly, the same productivity levels are considered per crop. Because of the mixed cropping systems that are applied over the different seasons, it is difficult to estimate the productivity levels for each individual farm. The productivity levels are determined based on own calculations and reports.

Table 5.1: Parameters of the model

Code	Meaning	Unit
P_j	Price of 1 kg of crop *j*	USD
x_{jkl}	Quantity of crop *j* produced in season *k* in farm type *l*	kg
I_{ijk}	Quantity of input *i* necessary to produce 1kg of crop *j* in season *k*	USD, hours, ha
Q_{ikl}	Quantity of input *i* available in season *k* in farm type *l*	USD, hours, ha
N_{jh}	Nutrient content[1] *h* of 1 kg of crop *j*	g, kcal
F_{hl}	Minimum food nutrient *h* annually required for household type *l*	g, kcal
S_{hkl}	Minimum food nutrient *h* required in season *k* for household type *l*	g, kcal

Note 1: *Calculations of nutrient content is based on FAO table: Agriculture, food and nutrition for Africa*

5.3. Results

5.3.1. Descriptive analysis

5.3.1.1. Types of farm households and their characteristics

From the results/findings, four farm clusters are distinguished (table 5.2). These are: large, medium, small and nearly landless farms. Large and medium farms (32 % of the sample) have more lands per capita with low availability of labour per unit of land. Small and landless (68 % of the sample) households have an excess of labour and a high rate of livelihood diversification into low paid agricultural work. Previous analyses on the 2007 dataset highlighted that the poorest groups had a higher likelihood to participate in off-farm activities, suggesting push diversification as a dominant coping strategy (D'Haese et al., 2010). Yet, also large farms diversify their livelihood with activities outside agriculture. The share of income from outside farms is 44 % on average. However wage levels and expenditure on food we registered were very low, suggestion that off-farm labour is not contributing significantly to the household's food security.

Corroborating with the work of Ndimira (1991) who calculated that 0.20 ha per capita is the minimum land required for each household member to survive in Burundi, almost 68 % of the sampled household depends on less land than this threshold.

Table 5.2: Types of farm households and their characteristics (n=60)

	Unit	Overall mean	Farm household types				F- test
			Large (12%)	Medium (20%)	Small (38%)	Nearly landless (30%)	
Farm size/capita	ha	0.17	0.52	0.24	0.13	0.05	64.45***
Labour available/ha	hour	2677.85	643.09	1367.67	1990.38	5221.05	46.26***
Share banana	%	22.42	20.84	18.77	22.87	24.88	0.35
Share cash crops	%	13.51	13.87	16.25	13.65	11.35	0.51
Share food crops	%	64.07	65.28	64.96	63.47	63.76	0.02
Livestock units	TLU[a]	0.60	0.56	0.83	0.53	0.46	1.19
Non-farm income	%	43.95	32.81	36.38	41.15	56.91	1.69*

[a] TLU: tropical livestock units;
Symbols indicate significant differences at ***: p-value ≤ 0.01, **: p-value ≤0.05, *: p-value ≤ 0.10

5.3.1.2. On-farm diversification and household food security

The agriculture sector of Burundi is dominated by poor farmers using very little inputs and producing for subsistence on highly fragmented lands. On average, a farm of 0.98 hectare counts six plots of often different land types, including land of marginal quality and steep slopes. Despite the poor quality of land, fertilizer use is very low and farmers rely mostly on manure or mulch. Manure is reported by farmers who have livestock. Cash investment in agriculture is very low. In general, 30% of the income is reinvested in agricultural production, but this varies over farm types. On most farms, the production decisions are linked to consumption decisions and farmers target household security. The dominant farm objective is to satisfy family food preferences and self-reliance by growing a diverse range of crops. Farmers prefer to grow crops for which they are certain to get production even if this is low. Many of the interviewed households produced more than 20 different crops. However, only the most commonly found 15 crops were taken into account for the analysis. On average, a household consumes 72% of the farm production while 28% is marketed and/or to a lesser extent exchanged through social networks. Only coffee and banana are marketed at large scale. Other crops such as cassava, beans, sweet potatoes, and potatoes are less important as income earners but their contribution to food security remains highly significant. We used FAO-WHO recommendations to assess the level of food intake among the sampled households (Latham, 2001).

Table 5.3: Household food security situation in Ngozi (2010)

Food intake requirements	Overall mean		Percentage by farm types				χ²-test
	N	%	Large farms	Medium farms	Small farms	Nearly landless	
Energy	60						11.28**
Achieved	42	70.00	100.00	91.70	69.60	44.40	
Not achieved	18	30.00	0.00	8.30	30.40	55.60	
Proteins	60						11.20**
Achieved	29	48.30	71.40	83.30	39.10	27.80	
Not achieved	31	51.70	28.60	16.70	60.90	72.20	
Fatty acid	60						12.71***
Achieved	17	28.30	71.40	68.30	39.10	11.10	
Not achieved	43	71.70	28.60	31.70	60.90	88.90	

Symbols indicate significant differences at ***: p-value ≤ 0.01, **: p-value ≤0.05, *: p-value ≤ 0.10

Table 5.3 shows that 72 % of sampled farmers fail to meet the minimal FAO household food recommendations in terms of fatty acid, 52 % fail to satisfy household protein needs while 30 % do not supply a sufficient amount of calories necessary to meet household minimum requirements.

5.3.2. Optimum farm production

5.3.2.1. Farm output levels and input shadow prices

The Mathematical Programming determines the optimal allocation of production factors by maximizing the economic surplus generated by the farms. The results show that when a farmer's goal is to optimize production (after specialisation), the farm output doubles (table 5.4a). Output increases even more if inputs can be traded. In addition, the resulting higher shadow prices (table 5.4b) of production factors push farmers to seek for trading extra units of inputs. Large and medium farms seek for more labour while small and landless farm search for land and employment. Any decision to hire in an extra unit of labour in large and medium farms could give daily additional returns of 2.8 USD (0.35 USD x 8 hours a day) to the farms in season B. This highlights the potential increase in opportunity cost of labour which is currently evaluated at 0.64 USD a day.

Shadow prices for land of small and nearly landless farms are estimated at 661 USD per ha in Season A and 2 126 USD per ha in Season C. In Season C (dry season) only wetlands and irrigated valleys are cultivated and therefore almost all farms are likely to experience shortage of agricultural land because they lack irrigation systems. The lack of agricultural investment is pointed out for all of farm households. Large and medium farms could increase their output with 28 USD in season A and 14 USD in season B per dollar invested. Likewise, the output of small farms and landless farms increase by 12 USD and 36 USD per additional unit of capital invested during the A and B cropping seasons respectively. These shadow prices of capital forecast the potential impact of rural credit in agricultural production in this area.

Table 5.4a: Value of farm output in specialisation scenarios I&II

Stages of production	Units	Farm categories				
		Large farms	Medium farms	Small farms	Nearly Landless	Average farm
Market oriented scenario						
Before specialization	USD	1,160.60	950.79	664.63	219.64	846.87
With specialization	USD	3,005.40	2,095.32	1,404.24	540.44	1,953.82
Exchange in inputs	USD	3,113.72	2,130.77	1,644.68	592.22	2,323.78
Subsistence oriented scenario						
Before specialization	USD	1,160.60	950.79	664.63	219.64	846.87
With specialization	USD	1,446.84	1,698.34	794.02	Unfeasible	1,598.85
Exchange in inputs	USD	2,496.15	1,745.90	1,222.40	Unfeasible	2,001.49

The optimal output decreases when minimum household food needs are added as constraints. The output drop results from changes in crops to be adopted in order to satisfy the newly introduced conditions. The sharp drop in output observed (table 5.4a) in large and small farm categories reflects the high pressure of food requirements (large families) compared to large farms. The model becomes even infeasible for landless farmers; their endowment levels are not sufficient to fulfil household food requirements by crop production.

Seasonality effects are tested in scenario III. Yet, all models were infeasible. This means that, household food requirements cannot be met by own production only in each of the seasons, especially in Season C (which is the dry season). This exhibits the potential impact of a good storage system in the community.

Table 5.4b: the shadow prices in production factors (scenario I)

Representative farms	Production factors		1st season (A)		2nd season (B)		3rd season (C)	
			Level	Marginal	Level	Marginal	Level	Marginal
Large farms	Land	ha	0.7887	0	0.8904	0	0.4035	836
	Labour	hours	1,312	0	2,450	0.35	1,292	0
	Capital	USD	33.44	28	43.95	14	32.64	8
Medium farms	Land	ha	0.2817	0	0.7823	0	0.2796	0
	Labour	hours	469	0	2,464	0.35	469	0
	Capital	USD	11.94	28	40.6	14	11.94	28
Small farms	Land	ha	0.3650	661	0.3750	0	0.0365	2,126
	Labour	hours	745	0	1,250	0	231	0
	Capital	USD	30.25	12	19.91	36	5.81	0
Nearly Landless farms	Land	ha	0.1660	661	0.2515	0	0.0208	2,126
	Labour	hours	285	0	505	0	132	0
	Capital	USD	7.96	12	8.04	36	3.32	0

note : marginal= SP: shadow price

5.3.2.2. Crop adopted at optimal farm production

Optimal land use predicted by the model suggests a sharp drop in the number of crops grown on the farms. Obviously, farmers with different resource endowment levels are likely to specialize in a different range of crops (appendix 5.2). However, large farms are relatively more suited to specialisation (low number of crops) and hence to shift from subsistence to market oriented system rather than small farms. While the model prediction highlights two and three crops for large and medium farms respectively (beans, rice and cassava), small and landless farmers need produce also potato in order to optimise production in the market oriented scenario. The same situation is observed for the subsistence oriented scenario where small farmers have to grow more crops compared to large and medium farms. The crops selected in the model have either a high productivity (banana), high content of major nutrients or high market prices (groundnut).

5.3.2.3. Changes in household food security

Optimum farm outputs predicted by the model are used to assess the improvement in households' food security situation. In table 5.5 farm production is divided by the household size expressed in adult equivalents and expressed as the contribution to food security. Important to note is that only landless farms are unable to meet their household food needs. The other farm types can produce enough for the household's survival. Nearly landless households will therefore depend on off-farm income to guarantee access to enough food.

Table 5.5: Agricultural specialisation and household food security situation

Food intake		Minimum intake/adult equivalent	Food produced per farm category			
			Large farm	Medium farm	Small farm	Nearly Landless farm
Energy	kcal	2895	3094	4367	2895	--
Protein	g	55	132	120	60	--
Total fat	g	48	70	48	48	--

5.3.3. Sensitivity analysis

All other factors kept constant, any change in crop prices is likely to affect the composition of farm output itself and the market value of total production. Table 5.6 shows the values of farm output with changing coffee prices in scenario I. In the base run, coffee is not selected in the model. However, when the price increases by as little as 50 BIF (0.04 USD) per kg, coffee enters in the model and the overall output increases considerably for all farms categories.

Table 5.6: Trends in farm outputs when the price of coffee varies

Changes in coffee prices	Large Farms (12%)	Medium Farms (20%)	Small farms (38%)	Nearly Landless farms (30%)	Average farms
Before (base run)	1,160.60	950.79	664.63	219.64	846.87
350 BIF/0.278 USD	3,005.40	2,095.32	1,404.24	540.44	1,953.82
400 BIF/0.318 USD	3,115.70	2,132.13	1,645.72	592.59	2,325.26
450 BIF/0.358 USD	3,150.82	2,131.50	1,658.32	608.72	2,345.93
500 BIF/0.398 USD	3,185.94	2,130.88	1,670.92	624.84	2,366.60

The model is also very sensitive to the price of banana. Because 93.3% of households get their income from selling both banana beer/wine and plantain, any change in the banana market could affect the livelihoods of many families. Table 5.7 depicts the trends in farm outputs when the price of banana changes.

Table 5.7: Changes in farm outputs when the price of banana varies (Scenario I)

Changes in banana prices	Large Farms 12%)	Medium Farms (20%)	Small farms (38%)	Nearly landless farms (30%)	Average farms
Before (base run)	1,160.60	950.79	664.63	219.64	846.87
210 BIF/0.167 USD	3,005.40	2,095.32	1,404.24	540.44	1,953.82
250 BIF/0.199 USD	3,005.72	2,095.32	1,404.24	540.44	1,953.82
280 BIF/0.223 USD	3,141.97	2,146.88	1,408.85	543.12	2,000.48
300 BIF/0.239 USD	3,270.54	2,201.90	1,429.92	555.41	2,092.88

5.3.4. Empirical validation of the predictions of the model

Given the local prices for agricultural commodities in 2010, the model predicts that rational households should shift their production pattern over time towards the most profitable crops. However, changing production patterns is a difficult decision and often requires costly investment because uprooting and replanting of certain crops is necessary. Hence, even if households are completely rational and base their decisions only on the variables included in the model (land, availability of labour and fertilizer and prices/nutritional value of the different crops), production patterns will only slowly change over time.

In addition, households can opt to change production along extensive or intensive margins which is not strictly determined by the model. In the former, it is assumed that fields devoted to the most profitable crops are expanded at the expense of fields previously used for the production of the least profitable crops. In the latter, households choose to target the scarce resources, labour and fertilizer, towards the most profitable crops, but do not expand the area devoted to these crops. Generally, changes at the extensive margins will require more time, as there are higher fixed costs involved, than changes along the intensive margins.

Our detailed panel dataset with 340 observations covers a time span of five years (2007-2012) which is arguably sufficient to investigate whether agricultural production indeed shifted over time towards the crops predicted by the model. The fact that the estimation of technical coefficients was based on data collected in 2010 does not imply that this shift should only have started in 2010, because the characterization of the different farm types was based on data collected in 2007. We assume therefore that the prediction of the model should be valid for the period 2007 to 2012.

Table 5.8 shows the evolution of agricultural production for the main crops between 2007 and 2012. For both periods the number of households growing a particular crop and the average production per household conditional on cultivating that crop are given. The former is a proxy for the extensive margin because if more households planted a certain crop in 2012 compared to 2007, some households must have decided to devote at least one new field to this crop. The second variable is a proxy for both the intensive and extensive margins because households can increase production through increasing the area assigned to a particular crop or through increasing labour efforts, or the use of other inputs such as fertilizer.

Table 5. 8: Evolution of production for the main crops between 2007 and 2012

	2007		**2012**		
	Average production (kg)	% of households growing this crop	Average production (kg)	% of households growing this crop	Difference between average production
Banana	4084	95	3190	98	-894***
Beans	145	95	254	98	109***
Cassava	461	62	389	59	-72
Coffee	439	63	258	55	-181***
Ground nuts	63	8	50	11	-13
Peas	24	15	24	26	0
Potatoes	225	41	284	40	59
Rice	177	39	159	45	-18
Sweet Potatoes	1050	92	880	95	-170***

Symbols indicate significant differences at ***: p-value ≤ 0.01, **: p-value ≤0.05, *: p-value ≤ 0.10

It is remarkable that the average production of beans per farm increased considerably from 145 kg in 2007 to 254 kg in 2012, while the number of households that cultivated beans also increased slightly. In both periods, more than 95% of the households cultivated beans which is one of the main staple crops in the Burundian diets. These results are in line with the model. In both scenarios I and II the model predicts that households should specialize in bean production because this crop has a high price/nutritional value and can be grown efficiently.

The average production of cassava and groundnuts decreased between 2007 and 2012, although the difference is not significant at a 10% statistical significance level. This evolution contradicts the findings of the model because cassava production was expected to increase according to scenario I and production of groundnuts should increase according to scenario II in which all households cultivate groundnuts because of its high nutritional value.

According to the model, the production of sweet potatoes and peas is not profitable for any of the farm types, while the production of potatoes is only profit maximizing for small and landless farmers in scenario I. Between 2007 and 2012 sweet potato production declined significantly, but it remained a very important staple crop for most households with an average production of 880 kg in 2012. Hence, this marked reduction is in line with the model. The production of peas remained however stable, while the number of households that cultivated peas increased from 15% to 26%.

Total rice production remained relatively stable between 2007 and 2012, but the number of households cultivating rice increased from 39% to 45% and the average production per household decreased slightly. This result is also not surprising because rice can only be cultivated in some parts of the wetlands and the scope for an increase in production is therefore limited. Wetland is not considered in the model as a separate input for rice production. This explains why, according to scenario I, all households should increase rice production which is probably not feasible in the short run given the non-availability of irrigation. We should recognize this as a clear limitation of our model. Additional properties and constraints such as soil quality and access to water should be added to account for the limited potential of rice production. We also might speculate that the profitability of rice production as predicted by the model increases the competition for the wetland suitable for rice production. It is worth noting that land allocation in wetlands is based on a complex traditional governance system. The banana production decreased dramatically between 2007 and 2012. This is probably not due to farmers' choice to reduce the number of banana trees, but rather it may be the effect of the *Xanthomonas wilt* a banana disease that affected many trees in the region and resulted in a sharp loss of production (Tripathi & Tripathi, 2009). Evidently, the model did not take this unexpected shock into account and did therefore not predict the recent evolution of banana production.

Coffee production in Burundi is biannual with an excellent harvest in 2007 and a bad harvest in 2012, which makes the interpretation of the reduction in average coffee production between 2007 and 2012 difficult (International Coffee Organization). There is however some suggestive and anecdotal evidence that farmers reduced the number of coffee trees and are no longer willing to invest in new trees because of the low local prices. In our sample, the number of households that cultivated coffee decreased from 198 in 2007 to 174 in 2012.

A second way to assess whether the households indeed behaved as predicted by the model is to investigate which crops were planted on fields newly acquired between 2007 and 2012. New fields often need extra initial investment and are initially more labour intensive than fields that are already a long time in the household. It is therefore reasonable to assume that a household will only be willing to buy fields and invest time, money and energy in those new fields if they are certain to make a profit over time. Table 5.9 shows which crops have been planted on the newly acquired fields.

Table 5.9: Main crops planted on new fields

Crops	percentage
Beans	31
Cassava	28
Banana	15
Reforestation	8
Coffee	7
Other	11

Eighty-seven households bought at least one new field between 2007 and 2012. These fields were mainly used to cultivate beans (31%), cassava (28%) and bananas (15%). Only 7% of the households planted coffee on those new fields or might have bought them already bearing coffee trees. The choice for beans and cassava corroborates the model predictions. The empirical evidence that confirms the reliability of the model is therefore mixed. The increase in bean production, decrease in sweet potato and coffee production and crop choice for new fields are in line with the prediction of the model. But, the limited decrease in cassava production and increase in pea production were not predicted by the model.

5.4. Conclusion and perspectives

Like most African countries, Burundi's agricultural sector is mainly dominated by small-scale farmers. These farmers produce for subsistence purposes on highly fragmented lands using very little inputs. Yet, the low input level, lack of market orientation and limited exchanges between farms have negatively affected land and labour productivity. With the current farm practices, more than half of the farming population is unable to satisfy their household food needs. Moreover, the options for livelihood diversification out of agriculture for these small farms are very low and limited to low paid irregular jobs on other peoples' farms or businesses. This has led to a rapid deterioration of the country's food security situation.

Nevertheless, despite the rampant land scarcity, our models show that it is still possible for households to find optimal crop combinations that could meet minimal food security requirements while generating a certain level of income, except for landless households. By growing specific ranges of crops, farmers can benefit from an optimal land use that further contributes to improved farm output and to rising opportunity costs of family labour. At the optimal level of production, farmers with different resources and capabilities are likely to adopt different activities. By producing crops in which the farms have comparative advantages and trading, large and medium farms get better off and are willing to hire in extra hours to complement family labour which exerts a strong demand in their neighbourhood. On the other hand, the model highlighted that the optimum resource combination for agricultural production was not possible in nearly landless farms. They, have to rely on labour market in order to fulfil the household basic need. Therefore, any policy toward improving off-farm activities and labour market might improve the living conditions in these farms with a limited access to land.

The implications of our results are that at local level, there is scope for specialization, improved farm output and more intra-rural exchanges between farms. According to Hazell and Wood (Hazell & Wood, 2008), as per capita incomes rise, labour becomes more expensive relative to land and capital, and small farms may get squeezed out by larger and more capitalized farms that become better placed to compete. Therefore, the former farm group should exploit their comparative advantages (available labour in the household) and benefit from the increasing off-farm employment opportunities.

Although the model has several flaws due to simplifying reality, it is surprising that a straightforward model yields remarkable accurate results and enables to predict some general trends in farmer decision making on crop choices. The model seems to predict rather accurately how farmers choose crops that are either of high market or nutritional value, or that are relatively undemanding in terms of inputs. Even in absence of specific specialization policies, and in the presence of food insecurity and risk, farmers seem to act as optimising agents. More detailed optimisation models are therefore a valuable tool to investigate the main bottlenecks for agricultural production and to investigate the opportunities of increased specialisation between farm types.

Chapter 6:

Risk, intensive traditional farm practices and household food security, a triple challenge in small-scale agriculture in Burundi

Abstract

Farm households in Burundi suffer from food insecurity, poverty and the uncertainty of whether they will be able to produce enough food to feed themselves. This study analyses the impact of this risk on agricultural practices and food security in subsistence oriented farming communities in Ngozi, a northern province of Burundi. A mathematical programming model was applied to four typical farm types in order to predict farmers' decision-making in this uncertain setting. Monte Carlo simulations were applied in a model that used household survey data collected in 2010. Three different scenarios were run; a model without uncertainty, a risk bounded one, and one that accounted for existing food storage constraints. The objective function of the models was the minimization of household food shortages. Our findings show that all farm types adopt multiple cropping systems in order to minimize yield variability and that number of crops grown increase with the level of risk in the farming system. Yet, the results suggest that the household food security situation could improve if farmers planted a more limited number of crops in an optimal combination. Finally, we also show the impact of having basic storage which also improves food availability.

Key words: risk, crop choice, food storage, food security, small-scale agriculture, Burundi

This chapter is based on:

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The leading author coordinated the data collection by the enumerators of the University of Burundi in the framework of a VLIR-UOS project. He did the literature search, conceptualised the model with the help of Professor Jeroen Buysse, and wrote the chapter. The co-authors (promotors) helped with revising the text and improving the structure.

6.1. Introduction

Despite increasing interest among policy makers towards alleviating poverty and food insecurity, as inscribed in the Millennium Development Goals and Sustainable Development Goals (WorldBank, 2007; Ecker and Breisinger, 2012), more than 70% of people living in rural areas of poor countries are at risk of food insecurity (FAO, 2014). Notwithstanding efforts and policy declarations such as the Maputo Agreement (2003) that urge donors and governments to allocate at least 10% of the national budget on agriculture in African countries (Poulton et al., 2014), the continent has the highest prevalence of undernourishment, with around an estimated one out of four people to be undernourished (FAO, 2013b). Multiple sets of binding constraints limit the agricultural growth that is needed to reduce food insecurity and poverty on the continent (Adesina, 2010). Improved agricultural technologies are needed to overcome these constraints and develop sustainable rural livelihoods (Cunguara and Darnhofer, 2011); but the rates of diffusion and adoption of these techniques have fallen short of expectation (Barrett and Place, 2002; Worldbank, 2007).

Certainly, part of the failure of large scale development and implementation of improved agricultural techniques is due to the lack of complementary public investments (e.g. in rural infrastructure) (Barrett and Place, 2002). Yet another reason may (still) be the limited understanding of the drivers of agricultural decision making amongst the poorest farmer groups, and in particular the responses to uncertainty. There are few empirical studies on current rural practices and technology adoption for many regions of Sub-Saharan Africa (Lambrecht et al., 2014). Arguably, much research has focused on finding better agricultural practices that can close the gap between what smallholder farmers produce and what is feasible with the available technology (Muzari et al., 2012). Yet, the adoption of new practices might be problematic as farmers can be reluctant to adopt these technologies in the face of risk. In this chapter, we seek to model how farm decision making is affected by risk in subsistence agriculture in Burundi.

Risk is among the key determining factors that shape farmers' decision-making in agricultural production especially in developing countries (Anderson, 2002; Khan, 2008; Aggarwal et al., 2010; Bundervoet, 2010). The weak institutional and political settings undermine smallholder farmers' access to insurance mechanisms and other risk management tools, which results in a high reliance on informal and community based strategies (Dercon, 2000; Cervantes-Godoy et al., 2013). Such strategies include a more risk-averse investment behaviour which is reflected in decisions over crop choice, early or late maturing varieties, seeding rates, levels of fertilizer, and other agricultural inputs used (Pender and Ruben, 2004; Khan, 2008). Poor famers tend to allocate a larger share of land to safer, traditional varieties rather than to riskier high-yielding varieties. In mixed farming systems, they often combine several crops on one single plot along with some livestock production and off-farm activities, where these are available (Baghdadli et al., 2008; Cervantes-Godoy et al., 2013). They opt for farming and livelihood strategies that provide the best guarantee of survival, using technologies that allow flexibility in resource allocation and an activity mix that is adapted to local circumstances (Pender and Ruben, 2004). As such, high risk and uncertainty lower the returns to land and labour because they affect farmers' willingness and ability to invest (Pender and Ruben, 2004), and this contribute to the persistent poverty in most development countries (FAO, 2014).

Several studies have used mathematical programming models to study farm practices and to suggest an optimum farm plan in less favoured areas; see e.g. (Ndimira, 1991; Glen and Tipper, 2001; Hosu and Mushunje, 2013). Some models used opportunity costs to estimate the likelihood of on-farm adaptation of different activities (Hazell and Norton, 1986). Yet, scholars investigating optimum production have often focused on profit maximization (Dercon, 2000; Osaki and Batalha, 2014) and only few have incorporated risk. When risk is ignored, the model outcomes highlights the optimum combinations with the highest returns but fails to differentiate strategies that carry unacceptable risk levels (Osaki and Batalha, 2014). Poor farm households depend on subsistence agriculture in which production and consumption are intertwined. Modelling the behaviour of these rural households in the context of market failures implies that production and consumption decision are non-separable (Janvry and Sadoulet, 2006). Subsistence farmers may accept some uncertainty at the time of planting, but they will aim for a certain minimum production to cover their subsistence needs. This behaviour can best be studied by safety-first type of models (Simbizi, 1996). One particular type of risk is the loss of food due to lack of adequate storage. Post-harvest losses are very high in the most vulnerable tropical regions, yet little is being done to develop appropriate storage systems to preserve harvest produce (Aidoo, 1993). Over the past 30 years, almost 95% of all research investments have focused on increased productivity while only 5% was devoted to food losses (Costa, 2014).

Against this background the overall goal of this study is to investigate the optimal crop combination needed to raise the level of household food security in small-scale farms in the context of widespread risk averse behaviour and the limited food storage facilities of Burundian households. The absence of credit, insurance markets, storage facilities and social security schemes, see for e.g. Baghdadli et al. (2008) pushes subsistence farmers to hedge against risk through crop diversification and to adopt mixed farming systems that often only produce a bare minimum level of food. To the best of authors' knowledge, very few models have incorporated both risk in production and traditional storage in mathematical simulations. This allows us to assess the importance of food storage systems in poor peasant agriculture.

The realities facing Burundian farm households means that the need to protect oneself against risk dominates farmers' decision-making processes (Cochet, 2004; Bundervoet, 2010). This hinders farmers from optimizing farm production and commercialization. This chapter examines the crop combinations that could increase production given the available resources and technology and accounting for household subsistence needs. It also asks if there is any link between a farm household's asset endowment and its adoption of activities that represent risk mitigating behaviour. Finally, it asks how improved storage systems could affect smallholder farmer households' food security and improve rural livelihoods?

To provide an answer to these questions, we developed a mathematical programming model which was applied to four representative farms types purposely selected to reflect the diversity of the farming systems in Burundi. The model determines the optimal crop combination by minimizing the total food nutrient shortfall at the household level using Monte Carlo simulation which characterizes risks and uncertainty. A model without uncertainty calculates the crop combination that minimizes food shortages to the household that does not take potential fluctuation in yield into consideration. The risk bound scenario explicitly takes into account differences in yield variability between the different crops. A third scenario calculates how the availability of food storage facilities could mitigate the food shortages during certain times of the year. This is critical because Burundian farm households mostly suffer from food insecurity during the lean periods preceding the harvest.

A Monte Carlo model was developed to simulate variability in yields of different crops. The Monte Carlo simulations use statistical distributions that enabled us to calculate different kinds of risk and to generate estimates of the likelihood of each outcome (Jones et al., 2009). Production varies over time under the influence of numerous factors (e.g. weather conditions, market inputs, agricultural pests, etc.) which are difficult to quantify separately or for which to accurately define parameters. Given insufficient data and much uncertainty on real figures in the agricultural environment, the Monte Carlo procedure is an appropriate tool to capture missing and or highly uncertain parameters (Lauwers et al., 2010). Following the recent findings that decision-making on production patterns is strongly influenced by farmers' experiences in previous years (Huang et al., 2014), the model's computation of risk was based on variations in yields observed over a period of 23 years[41]. The programming model was formulated using the General Algebraic Modelling Systems (GAMS) software packages.

This chapter contributes to the scientific literature because it is the first, to our knowledge, that combines strategic household production decision making given production constraints in a mathematical programming model with different nutritional target as objectives with yield variability modelled using Monte Carlo analysis in the context of households in developing countries. The combinations of approaches results in a multiple criteria stochastic dynamic programming model with one time period decisions applied on different individual household types.

This chapter is structured as follows: in the next section, we briefly describe the study background. Section 3 provides details of the characteristics of the study area, the sampling methodology, the data processing and the GAMS model specification on farmers' activities and household food security. Section 4 presents and discusses the model results. The final section (5) draws conclusions and highlights some limitations of the study.

[41] FAO statistics: http://faostat.fao.org/site/339/default.aspx

6.2. Study background and data

6.2.1. Risk and income source diversification

In Burundi, households adopt livelihood strategies to suit their asset endowments taking into account the constraints of market failures and their exposure to uninsured risks. Their main source of household income has traditionally been sales of crop and livestock products, but faced with an absence of public insurance or stabilization programmes, farmers have devised methods to reduce income fluctuations from both farm and non-farm income sources to acceptable levels (Niragira,2011). Combining crops has become almost systematic and very complex. In addition, off-farm and non-farm income in Burundi have increased in importance over the recent decades. In particular, young farmers with small agricultural holdings look for work on other people's farms or outside agriculture (Verhaegen et al., 1991; MINAGRIE, 2013). That is because in case of a crop failure, the family's income can be sustained in the short-run through having diverse incomes. Wealthier households engage more in growing cash crops and in non-farm self-employment and less in low-paid unskilled agricultural wage labour (Bundervoet, 2010). Given the surplus of unskilled people on the African rural labour market, agricultural labour activities are badly paid and only taken up by poor households (Reardon, 1997). Richer farmers decide on the wages they pay for rural labour taking into account the uncertainty of their production settings (Niragira, 2011).

Yet, despite the low level of payment, labour income can be considered 'safe', since it is paid-for-work that does not involve any risky investments (Bundervoet, 2010). Earning income from outside the farm may also be complementary to on-farm work as it allows farmers to keep their family land for basic subsistence production and maintain their social identity (Verhaegen et al., 1991). Field observations suggest that off-farm revenue is not reinvested into the farm to improve the production system. In most cases, as described by Ndimira (1991) and still valid today, after more than 25 years, surviving continuing what was done in the past, wage income is no more than a way to earn money to buy food (and secure a balanced diet), to renovate the family house or to buy a small plot of land, with no goal beyond simple household survival.

6.2.2. Data processing

This study was conducted in Ngozi, a province located in the North of Burundi. Household data on farm activities was gathered in three survey rounds in 2007, 2010 and 2012. A cluster analysis was performed based on variables that are indicative of agricultural trajectories and the strategies employed by farmers in sustaining household survival, which are, at the same time, linked to farm characteristics. Details on the sampling procedure, data processing and rationale for selecting the study area can be found in sections 5.2.2 and 5.2.3.

6.3. Model specification

The level of complexity in the farming system of Burundi makes it notoriously difficult to study and model farmers' behaviour. In this model, for simplicity's sake, activities are limited to food crop production, despite the diversity in farm households' livelihoods. We do not underestimate the importance of coffee as a cash crop or of livestock as an additional farming system, yet we decided to focus on food crops because these are important for food security. The crops considered are food crops all of which are widely grown for subsistence purposes in mixed cropping (see 5.2.4). The food security levels were estimated in terms of calorie and food macronutrients with energy, proteins and fats being evaluated against the households' needs. The model considered three types of inputs: land, labour and capital, with the latter being the monetary investment in farm production during each cropping season of the reference year.

Farmers have to deal with many risks from different sources, production, market, financial and institutional risks. Risk management involves choosing between alternatives that reduce deviations to the preferred combination of activities. As most risk outcomes are often continuous rather than discrete (e.g. prices and yields), a statistical dispersion of distribution, such as the variance (V) or standard deviation (SD) is often used as a measure of riskiness (Kimura and LeThi, 2011). It is therefore common to abstract risk as the link between the dispersion of outcomes (V or SD) and the average mean or expected value E = E[X]. Building on this notion, some authors have found it convenient to express risk using the coefficient of variation CV = SD/E (Caddad et al., 2010). We followed this and calculated the coefficient of variation in yields for all crops introduced in the model using FAO data on agricultural production between 1990-2012.

Finally, the model captures four considerations that farmers take into account when allocating resources among different activities:

(a) the household's food and nutritional needs;
(b) the auto-consumption and minimizing food purchases;
(c) the self-sufficiency in production factors where farmer seeks to limit as much as possible, the use of external inputs, and;
(d) the level of risk that farmers would be exposed to if things turn out badly.

The model can be summarized as follow:

$$Min\ Z = \sum_{klh} \emptyset_{klh} \quad (1)$$

$$\emptyset_{klh} = \sum_{r} \frac{\delta_{klhr}}{R_{klh}} * 100 \quad (\textit{for all } r = 1,2,3, \dots ,100)$$

Subjected to:

$$\sum_{j} I_{ijk} X_{jkl} \leq Q_{ikl} \quad (2)$$

(for all i = 1,…,n; k= 1,2,3; and l = 1,2,3,4)

$$\sum_{jk} N_{jh} X_{jkl} \theta_{jkr} \geq R_{hl} - \delta_{hlr} \quad (3)$$

$$\sum_{j} N_{jh} X_{jkl} \theta_{jkr} \geq R_{hkl} - \delta_{hlkr} \quad (4)$$

$X_j \geq 0$ (for all *j* = 1,...,*m*)

Where:

- X_{jkl} : the quantity of crop *j* produced in season *k* in farm type *l* (kg)
- I_{ijk} : the quantity of input *i* necessary to produce 1kg of crop *j* in season *k* (USD, hours and ha)
- Q_{ikl} : the quantity of input *i* available in season *k* in farm type *l* (USD, hours and ha)
- N_{jh} :the nutrient content[42] h of 1 kg of crop *j* (g, kcal)
- δ_{klhr} : The food nutrient *(h)* shortage in period *k* for household type *l* (g, kcal)

[42] *Calculations of nutrient content are based on FAO's table: Agriculture, food and nutrition for Africa* http://www.fao.org/docrep/W0078E/w0078e11.htm#P9840_707166

- R_{hkl} : the minimum food nutrient *h* required in season *k* for household type *l* (g, kcal)
- $\emptyset_{kh}$: the percentage food shortages of nutrient *h* in household *l* and season *k*
- θ_{jkr} : the coefficient of variation in production of crop *j* in season *k; r* indicates that the model will randomly select one hundred (100) scenarios of possible combinations of activities in simulation.

X_j : the level of farm activity *j, m is* the number of activities and *n* the number of input types

The model minimized food shortage (Z) at the household level (equation 1) with respect to production using the available resources (labour, land and capital) at the farm household level (equation 2). Food shortfall was defined as the calculated household food requirement (R) deducted from the simulated farm production (in percentages). Production varies over time under the influence of numerous factors (e.g. weather conditions, market inputs, agricultural pests, etc.) which are difficult to quantify separately. For simplicity, the variations observed in yield over the last 23 years (1990 to 2012) were entered into the simulations. We argue that yield fluctuation is the most important risk factor for households when it comes to food security. As farmers' experiences largely determine the production patterns, we assume that these variations can provide an indicator that is likely to shape the farmers' decision-making. This might be one of the model's limitations, which we discuss in the final section.

Finally, the model simulated three scenarios: the first scenario considers farm produce can be consumed by the household during the course of the year (equation 3). However, this can be misleading since many agricultural commodities are perishable and need to be consumed immediately or few weeks after the harvest. This raises the issue of seasonality in household consumption (equation 4). The third scenario aimed to capture the specific storage time of commodities in the household consumption model (equation 5). The lack of adequate storage facilities and conditioning services complicates post-harvest handling. Agricultural produce is mostly consumed fresh and the surplus is sold at low prices immediately after harvest. The traditional method often used to lengthen shelf life is drying the produce in the sun and storing it in bags, barrels and baskets for some months. Some staple food crops, such as sweet potatoes, are prone to heavy losses, of up to 50% of the quantities harvested (NEPAD and FAO, 2006), which greatly contributes to rural household food insecurity. This was incorporated in the model by assigning each crop with the specific storage time of commodities.

The model on storage time and consumption of commodities is summarized as follows:

$$Min\ Z = \sum_{hlt} \frac{\varphi_{hltr}}{(R_{hl}/12)} * 100 \quad (5)$$

Subjected to:

$$R_{hl/12} \leq \varphi_{hltr} + \sum_j \omega_{jltr} N_{jh} \quad (6)$$

$$\omega_{jltr} + \mu_{jltr} \leq \pi_{jltr} - \rho_{jltr} + \rho_{jlr(t-1)} \quad (7)$$

$$\pi_{jltr} \leq \sum_\tau \omega_{jltr} + \sum_\tau \mu_{jktr} \quad (\textit{for all } t = 1,\ldots,12) \quad (8)$$

Where:

φ_{hlt} : the shortage of nutrient *h* in farm type *l* and month *t,*

ω_{jlt} : the quantity of crop *j* consumed in household type *l* and month *t,*

μ_{jlt} : the quantity of crop *j* not consumed in household *l* and month *t,* reached storable limits (*waste)*

π_{jlt} : the quantity of crop *j* produced in the farm type *l* in month *t,*

ρ_{jlt} : the quantity of food crop *j* stored in farm type *l* in month *t,*

τ *:* the factor of order in food consumption taking into account the specific storage time of commodities.

6.4. Results and discussion

6.4.1. Farm types and their characteristics

Some background information permits a better interpretation of the results of the models that follow in the remainder of the chapter. Farm households differ in their individual characteristics and livelihood patterns. We distinguished four clusters of farm groups with similar characteristics. This allowed us to conduct the analysis and to formulate recommendations for farm types rather than individual farms (section 5.3.1.1 provides more details on characteristics of the clusters).

Table 6.1 gives the socio-economic and production characteristics of the representative farm households.

Table 6.1: Major characteristics of the representative farms

Characteristics	Units	Large farms (12%)	Medium farms (20%)	Small farms (38%)	Nearly landless farms (30%)
Age of farmer	years	51	58	55	42
Farm size	hectares	2.69	1.43	0.73	0.42
Agricultural active workers	persons[α]	3.50	3.25	3.50	2.50
Number of coffee trees	scalar	450	300	345	126
Number of plots	scalar	12	10	7	6
Number of crops	scalar	11	9	8	5
Labour used in agriculture	hours	4 830	3 835	3 740	3 150
Labour hired (+in/-out)	hours	(+)272	(+)189	(-)140	(-)685
Agricultural investments	USD/ha	40.91	45.11	78.43	57.07
Annual farm production	USD	1 161	951	665	220
Annual non-farm income	USD	387	196	172	269

[α]: Some family members work part time on the farm, therefore decimals are used to capture their contributions

Table 6.1 provides a snapshot of the structural and operational conditions of the representative farms during the 2010 cropping year. Large and medium farms own more land and livestock than the other households in the sample and are therefore likely to hire in extra labour, especially during the main cropping season (B). They also have more economic capital. Small and nearly landless farm categories include mainly farmers with limited access to land and low levels of livestock ownership. They prefer to diversify in waged daily labour to complement their low income from agriculture. Wealthier farms also diversify in non-farm income and invest in more income-generating activities, especially trade. For them, income diversification is a choice, in contrast to the poorer farmers whose diversified incomes are a matter of necessity. The share of non-farm income is very high on landless farms, with almost 57% of farm revenue coming from outside the farm. The level of investment is very low in all farms, at an average of only 55.38 USD yearly per hectare of landholding.

6.4.2. The optimum crop combination

As mentioned above, in terms of food security, the optimum farm production is the one that minimizes the household's food energy and nutrient shortfalls. The models show that the number of crops increases when risk was taken into consideration. Table 6.2 highlights the main crops selected for each farm category for both the model without uncertainty and risk-bounded scenarios.

Table 6.2: Crops produced with optimum farm planning

Optimum situation	Large (12%)	Medium (20%)	Small (38%)	Nearly Landless 30%)	Average farm
Without yield uncertainty	Banana Beans Groundnut	Beans Groundnut Rice	Bananas Beans Cassava Groundnut	Bananas Beans Cassava Groundnut	Beans Groundnut Rice
With yield uncertainty	Bananas Cassava Groundnuts Maize Soybeans	Bananas Beans Groundnuts Maize	Bananas Cassava Groundnut Maize Peas Rice Beans Soybeans	Bananas Beans Cassava Groundnut	Bananas Beans Cassava Groundnut Soybeans

In the model without uncertainty, large farms can optimize their production by combining three crops, in the risk-bound scenario it takes a combination of five crops to achieve a level of food security. A similar pattern can be observed among all four farm categories, except for nearly landless farm households. Medium sized farms should grow one additional crop to secure their minimum household survival when risk is accounted for. The number of crops to be grown doubles (from four to eight crops) in small farms and increased by 66% (from three to four) on medium sized farms when risk factors were taken into consideration. Near landless farms showed a different pattern; they mostly depend on labour income, which makes up to 57% of overall household income. Therefore, reallocating the resources they currently have does not have a major impact on farm production plans.

It was expected that wealthier farmers might be willing to invest more than poor households in risky activities with a higher return. However, we found no significant differences between farm types in their adoption of more or less risky crops. These results confirm previous findings from the Mugamba region of Burundi by Simbizi (1996), who highlighted (many years ago) that farmers need to realign their production activities, since the realities of their economic and technical performance do not necessarily fit well with their production factor endowments.

6.4.3. Optimum farm planning and land use under risk

Factoring in uncertainty did change the way land is currently allocated to each crop (table 6.3). Bananas would be grown on all farms, and would account for much of the land. The growing importance of bananas in Burundi in recent decades has been described by Cochet (2001): they are an important source of food and income for small-scale farmers (Rishirumuhirwa and Roose, 1998).

Note that the land area presented on a yearly base (table 6.3) is higher than the available land. This is because we account and sum the areas in production during two cropping seasons, sometimes complemented with irrigated cropping in the marshlands. According to the optimal farm plan predicted by our models (table 6.3), all households should increase the intensity of their land use except for large farms where only 80% of the land is used for food crop production. Intensification levels are higher with a decrease in farm size.

Table 6.3: Choice of crops and levels of land use

Crops	**Annual land area used per farm type (ha)**			
	Large farms	**Medium farms**	**Small farms**	**Nearly Landless farms**
Bananas	1.04	0.98	0.43	0.09
Groundnuts	0.60	0.23	0.02	0.15
Soybeans	0.01		0.04	
Cassava	0.08		0.08	0.08
Maize	0.40	0.32	0.12	
Beans		0.15	0.09	0.32
Peas			0.09	
Rice			0.04	
Total used (ha)	**2.13**	**1.68**	**0.91**	**0.64**
Farm size (ha)	**2.69**	**1.43**	**0.73**	**0.42**
Land use intensity	**80%**	**117%**	**125%**	**152%**

6.4.4. Explaining farmers' objectives and on-farm crop choices

The survey identified 15 crops as being the main on-farm activities in the region. In general, all farm types grow a wide range of crops in order to minimize yield variability while maximizing output diversity, giving a minimal nutritional shortfall. Farmers probably prefer to secure autonomous household consumption due to the unreliability of the food market, consumption preferences and their attitude to risk. The observed (current) practice shows that farmers adopt as many crops as their available land allows them to grow. This results in large farms growing more crops. Moreover, they may be exposed to more risk as the larger the farm is, the bigger the loss from a failed harvest could be (Huang et al., 2014). Figure 6.1 compares the number of crops calculated by the model in an optimum plan with current practices. The models suggest that farms could benefit from producing fewer different crops.

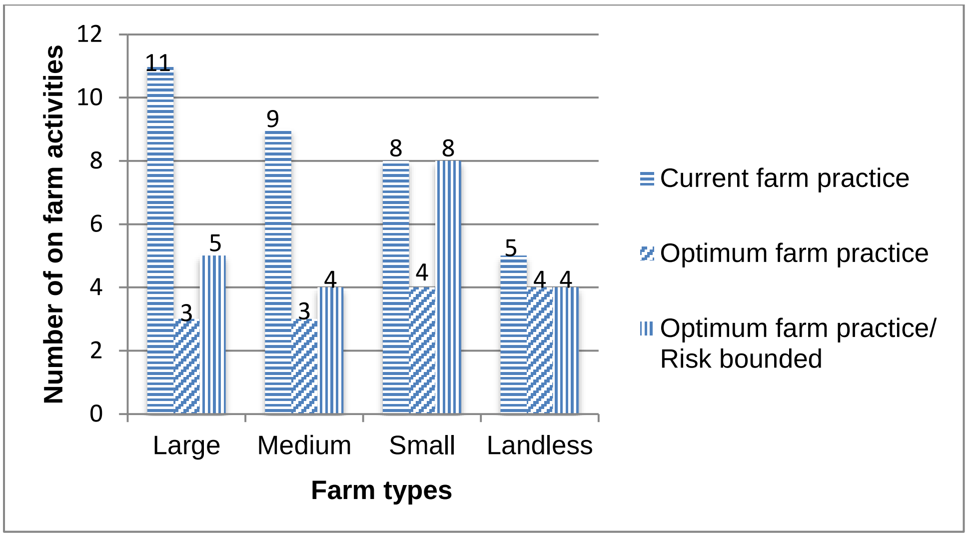


Figure 6.1: Farm objective and crop choice

If farmers, especially large and medium farms, were able to manage risk, they would be better off specializing in a smaller number of crops. Yet when the risk of yield variability is a factor to be considered, the results suggest farmers, except for those who are nearly landless would be better off growing a larger range of crops. The land area available to near landless farmers is too small to allow them to cultivate more than five crops and to secure food security they would need to grow at least four crops.

6.4.5. Explaining crop choices from a nutritional point of view

Our objective was to search for a strategy that would minimize the shortfall in energy and food macronutrients (proteins and fat) from domestic production. We recognize that these three elements only capture a limited part of the household's nutrition security and that we did not consider other necessary micronutrients, such as vitamins and minerals, and that we did not include food consumed from animal origin. However, the consumption of animal based products is very limited in Burundi: annual meat consumption in Burundi is estimated at 3 kg per person per year (Speedy, 2003) while consumption of milk and eggs is negligible. Table 6.4 shows the shortfall in satisfying household food needs from the crops produced in each category of farm.

Table 6.4: Farm household food shortfall

Food intake	Food shortage per farm type (%)				
	Large farms	Medium farms	Small farms	Nearly landless farms	Average farm
Energy	0	0	10.20	38.23	0
Proteins	0	0	6.23	15.50	0
Fats	0	6.89	11.03	41.01	0

The results in table 6.5 suggest that, at the simulated optimum farm production, and despite the risky environment, large and average farms should be able to fulfil their household food needs in terms of calorie and macro nutrients. Medium farms can still be considered to be food secure as only 6.89% of recommended fat intake was lacking. Small farms were relatively food secure as they could cover around 90%, 94% and 89% of the energy, proteins and fat requirements respectively if they adopted the optimum farm plan. However, nearly landless households were unable to cover their food needs. Their production would fall far short of their energy, protein and fat requirements. This scenario suggests an overall food deficit of 5.3%. These results corroborate with an FAO report that Burundi is potentially self-sufficient in food production. The country has resources needed to produce sufficient amounts. It has abundant rainfall allowing three cropping seasons, a wide range of agricultural products, abundant labour, substantial hydrological network (lakes and rivers), and potential market expansion (FAO, 2015).

6.4.6. Adding seasonality to the equation

Food shortage problems are seasonal, especially for farmers who depend on rain-fed agriculture. The seasonal nature of agricultural production causes variations in consumption and nutrition, particularly in countries like Burundi where storage facilities are scarce. All crops respond to climatic conditions and, as a result, consumption patterns often follow agricultural cycles. There are excesses in food production in one harvest season (e.g. season B), but since some produce cannot be stored and consumed during subsequent cropping periods it cannot be considered as available for household consumption. It is common to find farm households suffering in the lean seasons, when consumption is low (the periods between harvests) especially in November, March and April (appendix 6.2). Table 6.5 illustrates how nutrient shortages increase when seasonality is taken into account. The model is recalculated by each season and assumes that food is not stored nor transferred from one season to the next.

Table 6.5: Total food shortfall with seasonality of production/no storage taken into account

Food intake	Food shortage per farm type (%)				
	Large farms	Medium farms	Small farms	Nearly landless farms	Average farm
Energy	0.24	16.74	19.39	38.32	1.22
Proteins	0.00	0.07	30.40	30.22	2.45
Fats	10.34	22.42	32.12	43.81	29.07

The model suggests that when cropping seasons are considered separately, all farm categories experience food shortages with fats being the main shortfall. An overall food shortage of 18% was calculated. The third (or dry) cropping season when only wetlands and irrigated valleys are cultivated is very critical. During this season almost all farms are faced with an acute scarcity of cultivatable land. By contrast in the main cropping season (B) almost all farm types can produce enough food to meet household needs except the near landless farm. The first season (A) is productive, but volumes are low compared to season B.

6.4.7. The impact of inter-annual storage on household food security

Effective post-harvest handling plays an important role in stabilizing food availability at the household level by smoothing the seasonal food supply. Farmers in Burundi rely on traditional storage systems to store part of their harvests for future consumption needs and for seeds, and for their liquidity needs by selling the remaining part of the stocks. Yet, most commodities can only be stored for a few weeks/months (or sometimes up to one year). Table 6.6 shows households' nutrient gaps when the model factored in storage and the consumption of crops across seasons.

Table 6.6: Traditional storage and household food security

Food intake	Food shortage per farm type (%)				
	Large farms	Medium farms	Small farms	Nearly landless farms	Average farm
Energy	0.00	12.18	10.20	38.24	0.00
Proteins	0.00	0.06	6.23	15.81	0.00
Fats	0.00	7.85	11.10	41.25	3.09

Traditional storage allows farmers to smooth consumption and attenuate food shortages to a certain extent. Large farms can easily meet their minimum food energy and nutrient requirements while medium and small farms can significantly reduce food shortages. Storage will not solve the food shortages on nearly landless farms. The quantities produced on these farms are already small and what is produced is likely to be consumed right after the harvest. A small decrease in shortfalls 9.8% is observed when comparing seasonal food shortages (18%) without storage (appendix 6.1).

Another point to note is that storage systems tend to spread the food shortage over the year, which attenuates the severity of hunger during the lean periods (appendix 6.2). Thus, storage facilities may offer opportunities to both smooth hunger and improve farm incomes by selling crops at premium prices when demand is higher later in the post-harvest period.

6.4.8. Impact of risk management on farm gross margins

As mentioned above, subsistence farmers are highly risk averse. In their choice of activities, they often prefer to minimize variability in production since they lack safety nets. Yet, risk averse behaviour reduces welfare in the short run as it hinders farmers from targeting production surpluses. Table 6.7 compares the overall gross margin in the baseline situation with that of an optimum farm planning for both without/with uncertainty scenarios.

Table 6.7: Risk and farm gross margins in USD (2010)

Farm categories	Baseline	Without uncertainty	With uncertainty
Large farms	1 160.60	2 496.15	1 472.55
Medium farms	950.79	1 745.90	1 228.48
Small farms	664.63	1 222.41	738.47
Nearly landless farms	219.64	479.84	297.81
Average farm	846.87	2 001.49	889.52

Overall, the gross margins are low. Large farms only earn a gross margin of 1 160 USD per year, medium farms can make up to 951 USD, small farms 665 USD and nearly landless farm 220 USD. The average farm earns 847 USD. However, the optimization model suggests that, when farm activities are rationally combined, the average farm's gross margin can be doubled. However, when risk is incorporated in the model simulation, the increase in farm gross margin is less pronounced (table 6.8).

Table 6.8: Increase in farm gross margins in optimal scenarios (%)

Farm categories	Without uncertainty	With uncertainty
Large farms	115	27
Medium farms	84	29
Small farms	84	11
Nearly Landless farms	118	36
Overall increase	**100**	**26**

Overall farm production could double if farmers were more protected against risk. Similarly, the figures in column 3 of table 6.8 suggest that farmers can still optimize their farm plan in a risky environment, although the increase in overall farm gross margin is low, increasing by 26% on average (table 6.8). However, the increase in the gross margin for the nearly landless farms needs to be interpreted with care. The level of food shortages for nearly landless famers is very high and this may constrain them from optimizing food production. Even in an optimum farm plan, only 55% of their household energy needs will be met by domestic production. Moreover, the small land holding size means that these farmers more dependent on labour than land, and as Verhaegen et al. (1991), warned there is a risk of them becoming progressively marginalized from Burundi's farming systems.

6.5. Conclusions and the study's limitations

This study modelled the impact of risk on both agricultural practices and food security in subsistence-oriented farming communities of a northern province of Burundi. Decisions regarding which crop to grow and how the products will be stored are made under risky conditions while insurance and credit markets are rarely available to rural farm communities. This induces households to manage their production decisions so as to reduce their consumption risk. We ran a mathematical programming model to estimate farm plans that could reduce food energy and nutrient shortfalls and compared the current practice to results of the model without uncertainty and the one with uncertainty.

The results show that farmers' perceptions of risk are the driving force for them adopting multiple cropping. This holds within all farm categories. Rural farmers adapt production decisions to hedge against risk by increasing the number of crops grown as this minimizes production variation and helps to sustain household consumption. No significant differences were found in respect to the crop choices (more/low risky) between farm categories. However, the production levels and gross margins are low, even on the relatively large farms. This reduces the possibilities for investment, and limits the adoption of more efficient techniques.

Even under the severe constraints of land shortage, subsistence production and risk, an optimal land allocation between crops could attenuate food insecurity among farm households, at least to a certain level. However, the solution to food insecurity requires more than optimal agricultural production. While almost three out four farm categories (70%) can potentially satisfy their year round household food needs, the seasonal nature of agricultural production causes seasonal variations in food supply. The results highlight that a reliable storage system is necessary to secure year-round food availability at the household level.

Traditional storage is unable to prevent all post-harvest losses and could only prevent half of the food shortage among households. One viable way to mitigate hunger and poverty would be to adopt optimal farm planning and developing a rural storage infrastructure capable of preserving food. Such infrastructure is currently lacking or inefficient in Burundi. Reduced post-harvest food losses at the farm level might improve family well-being, increase agricultural surplus and, possibly, improve household finances.

The model presented in this chapter gave robust results on the impact of risk on production and of storage on smoothing household food consumption. However, the study has some limitations that warrant further comment. The model accounts for shortfalls in energy, protein and fat supply, but ignores micronutrients and products of animal origin. These micronutrients and livestock products could have been included. This study also does not include the effect of crop perishability on production planning and we do not account for the possible effect of farmers being unwilling to grow perishable crops. On the model itself, the data used to compute yield fluctuation was taken from FAO estimates. These data may be less accurate at the farm household level but were the only data available. We also did not account for market and price risks, and the possible impact of uncertain events. The ideal procedure would be to use a panel dataset to ensure a closer representation of variations in farm yields, but this was not available.

Chapter 7:

General discussion and conclusion

Abstract

This chapter presents the general findings, discusses them and concludes the dissertation with a number of implications for policy making. The research questions and general objectives of the study are revisited. The chapter ends with recalling the limitations of the study and points out the major themes that deserve attention in future studies.

7.1. Research objectives, questions and methodology revisited

Within this dissertation, an analysis is done of the scope for improving rural livelihoods and households' living conditions on small-scale farms in Burundi. The main goal is to gain understanding of the country's agrarian systems and to identify possible trajectories that could improve households' food security levels. Five main data sources were used to assess the evolution in farming systems, the actual facts and possibilities for improvement in farm household living conditions. The study is divided into two parts. Part one consists of three chapters that provide a background on the past and present farming systems based on qualitative research and statistical analysis. This led to the identification of major problems the agricultural sector of the country is facing. In part two, optimisation models compare possible future directions and the current situation of the smallholder farming systems. A household model which optimises resources use, farm practices and activity choices as to achieve household food security in a context of subsistence farming was developed and applied in this study. Farm trajectories are identified that could lead to a more sustainable agricultural production.

7.2. General findings and discussions

The objective of this section is to synthetize and briefly discuss how the findings in each chapter contribute to answering the main research questions put forward in chapter one. The main empirical findings are given in the respective chapters.

RQ1. *What are the major challenges in small-scale farms of Burundi and which mechanisms have been adopted to address these?*

A critical review of literature on the country's rural environment served to provide an answer to this research question. The literature review was complemented by FAO data on area cropped and production which allowed us to assess the evolution of agricultural production against the population growth. A review of the evolution of the smallholder farming systems of Burundi is presented in chapter 2. It shows that farming societies have evolved by adapting their livelihoods to the changing environment, especially the ever increasing population pressure and the related fragmentation and atomisation of the agricultural land. This chapter also highlights the limitations to further adaptations in the farming system. Hence, both Boserupian and Malthusian effects are observed in the farming communities of Burundi. The thesis of Malthus states that land scarcity limits the amount of food available per person, which would result in what is called ‘positive checks’ such as war, starvation or epidemics. Yet, several strategies and adaptation patterns have been gradually adopted by the farmers. Also policy makers have attempted to counter the effect of the demographic pressure on productive resources and to increase agricultural production, even though the impact of these policies has been relatively low.

As population grew, land resources became scarce which induced a search for new technologies and ways of agricultural intensification (Boserup, 1965). Changes of the farming system were mainly initiated by the farmers themselves. Agricultural policies implemented by the government aimed at increasing production and productivity, as well as increasing market orientation. Yet, the technology adoption promoted by the extension services was curbed as it was not well transmitted, and the poor purchasing power of the population limited their access to different inputs. The use of mechanisation was obstructed by the bio-physical environment, the mixed cropping system and the land fragmentation. The plots are difficult to access and plough by tractors. The attempt to stimulate market participation for food crops did not work either. Only for some cash crops food manufacturing factories are operational (sugar factory in Kumoso region, coffee washing stations, tea conditioning factories…).

Indigenous adjustments in land use and management included the exploitation of new mostly marginal land and the adoption of new short-cycle crops which allowed farmers to achieve two to three cropping seasons per year. However, the permanent use of plots resulted in soil nutrients mining and land degradation. Continuous cultivation has limited the time that land is left fallow to regenerate, which is the traditional way to restore its soil fertility. Therefore, farmers initially started to apply manure. Yet livestock numbers fell due to conversion of traditional grazing land into arable land or for housing. Actually, the livestock activities adapted in turn to pressure on land, through changing the free grazing to more zero-grazing livestock systems, and the substitution of cattle by small(er) livestock.

Farmers developed alternative methods to improve soil fertility by recycling biomass and composting. Incorporation of crop residues at ploughing, occasional application of manure and or compost in planting holes, crop rotation, and short fallows are the most observed strategies. Yet, it seems that the farmers’ intensification levels have reached their limits: land is almost not left fallow anymore, grazing pastures were decimated, land is overexploited, soil fertility of the plots has decreased, yields are lower, land is deforested and prone to erosion. As a result, farmer households became even poorer, and experience worsening malnutrition (in line with concerns described by Malthus).

RQ2. What are the current agricultural practices and their subsequent impact on factor productivity, and household welfare?

To assess the current practices in agricultural production, the data from a unique and representative household survey conducted by the Ministry of Agriculture, the statistical service and the Belgian Technical Cooperation, and the World Bank in 2011-2012 was used. The analysis included basic statistics to capture the figures and facts of agricultural production. Second, a robust DEA model was applied to generate standard and bootstrap-bias-corrected technical efficiency scores. Next the correlation between these efficiency scores and household poverty levels was checked. Finally, an instrumental variable approach was used to assess the link between household welfare and efficiency scores. The results show that increasing pressure on land, unreliable food markets and failing policy have triggered the development of risk-averse strategies in smallholder farming systems. Smallholder farmers are characterised by a high rate of subsistence farming and a mixed cropping pattern. Farmers now grow a diverse range of crops including different food crops used mainly for the household's own consumption, cash crops and banana which actually is a semi-cash crop as part is consumed by the household and another part is sold mainly for beer production (Baghdadli et al., 2008).

Farmers differ in managerial capabilities and the way they organise their farming system. Yet, what they have in common is that they are all subsistence oriented, small-scale and they use very little external inputs. The yearly average expenditure on agricultural inputs amounts to 60.19 USD with 23.39USD spent on seeds, 26.23 USD on labour and only 10.57 USD on chemical fertilizers and pesticides. These low levels of investment in agriculture reflect the low purchasing power of the farmers, but also the risk-averse behaviour. This was also stated by Godfray et al. (2012), that farmers may choose to cut on investments as the most rational decision to cope with a risky environment. It was expected that a large number of farmers would nowadays have access to agricultural extension services as these extension officers are located in the respective collines. Yet, only 10% of the farmers interviewed reported to have received an agricultural training and only 38% applied soil conservation techniques. As highlighted by FAO (2015), the weak linkage between research and extension services has led to a low rate of technology adoption. The extension officers, who are poorly trained and not very much motivated, seem to have a limited impact. This is in line with observations made by Nkurunziza and Ngaruko (2005) who described the distrust farmers have in the extension services.

The smallest farms tend to be the most intensively managed and they have relatively high efficiency scores, confirming the traditional Inverse Relationship between farm size and productivity (Schultz, 1964; Wiggins et al., 2010 ; Verschelde et al., 2013). The overall productivity of land and labour is very low. These findings are consistent with the concerns expressed by the International Monetary Fund (IMF, 2014) as low agricultural productivity would significantly hamper poverty reduction in Burundi. While labour productivity is relatively high on large farms (381 USD per worker), it is very low on small farms (193 USD). Even very small farms tend to ‘employ’ large number of people, consequent to less alternative employment for the household labour force, resulting in high underemployment rates on nearly landless farms (Cochet, 2001; Baghdadli et al., 2008; Niragira, 2011). The marginal productivity of labour is almost zero.

The results show that about 75% of the sampled households live on an income below the poverty line. The average poverty gap and poverty severity are estimated at 0.40 and 0.26 respectively. This implies that only 25% of the sample had an income that was sufficient to meet households’ food and non-food needs. Farmers use on average 0.71 hectare of land for agricultural production (0.89 hectare of total landholding). This is not sufficient for a household to live from. Based on calculations for other densely populated regions in Africa, Mellor estimated that around one hectare of land is needed to provide sufficient income to cross the poverty line (e.g. 0.90 ha in Ethiopia) (Mellor, 2014). Land scarcity in Burundi is expected to worsen due to the prevailing inheritance system that keeps on subdividing the paternal farms.

Finally, the results presented in chapter 3 suggest that both consumption and income increase with the size of the landholdings. Most landholdings in the bottom quartile of land size are so small that they do not provide enough income or food for the household to survive. These nearly landless farm households diversify income (with on average 44% of their income coming from off-farm and non-farm sources).

Yet, the wage levels at the off-farm jobs are very low and do not compensate the low agricultural production. Only 32% of the sampled households managed to cross the food poverty line. This is in line with the recent reports that almost 67% of the population live in situation of food insecurity (MINAGRIE, 2011a) and raises true concerns on the small farm viability in these densely populated regions. Although these very small farms are relatively efficient (in terms of input over output measures) in absolute terms they don't produce enough for the household to survive.

RQ3. What are the major determinants of livestock keeping on small-scale farms in Burundi?

Livestock allowed the agriculture to adapt to land scarcity especially as a source of manure. With the extension of agricultural activities on the traditional grazing lands, the livestock sector has faced several challenges which greatly affected the decisions of investing in livestock. Several changes have occurred in livestock keeping including intensification of livestock activities and progressive adoption of small animals especially goats (Hatungumukama et al., 2007a). This chapter used a multivariate probit to estimate the determinants of livestock keeping in Burundi which are determined by the local environment, and households' wealth. Three groups of livestock are distinguished for investment based on the tropical livestock unit: cattle, small livestock (sheep, goats and pigs) and other small livestock (chicken, rabbit, guinea pig).

The results show that farmers with low resource endowments are likely to have small ruminants rather than cattle due to the high maintenance demands of raising cattle. In the lower land quartile (0.16 ha), only 8% of the farmers kept one or more cows while 41% own goats, and 27% were engaged in other small livestock rearing including poultry, rabbit and guinea pigs. Due to the limited access to land, these farmers were not being targeted by livestock rehabilitation programmes. Only farmers with a minimum threshold of land (0.5 ha) are eligible to these programmes. Even relatively wealthy farmers in the densely populated regions are unlikely to keep cattle and switch to smaller animals such as sheep, goats, pigs or smaller livestock, which are less vulnerable to feed shortages or feed of poor quality (e.g; 58.6% and 67.9% of the households in the third and fourth quartile respectively owned goats).

On the other hand, livestock activities shifted progressively towards more intensive practices by keeping animals in compounds and feeding them on 'cut and carry' feeds from the fields and crop harvest residues. This puts limits on the scope for nearly landless farmers to engage in livestock activities (more than 23% of farmers in the lowest land quartile did not keep animals). Also poor market incentives reduced investment in cattle. Households only shifted to cattle if the expected return on investment is sufficiently large.

RQ4. Are there optimal farming methods that are technically feasible, capable to increase productivity and therefore profitable to the farm households?

As mentioned earlier, farmers produced for subsistence purposes on highly fragmented land using very little inputs. With the current farm practices, more than half of the farming population is unable to meet their household food needs. Almost 72% of the sample failed to meet the minimal requirements in terms of fatty acids, 52% failed to achieve the household's protein needs while 30% did not produce sufficient amount of calories. This is consistent with the findings of Ahishakiye (2011) and Baghdadli et al. (2008). Moreover, options in landless farms for livelihood diversification out of agriculture are very low and limited to low paid irregular jobs. Therefore, the off-farm income is unable to improve the food security situation of the households as more diversified households are even more likely to be poor and food insecure. These challenges require radical changes in the way food is produced, stored and consumed by the households which implies measures directed to increase both productivity (of land and labour) and market access (Collier and Dercon, 2009, Eicher and Staaz, 1998; Pander and Ruben, 2004).

A Mathematical Programming model that maximises the annual farm output (expressed in monetary terms) taking into account limited production factors at farmer's disposal (land, labour and agricultural expenditures) and the availability of the sufficient calorie and primary macronutrients for the household throughout the year was applied on data from a sample of 60 farms collected in 2010. The results are presented in chapter 5. The chapter highlights possibilities for households to optimise production for family consumption while stimulating market exchanges in the neighbourhood. In line with Adesina (2010), results suggest that poor infrastructure, high transport costs and perishability of many staple food crops may limit the intra-regional trade and large scale exchanges. Our results propose specialisation in crops choice. Fewer crops that fit the comparative advantages of the farmers could induce trade between farms at closer distance. Agricultural specialisation has been long advocated in Burundi as a prominent tool for agricultural growth (e.g. Bergen, 1986).

This study demonstrated how this reduced number of on-farm activities would affect farmers' consumption and income. While 30% of the farmers in the sample were unable to achieve the household food security, specialisation would have a positive impact on farm output, it would increase the opportunity cost of family labour and have a positive return on agricultural investment. Almost all farmers can double their production, and the opportunity cost of labour increases from 0.64 to 2.8 USD a day. Any additional unit investment in farm expenditures would generate at least 12 USD incremental income.

Specialization actually may not suit the specific case of Burundi farming systems due to the higher risks it would entail due to the unreliability of the markets. Yet, the results showed that a reduced number of crops could stimulate optimal land use that further stimulates trade between farms while raising the income of both producer and labourer. By producing crops for which the farms have comparative advantages (due to the biophysical and socio-economic conditions) and trading options, large and medium farms get better off and are willing to hire in extra hours to complement family labour which exerts a strong demand in the neighbourhood. This provides an increasing off-farm employment opportunity for less endowed farmers (their comparative advantages lay in the available labour of the household). The fact that farmers do not adopt this strategy yet is very likely due to limited reliability in markets, production and price risks in case of shortage or surplus. This was addressed in the next chapter.

RQ5. What are necessary conditions for farmers to change the farming practices as successful pathway out of poverty?

Farmers act as optimal agents, but design livelihood strategies to suit their asset endowments within their objectives and operational environment. This may result in sub-optimal investments. They manage production decisions in such a way that it reduces their consumption risk or any situation able to affect the net return of the farm family. A Mathematical Programming model which minimises food shortages (expressed in major food intakes: calorie support, proteins and fat) taking into account limited production factors at farmer's disposal (land, labour and capital invested) was applied on a sample of 60 farms surveyed in 2010. Different from the model in chapter 5, this model introduces risk and storage.

The results are presented and discussed in chapter 6. The impact of the risk-averse behaviour of farmers on the production and on household food security is illustrated. In line with Bundervoet (2010) we concluded that risk perception is the driving force to livelihood diversification in order to minimize production variation as to sustain the household's survival. The number of crops on the farm is large and may even double on small farms. This significantly affects the farm's returns (Pender and Ruben, 2004). When risk is incorporated in the simulation model, farm gross margin of an optimal land use plan is lower. The overall gain in farm gross margin is only 26% on average. Yet, even under the severe constraints of land shortage in subsistence production and risk, an optimal land allocation between the crops could attenuate food insecurity among farm households to some extent.

Food production patterns follow agricultural cycles causing variations in consumption and nutrition throughout the year. There are excesses in food production of one harvest season and less food in lean seasons. While the traditional storage system cannot fully prevent all post-harvest losses, having at least basic storage infrastructure can contribute to consumption smoothing in traditional agriculture. The optimum production indicates an overall food shortage of 5.3%, with seasonality it picks up to 18% which can be abated to 9.8% with the traditional storage system.

7.3. Toward a good understanding of the scope for policy making

Despite the acute land scarcity, this PhD research identified a number of possibilities for improving agricultural productivity and therefore food security among households. These possibilities are more grounded in sustainable agricultural intensification. Yet, for agricultural intensification to succeed in achieving the agricultural growth and poverty reduction, several long term efforts are to be put in place at the levels of both farm and the policy making. The study highlighted impressive farmers' adaptability to altering conditions, while also showing continuous advances in policy re-formulation. Today, the interaction between policy makers and farmers is critical for successful strategies toward sustainable agricultural growth.

Even though farmers might have ignored the technology proposed by the decision makers, the current limiting trends are beyond their ability to succeed in productivity growth. The first part of this dissertation ascribed the change in farming systems, yet, it also called for imperative changes in farm production patterns. The continuous land fragmentation, the drastic reduction in grazing pastures extents, the overexploitation of land, the decreased soil fertility and yields, deforestation, erosion and growing impoverishment of farmers all point to the ultimate limit of farmers' capability to further intensify. Several interventions were designed to enhance the agricultural productivity that aimed at a structural transformation towards market orientated production systems. This is highlighted in several policy instruments and political discourses in the framework of agricultural development (MINAGRIE, 2008; MINAGRIE, 2011a,b). As such, the agricultural sector received important investments from both government and donors but could not induce the expected agricultural growth. Poverty continued to increase and the food and nutrition situation is alarming among households (MINAGRIE, 2012). This has great policy implications for the governments, NGOs and farmers to rethink the strategy towards sustainable smallholder-led agricultural intensification. The major questions are then ─ how to deal with the continuously declining land availability, fragmentation and degradation ─ how to deal with the suboptimal allocation of resources at farm level as confirmed in chapter 3 and ─ how to induce necessary fundamental changes in agricultural policies and farming systems and sustainably save the productive resource base.

While advocating for agricultural intensification and a reduction in the number of crops as prominent measures for poverty reduction and to stimulate the country's economic growth, several limitations are clearly observed. Limited access to new and promising technology has been and still is a significant hindrance for small farmers due to weak linkages between research services and extension (chapter 2&3). The extension officers are not well trained and poorly motivated, and the purchasing power of farmers is not high enough for them to invest in new technologies. In addition, farmers are more reluctant to adopt new technologies as they fear they may not gain enough to cover the risk they take due low market development (infrastructure, insurance, credit,…) and low effective policy support systems.

African governments show a renewed interest in the lessons of the Asian Green Revolution and direct support for agriculture, input promotion programs, and subsidies (Nin-Pratt and McBride, 2014). Yet, the Green Revolution agriculture is also criticized for promoting high levels of chemical use in specialized agriculture which has significantly affected biodiversity (Subramanyachary, 2012). In Burundi, the intensification of the agricultural activities is also likely to lead to land degradation due to the persistence of poverty and insufficient financial resources for nature conservation. Therefore any sustainable policy intervention would need to consider both increased productivity and production while accounting for environmental conservation.

Finally, chapter 5 and 6 showed that shortage of land has reached such level that the agricultural sector alone can no longer support the entire population. Beyond that, it is irrational that the whole labour force remains in agriculture. The level of labour overemployment on own farms is pervasive, resulting in rampant under employment and low marginal productivity. Whatever the levels of productivity increases, the overall production levels in agriculture are insufficient to raise smallholders' income above the poverty line so that, other employment options are necessary to support landless and nearly landless agricultural households.

7.4. Policy actions emerging from the study findings

In the absence of non-farm income opportunities, agriculture remains the engine of economic growth of Burundi. The source of rising local income should be found in the agricultural activities of small farms and thereby catalysing a more successful economic transformation. Sustainable intensification would lead to more food availability, increased producers' income, improved payment for agricultural labourers and further investment in non-farm sector. As per capita incomes rise, labour becomes more expensive relative to land and capital, and small farms may get gradually squeezed out by larger and more capitalized farms that become better placed to efficiently operate in agriculture. This could support agricultural growth among the small but sustainable farmers especially farmers able to invest in soil fertility restoration and conservation, and therefore able to take advantage of any agricultural policy intervention. To achieve this, fundamental changes in agricultural policies and farming systems are necessary for sustainable smallholder-led agricultural intensification. Innovative approaches that may contribute to reducing food insecurity and poverty are associated with diversification of agriculture to high value and nutritious crops, livestock production, and creation of linkages between the farm and non-farm sector.

To encourage more intensive agricultural and livestock methods, the starting point should be in risk reduction strategies. A less risky economic environment will allow farmers to engage in more productive, more dedicated crop production that could partly be consumed by the family and marketed. Therefore, promoting domestic markets at least for farm outputs through the intra-rural systems of distribution would also contribute to the overall production of the system. Rational choice of crops and livestock according to the comparative advantage is critical in improving the sustainability of farming activity and household income. Moreover, an effective storage system is necessary to secure food availability and possibly improve household finances. This requires more targeted research and development, an effective extension service, credit access and a good infrastructure.

It is well documented that the traditional communication approach following research, has low rate adoption by users. The technology transfer channel needs to evolve toward social learning extension systems. More participatory and interactive methods are necessary to solve the problem. Three different but complementary approaches can help in both vertical and lateral knowledge transfer to farmers. These are: a) encouraging pilot farmers; b) promoting and strengthening producer organisations and finally c) promoting and strengthening the Farmer Field Schools. These could accelerate the farmer-to-farmer learning which could help to overcome the distrust of farmers in extension service officers while improving farmers' access to financial means.

The pilot farmers are early adopters and more likely to access required capital. Therefore, encouraging them would shape informal farmer learning, as they are more likely to adopt successful technology from their neighbourhood. The Farmer Field School (FFS), has become an innovative model approach for farmer education and has proven significant success in many areas of the world. They are likely to enhance lateral transfer of knowledge. On the other hand, strong producer organizations can help to move gradually from traditional subsistence towards more market orientation. They facilitate the extension service to directly strengthen the technical skills of farmers and constitute a social capital for many smallholders which induces their access to financial means and competitiveness (World Bank, 2007).

On the other hand, the population growth and the traditional inheritance systems may cancel the efforts in this matter. This implies a population control policy that should work through improved education and employment opportunities especially for women (Headey and Jayne, 2014). This would have a positive impact on access to contraceptive knowledge and female empowerment (Kohler, 2012). Additional policy options able to contribute to successful actions would rely on land consolidation through encouraging solidarity between heirs to exploit their land jointly. This can be extended at village level and therefore accelerate the process of villagisation. Land tenure security is also necessary in Burundi. It can improve productivity through access to institutional credit (Feder and Nishio, 1999) and thus technology adoption (Bidogeza et al., 2009). Farmers would also exercise their property right through a transaction market, to acquire or free land for farming activities.

Finally, on a longer-term perspective, agriculture per se cannot be a way out of poverty for all rural households due to constraints of farm expansion and continuing growth of rural population. Efforts are needed to develop sustainable rural employment in order to encourage the nearly landless farmers to leave the farming activities (or to free labour from the farms) which may benefit those who might remain on farm operations as well. The transfer of the workforce to other sectors would make agriculture more viable for several reasons: first, it would free up agricultural land. Second, it would allow more investment in agriculture via a transfer of investment or remittances. Third, it would improve the market for those farmers who stay in agriculture. This could boost the potential for agriculture to generate positive spill-over effects on the growth of other sectors.

Table 7.1 gives an overview of the policy and necessary activities to shape a conducive production and market environment required to increase adoption of new farm practices as part of a trajectory out of poverty for the future.

Table 7.1: Recapitulation of the policy implications

Order	Themes of focus	Activities	Stakeholders
1	Strong agricultural research and development	- to increase research activities in different agro-ecological zones - to renew (regularly) the crop varieties - to conduct farmer's driven research (in line with farmer's real needs)	Government Private sector NGOs
2	Strong agricultural extension service	- to encourage and strengthen pilot farmers - to promote and strengthen farmers organisations - to promote farmer field schools	Government Farmers NGOs
3	Improved farmer's access to credit	- to promote rural credit system - to invest in micro-finances	Government Private sector NGOs
4	Improved rural infrastructure	- to improve the transport system - to improve the agro-industries - to create improved storage facilities - to improve the energy (power) supply systems	Government Farmers NGOs Private sector
5	Population density control	- to improve the education and employment opportunities for women - to empower rural women - to increase campaigns on family planning (birth control)	Government Farmers NGOs
6	Improved land right and land management	- to secure the farmers' right to land - to promote solidarity between heirs to exploit their land jointly - to encourage and promote the process of villagisation - to encourage more environmental friendly agricultural practices	Government Farmers NGOs Private sector
7	Income generating activities	- to invest in non-farm job opportunities - to provide incentives to income generating investments (taxes, duties…)	Government Farmers NGOs Private sector

7.5. Limitation of study and further research

This PhD research project analysed the agricultural production in small-scale agriculture of Burundi using a state-of-the art framework. While the past evolution and current trends in agricultural production systems are very well documented, the study also earned robust results on the impact of crop specialization, risk attitude and storage systems. The study predicted with accuracy how farmers choose crops to secure their household. However, the study has some important limitations that warrant further research.

The lack of panel data on agricultural production at farm level was among the greatest shortcomings for this study. The use of FAO statistics as alternative data leads to less accuracy and may not fully accurately reflect the reality at farm level. Therefore, future research activities should complement the existing datasets with new cross-sectional surveys in the same sample households to build up a panel dataset that can capture both evolutions in farm practices and yields. Moreover, the complexity of the traditional agricultural system of Burundi limits the scope of precisely defining the parameters for each activity. More detailed data collected over several years would provide more accurate estimates. Moreover, there are several aspects linked to institutional or/and failing markets that influence the choice for a particular crop that were not included while playing an important role. Similarly, other inputs such as organic fertilizers that contribute significantly to soil fertility could not be included due to difficulties in measuring the amount used. The micronutrients and products of animal origin could not be included due to their erratic occurrence in household consumptions while they can make a big contribution in some households. This study also did not include the effect of crop perishability on production planning. Yet, farmers may be less willing to grow perishable crops.

Despite these shortcomings, we are confident to have made a substantial contribution to understanding these complex rural settings, and thus to have aroused the interest for future research and actions. Future research is recommended on the development of more detailed optimisation models to analyse rational choices in crops and livestock production taking into account the comparative advantage of farmers. This could help to investigate the main bottlenecks for agricultural production and accurately propose critical measures and strategies towards improving the sustainability of farming activity and household income.

Appendices

Appendix 2.1. Evolution of Burundi population and density, area cropped and food production

Year	Population** (inhabitants)	Population density	Area cropped (hectares)*	Fertilisers use (tonnes)*	Total production (10^9 kcal)	Production per capita (kcal)
1935	1 524 000	59	-	-	-	-
1940	1 716 000	66	-	-	-	-
1945	1 523 000	59	-	-	-	-
1950	1 836 000	71	-	-	-	-
1955	2 035 000	78	-	-	-	-
1960	2 234 000	86	-	-	-	-
1965	3 121 927	124	680 321	-	4 564.296	4 061.14
1970	3 457 113	139	732 454	555	4 735.933	3 805.30
1975	3 791 826	152	759 968	747	5 014.479	3 673.41
1980	4 126 538	156	807 854	1 100	5 047.179	3 397.50
1985	4 866 206	178	870 530	2 331	6 001.305	3 425.72
1990	5 356 266	206	898 603	2 100	6 776.667	3 357.92
1995	6 140 080	225	855 764	3 000	6 265.309	2 834.43
2000	6 674 286	244	901 002	3 500	6 328.106	2 633.70
2005	7 953 520	291	975 400	5 452	6 917.151	2 500.82
2010	8 444 784	338	967 800	6 495	7 182.816	2 362.67

Sources :

1. *http://faostat.fao.org/site/339/default.aspx
2. **http://www.geohive.com/cntry/burundi_ext.aspx
3. **Barampanze, G., Ndikumana, F., 1994. Expansion démographique et développement au Burundi : L'impossible adéquation? Institut de Recherche et développement, Paris.

Appendix 2.2 : Major crop combinations

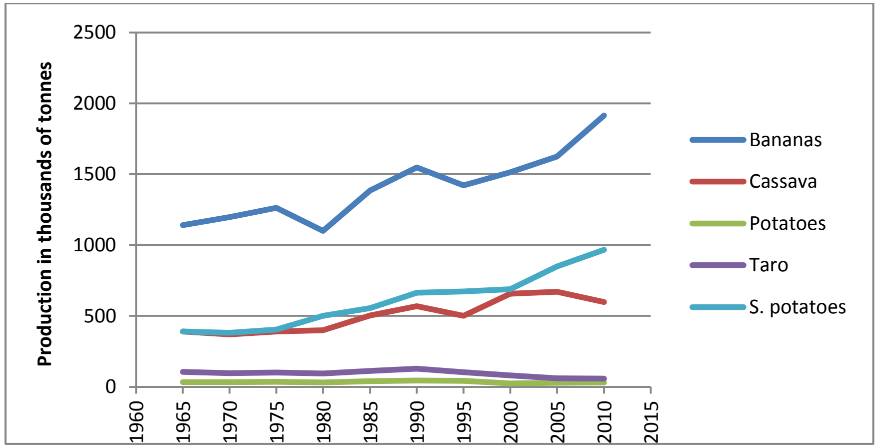
Plot with 4 crops	**percentage**
Beans, banana, cassava, sweet potatoes	17.2
Beans, banana, taro, cassava	7.5
Maize, beans, banana, cassava	6.4
Beans, peas, banana, cassava	5.8
Maize, beans, cassava, sweet potatoes	5.5
Plot with 5 crops and more	
Beans, peas, banana, cassava, sweet potatoes	24.9
Baens, cajanus caja, banana, cassava, sweet potatoes	9.5
Beans, banana, cassava, taro, sweet potatoes	6.5
Beans, maize, banana, cassava, sweet potatoes	5.1
Beans, maize, voandju, banana, cassava, sweet potatoes	3.3

Source:

MINAGRIE, 2013. Enquête nationale agricole du Burundi: 2011-2012. Républqiue du Burundi, Bujumbura.

Appendix 2.3. Evolution in agricultural production, Burundi (1960-2010)

Figure 2.1: Evolution production of banana, tubers and roots **Figure 2.2: Evolution in production of pulses and oilseeds**



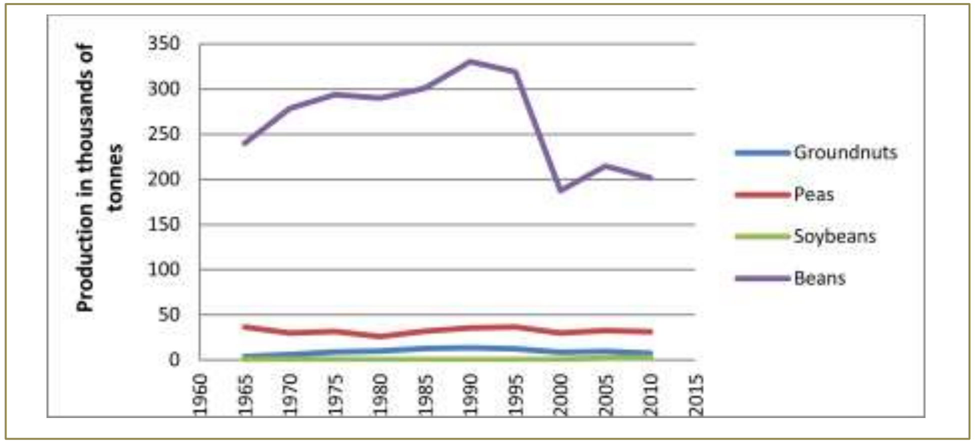
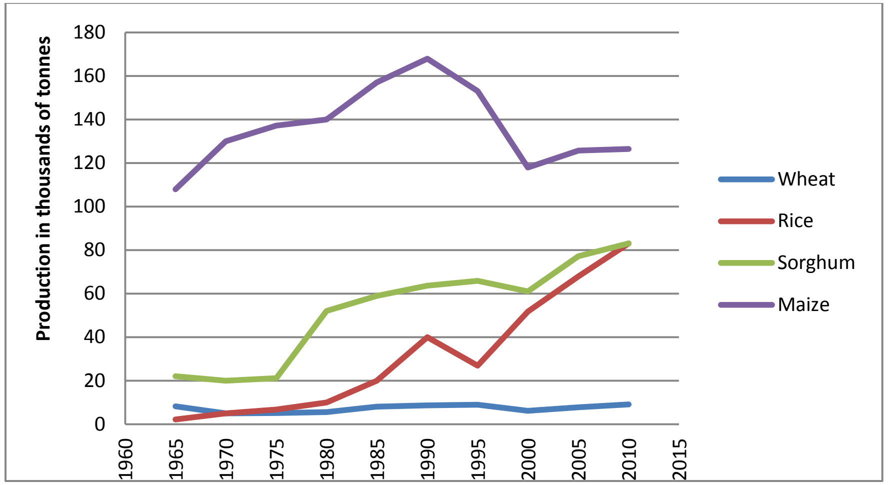
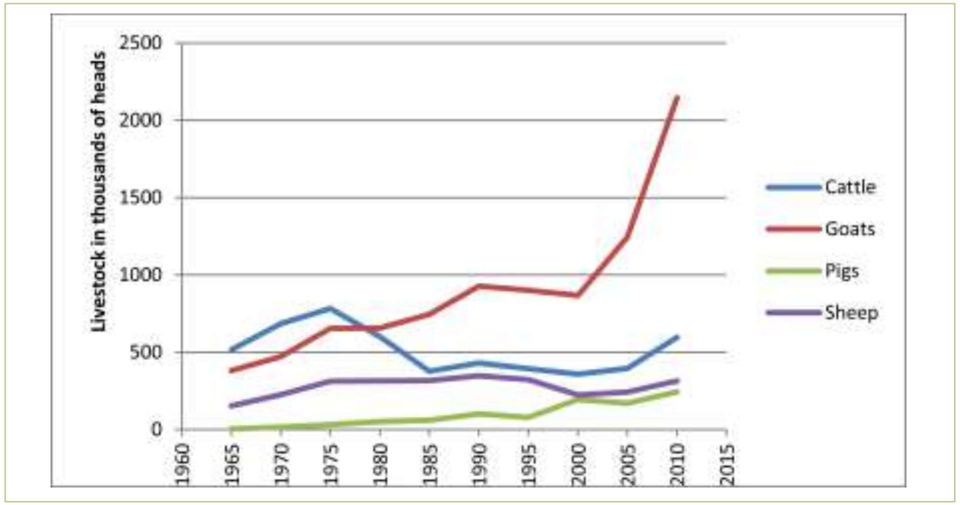


Figure 2. 3: Production of cereals **Figure 2.4: Livestock husbandry**





Source: http://faostat.fao.org/site/339/default.aspx

Appendix 2.4: Timeline in agrarian changes in Burundi

Themes	Before the colonisation		During the colonisation	After the colonisation
	Before the 18th century	**18-19th century**	**1903-1962**	**1962-**
Institutional environment	• access to land upon clearing and using the land • redistribution or reclaim the land by the King • patrilinear transfer of land property	• access to land upon clearing and using the land • redistribution or to reclaim the land by the King • patrilinear transfer of land property right • Serfs	• patrilinear transfer of land property right • Serfs • redistribution of land by administration	• patrilinear transfer of land property right • informal land sales • authentication of land sales
		• famines induced migration • access to land via migration	• access to land via migration • famines induced migration • paysannat migration policy	• paysanat migration policy • individual migration • attempt to villagisation
			• agriculture research and development by INEAC/Congo-Belge	• agriculture research and development by ISABU • local agriculture extension
Farming systems	• Sorghum and finger millet based farming system • shifting cultivation • other indigenous crops (vegetables, beans, trees,….) • Crop of Asian origin	• Sorghum and finger millet based farming system • settled agriculture • other indigenous crops (vegetables, beans, trees,….) • crops of American origin • concentric circles • cattle livestock	• Crop of American origin based farming system • concentric circles • introduction of coffee • compulsory crops to fight famines • follow systems • cultivation of marshlands • predominance of cattle livestock	• Crop of American origin • Suppressed concentric circles • stringent agriculture extension • mixed cropping system • disappearance of fallow • intensive cultivation of marshes • predominance of small livestock • rehabilitation of livestock
	• ashes for fertilizer	• Fertilisation with ashes • fertilization with cow dung	• fertilization with cow dung • Fertilisation with ashes • banana groves • crop residues/fallow	• banana groves • fertilisation with manure • compostage/crop residues • crop rotation/short fallow
Food security indicators		• famine linked to epidemics (disease, drought,…) • low population growth	• famines • high population growth	• demographic pressure • production of less demanding/poor food crops : banana, tubers, roots • recurrent food insecurity

Appendix 3.1: Average and median production in caloric content by land quartile for subsample excluding the top 10% producing farms

	Median	Mean	Std. Deviation
Quartile I	1602,12	2583,03	2723,145
Quartile II	2228,05	3310,70	2976,668
Quartille III	2589,61	3644,25	2968,253
Quartille IV	3890,15	4655,90	3209,957
Average	2456,65	3509,57	3054,076

Appendix 3.2. Food nutrient density of some crops

Crops	Energy (kcal)	Proteins (g)	Fat (g)	Protein density (mg/kcal)	Fat density (mg/kcal)
Groundnut	570	23.00	45.00	40.35	78.95
Maize	345	9.40	4.20	27.25	12.17
Beans	320	22.00	1.50	68.75	4.69
Sweet potatoes	110	1.60	0.20	14.55	1.82

Author's calculations based on the FAO publication http://www.fao.org/docrep/W0078E/w0078e11.htm#P984

Appendix 5.1. Characteristics of clusters based on data collected in 2007 (n=601 of which 340 in Ngozi province) – variables included in the cluster analysis (run in SPSS)

	Cluster 1 (n=44)	Cluster 2 (n=84)	Cluster 3 (n=191)	Cluster 4 (n=282)	ANOVA Test
Surface per person (m^2/pers)	5000 (600)	3000 (450)	1600 (330)	625 (300)	2556.48***
Importance of food crops (%)	67	72	77	80	6.81***
Importance of cash crops (%)	12	9	12	12	1.74
Importance of banana (%)	16	16	19	22	5.69***
Livestock units (LU)	0.6 (1)	0.6 (1)	0.5 (0.8)	0.3 (0.5)	7.52***
Family labour workers	2 (1)	2 (1)	3 (1)	3 (1)	1.24
Importance of non-farm earnings (% of total income)	25 (24)	30 (28)	40 (32)	45 (34)	6.84***

Symbols indicate significant differences at ***: p-value ≤ 0.01, **: p-value ≤0.05, *: p-value ≤ 0.10

Appendix 5.2: Crops adopted at optimum situations in Ngozi province

Optimum situation	Farm categories			
	Large	Medium	Small	Nearly landless
Scenario I	beans cassava rice	beans rice	beans cassava potato rice	beans cassava potato rice
Scenario II	beans banana ground nut	beans rice ground nut	beans cassava ground nut banana	*n/a*

Appendix 6.1: Household food shortages (%) under three scenarios

Food intake	**Food shortage per farm type (%)**				
	Large farms	**Medium farms**	**Small farms**	**Nearly landless farms**	**Average farm**
	Annual				
Energy	0	0	10.20	38.23	0
Proteins	0	0	6.23	15.50	0
Fats	0	6.89	11.03	41.01	0
Seasonal					
Energy	0.24	16.74	19.39	38.32	1.22
Proteins	0.00	0.07	30.40	30.22	2.45
Fats	10.34	22.42	32.12	43.81	29.07
With storage					
Energy	0.00	12.18	10.20	38.24	0.00
Proteins	0.00	0.06	6.23	15.81	0.00
Fats	0.00	7.85	11.10	41.25	3.09

Appendix 6.2: Monthly food shortages (%) with storage scenario

Farms	Food intake	Jan.	Feb.	Marc.	Apr.	Ma.	Jun	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Large farms	Energy												
	Protein												
	Fat												
Medium farms	Energy	38.17	34.41	36.84	36.72								
	Protein	0.34	0.12		0.17								
	Fat	8.06	10.58	8.27	10.92	3.44	3.15	4.11	1.81	6.09	7.29	7.64	22.82
Small farms	Energy	17.97	10.06	15.91	8.74	14.29	16.37	13.15	13.59	2.26	3.84	2.64	3.58
	Protein	11.43	12.00	12.32	11.54	2.19	3.23	1.98	2.48	5.23	1.96	5.40	5.03
	Fat	5.48	8.38	8.02	6.06	11.61	5.80	9.53	13.99	22.16	11.6	16.75	13.76
Nearly landless	Energy	43.36	43.00	43.61	43.55	49.43	51.53	54.03	51.55	16.63	18.08	22.34	21.73
	Protein	6.45	6.91	8.10	9.72	14.49	16.64	16.23	20.07	26.10	19.58	22.88	22.5
	Fat	30.69	34.78	35.71	35.63	25.13	41.00	36.11	42.77	49.2	51.77	52.86	59.38
Average farm	Energy												
	Protein												
	Fat												37.1

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Curriculum Vitae

Sanctus Niragira was born in Banda-Ruhororo, the province of Ngozi in Burundi, on October 27th, 1977. He graduated at the University of Burundi with a bachelor degree in agricultural engineering in 2007 and served as junior researcher at the Department of Rural Development. In 2009, he started his academic education at Ghent University, where he obtained a Master of Science degree in Human Nutrition and Rural Economics and Management on September 16th, 2011. He registered for the doctoral training at the Faculty of Biosciences Engineering within the Department of Agricultural Economics. During the period of the PhD research, he participated in different national, international conferences, seminars and workshops, where he presented oral and posters. Sanctus Niragira has successfully completed the curriculum of the doctoral training programme of Ghent University, Belgium.

Important additional training

2015 : Personal Effectiveness, Ghent University

2015 : Leadership Foundation Course, Ghent University

2015 : Fostering Responsible Conduct of Research, Ghent University

2014 : Impact & Research Communication skills, Ghent University

2013 : Logistic regression, Ghent University

2012 : Free and open source software for GIS, KU-Leuven

2011 : Information Cycle, Belgian Technical Cooperation, Brussels

2010 : Permanent training "Low Country Studies", Ghent University

2007 : Vulnerability Analysis and Mapping. WFP, Burundi

Publications

1. Niragira, S., D'Haese, M., D'Haese, L., Ndimubandi, J., Desiere, S., Buysse, J., 2015. Food for Survival: Diagnosing Crop Patterns to Secure Lower Threshold Food Security Levels in Farm Households of Burundi. Food Nutrition Bulletin 36 (2) 196-210.
2. Desiere, S., Niragira, S., D'Haese, M., 2015. Cow or Goat? Population pressure and livestock keeping in Burundi. Agrekon, 54 (3) 23-42.

3. Desiere, S., D’Haese, M., Niragira, S., 2015. Assessing the cross-sectional and inter-temporal validity of the Household Food Insecurity Access Scale (HFIAS) in Burundi. Public Health Nutrition pp. 1-11.
4. Niragira, S., Buysse, J., Van Orshoven, J., D'Haese, M., 2016. Risk, intensive traditional farm practices and household food security, a triple challenge in small-scale agriculture in Burundi. Agricultural systems. *Under review*.
5. Niragira, S., D'Haese, M., Buysse, J., Van Orshoven, J., 2016. Historical changes in the traditional agrarian systems of Burundi: Endogenous drive to overcome food insecurity. Human Ecology. *Under review*.

Contributions scientific to conferences

1. Risk attitude, farm practices and household food security in small-scale agriculture of Burundi. October 2015, 2nd Global Food Security Conference, Ithaca, NY, USA.
2. Livelihood diversification in rural areas of Burundi, a successful pathway out of poverty? September 2013, Sustainable Rural Livelihood, Mekelle, Ethiopia.
3. When only land matters: mathematical models to study crop specialization, resource endowments and food security on small-scale farms in the north of Burundi. September 2013, European association of Agricultural economics, Ghent University, Belgium.
4. The scope of small-scale agriculture in tackling food insecurity challenges in rural Burundi. December 2013, GAPSYM7, Ghent, Belgium
5. Optimizing land use among small-scale farms through agricultural specialization in the north of Burundi. May 2012, European meeting of the International Micro simulation Association, Teagasc Food Research Centre, Ashtown, Ireland.
6. Optimizing land use among small-scale farms through agricultural specialization in the north of Burundi. May 2012, Wheat expert workshop for researchers from central and East Africa, Bujumbura, Burundi.

Additional academic tasks

1. Assistant Lecturer University of Burundi, Department of Rural development. From April, 2013 onward.
2. Research assistant VLIR-UOS/IUC project (SADeR), University of Burundi. From June 2012 onward.