Nutritional security in Tanzania

Fausta Marcellus Mapunda

Agriculture productivity, crop diversity and nutritional security in Tanzania

Fausta Marcellus Mapunda

Propositions

1. The use of the production frontier is an innovative way of assessing variation in the quality of modern seeds in the African rural market.
(this thesis)

2. Crop diversity in the field of a smallholder household provides no guarantee that the adult women in the household eat a more diverse diet.
(this thesis)

3. In most developing countries, policymakers do not use empirical evidence to target policy interventions addressing people's needs.

4. Malnutrition will decline rapidly if fought with the same dedication as COVID-19.

5. Writing a PhD thesis is like a societal concern with competing interests and expectations from various actors.

6. Women's increasing role in agricultural production will not reduce food insecurity in Africa.

Propositions belonging to the thesis, entitled

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To my family

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Chapter 1
Introduction

1.1 Background

Agriculture remains the primary source of income for 36% of the world's workforce. In sub-Saharan Africa, it supports the livelihood of over 80% of the population (FAO and OECD, 2016; WorldBank, 2016). The sector accounts for 57% of employment while contributing only 16% to gross domestic product (GDP) (WorldBank, 2017). This implies a large productivity gap between urban and rural areas. Indeed, most African poor reside in rural areas. Nevertheless, most analysts believe that the agricultural sector could play an important role in reducing poverty, raising incomes, and improving food and nutritional security.

Food security is achieved when all people at all times have physical, social, and economic access to sufficient, safe, and nutritious food that meets their food preferences and their dietary needs for an active and healthy life (FAO, 2009). Food security comprises multiple concepts supported by four pillars: availability, access, utilization and stability (Becquey et al., 2010). Nutrition security incorporates all the components of food security but with additional emphasis on the need for wholesome, healthful foods and drinks for all that promote well-being while preventing and treating disease. By definition, nutrition security is a situation that exists when secure access to an appropriately nutritious diet is coupled with a sanitary environment, adequate health services, and caring practices for a healthy and active life for all household members (FAO et al., 2017). Nutrition security differs from food security as it considers deliberate aspects of enough caring practices, health, and hygiene in addition to dietary adequacy. Undernutrition occurs when people cannot obtain sufficient energy, protein, and micronutrients that are necessary for the body (Alemu, 2020). Food insecurity and undernutrition continue to affect many people in sub-Saharan African countries (Habtemariam et al., 2021). Over 204 million people in the region are undernourished (Bain et al., 2013; Koppmair et al., 2017), with women and children as the most vulnerable groups. In reality, the nutritious part often has been ignored or given little attention in national policies with the resulting emphasis on quantity i.e., availability of enough calories, rather than the quality (macro and micronutrients) and quantity. The current policies consider the term “food and nutrition security (FNS)” that encompasses both aspects of dietary well-being. Nutrition security looks at the nutritional value, affordability, accessibility, and safety of foods that promote well-being. With this dual context, when considering FNS security, diet quality is often linked to household income and socio-economic status. An increase in market food prices affects the accessibility of wholesome diets.

Among rural households, the challenge posed by food and nutritional insecurity is formidable, especially for children. About 144 million African children under five years of age are stunted, 47 million are wasted, and nearly 40 million are overweight. Almost 340 million children suffer from micronutrient deficiencies (FAO et al., 2020). The consequences of undernutrition are broad and negatively affect the health, growth, cognitive development, and thus the economic productivity of affected individuals (Dewey and Begum, 2011; Victora et al., 2008). Poverty accentuates food and nutritional insecurity since it limits the ability of rural households to invest in agricultural technologies that could increase agricultural productivity. Due to low income and limited access to markets, rural households rely on the consumption of starch staples. Projections for 2050 indicate that the world's population will rise to nearly 9.8 billion people. To feed this growing population, it is crucial to raise food production while using fewer resources.

Recently, more extensive forms of government involvement have been tried out. Yet, the state of food security in sub-Saharan Africa has not changed, and food insecurity remains a significant and persistent challenge. How to improve the productivity of Africa's agriculture? In recent decades, several policy approaches have been tried, from heavy-handed state intervention to market-based approaches. For example, from the 1980s to the 1990s, structural adjustment programs (SAPs) were the primary factors in shaping policies and influencing strategies and programs for agriculture, food and nutrition security. The SAPs include agricultural trade liberalization, deregulation and privatization. In the context of Africa, there was also a push away from communal land ownership toward private ownership, preferably supported through a formal titling system. However, the outcomes of these policy reforms did not live up to expectations, and in many countries, food production has failed to keep pace with the rapid population growth rate.

This thesis evaluates the outcomes of various policy interventions that aim to increase agricultural productivity and improve the food security of rural populations. Throughout the thesis, we focus on Tanzania, but hope some lessons may spill over to other countries in the region.

Food security situation in Tanzania

The agricultural sector is the mainstay of the Tanzanian economy, a source of food, employment, and rural household income. This sector employs over 65% of the labor force and contributes about 30% of GDP and 30% of export earnings (URT 2016). The three primary food crops in the country are maize, rice and cassava. Others include sorghum, millet, wheat, pulses, potatoes, bananas, plantains, sugar, groundnuts, sesame, coconuts and soybeans. Over 95% of the food available in Tanzania is grown by smallholder farmers. From 2012/13 to 2018/19, Tanzania attained surplus food production with a self-sufficiency ratio between 120 and 125 (URT 2016). This self-sufficiency ratio is mainly based on the production of cereals and legumes. While cereal production serves caloric sufficiency, it does not satisfy requirements for micronutrient intake, which necessitates consumption of a variety of food items such as vegetables, fruits, and animal-sourced foods.

Rural households in Tanzania suffer from input, output and financial market imperfections. These imperfections are due to poor rural market infrastructure, weak producer organizations, and low output prices. For example, Isaga (2018) argues that smallholder farmers face challenges in accessing credit due to insufficient collateral to support their loans, high transaction costs, unstable income, poor credit history, low literacy levels and high monitoring costs. The government aims to address some of these market imperfections.

Several strategies to boost agricultural production have been in place. These include the establishment of (1) the Agricultural Sector Development Program (ASDP) 2006/2007 to 2013/2014, a "basket fund" aiming to contribute to higher productivity, profitability, and farm incomes by providing farmers with better access to agricultural knowledge, technologies, marketing systems, and infrastructure; (2) the National Strategy for Growth and Reduction of Poverty (NSGRP) of 2005/2006, aiming to promote growth and reduce poverty; (3) the National Microfinance Policy (2000) aiming to provide smallholder farmers with the financial means to undertake investment opportunities, thus increasing productivity, improving household income and ensuring economic growth; (4) the Cooperative Societies Act (2003) aiming to promote and regulate collective action among smallholder farmers to overcome production and marketing constraints; and (5) *"Kilimo Kwanza"* (agriculture first) introduced in 2009 aiming to increase crop production, livestock husbandry and investment in fish farming. In crop production, the objectives include increasing the acreage under cultivation by improving knowledge; increasing the hectares under irrigation; controlling pests and diseases; promoting the use of modern farm tools such as tractors and power tillers, modern seeds and fertilizer; and investing in large-scale farming. However, none of these strategies has solved the challenges of food and nutritional insecurity in rural areas.

Nutrition situation in Tanzania

Even though Tanzania has made some progress in reducing malnutrition, levels of malnutrition remain high (Ministry of Health et al., 2016). The country faces multiple burdens of malnutrition, including (1) high levels of undernutrition in children, (2) high levels of micronutrient deficiencies among women and children, and (3) high levels of overweight and obesity (URT, 2016). Presently, stunting affects nearly 32% of children under five years of age, and rates of overweight and obesity for women of reproductive age have increased from 28% in 2015 to 32% in 2018 (URT, 2016). Evidence shows that micronutrient malnutrition affects 58% of children under five years and 45% of women of reproductive age. The demographic and health surveys of 2015/2016 indicate that even the leading food-producing regions with high self-sufficiency ratios in production record high levels of malnutrition. There is an undernutrition gap between rural and urban areas, with fewer undernourished individuals in the latter (URT, 2016). A comprehensive food security and nutrition assessment of 2017 shows that 97% of rural households depend on cereals to meet household dietary needs. The consumption of animal source foods, such as eggs and meat, is low. However, there has been little scholarly attention to the complex associations between crop diversity, market access, and nutritional security of rural farm households in the southern zone of Tanzania, the so-called breadbasket regions. This thesis aims to address these issues.

1.2 Key issues in this thesis: land titling, crop diversification, technical efficiency and off-farm employment in Tanzania

In this thesis, I examine some key issues that shape the productivity of the agricultural sector in Tanzania and affect household food and nutrition security. Small-scale farmers dominate agricultural production. Securing land rights may promote economic development because of the collateralization effect that facilitates credit access for investments. Using modern seeds as short-term investments may positively affect TE and productivity, with benefits for food security and household income. However, uncertainty about the quality of inputs in rural markets remains a challenge, and lowers productivity. Another important issue is crop diversity. Cultivating multiple crops to stabilize income or to use for one’s own consumption may be a rational strategy, depending on market conditions. Similarly, participating in off-farm employment may affect households' consumption of nutritious foods via multiple channels. All these relationships are contested and debated to some extent in the literature. Insights generated by this study help to clarify some of the controversial elements in the literature. In this section, I will briefly sketch the key relationships, which are fleshed out in more detail below in the core chapters of the thesis.

1.2.1 Heterogeneous effects of land titling on rural household's agricultural productivity

Chapter 2 contributes to the debate on whether formal land-property rights contribute to rural households' welfare. The first set of the existing empirical findings give evidence that formal land titles enhance land security and boost agricultural investments and productivity (Melesse and Bulte, 2015; Place, 2009). However, another set of empirical studies shows that customary land tenure is efficient Deininger and Feder, (2009b) and that formal land titles have only a limited effect on investment. For example, Deininger and Jin (2006) indicate that land titles had no impact on terracing investments in Ethiopia. There may also be distributional concerns. Deininger and Feder (2009a) show that formalizing tenure systems infringes on secondary rights of the poor in collecting firewood. In most African societies, the dominant system of land ownership has been customary land tenure, whereby chiefs, clans, or family heads own the land and acquisition is mainly through inheritance (Kalabamu, 2000). In Tanzania, over 120 tribes exist, and details of the land tenure system and ownership largely depend on the local cultural context. Most studies have evaluated the impact of land tenure security on the basis of land redistribution (Deininger et al., 2008; Jacoby and Minten, 2007).

In the early 2000s, Tanzania initiated a process to protect the land rights of rural inhabitants. Land scarcity was being increased by rapid population growth and rising land demand for investment in agribusinesses, such as biofuel and food production. This caused land fights among larger-scale investors and smallholder producers, as well as crop producers and livestock keepers in some parts of the country. The enactment of the Land Act and the Village Land Act of 1999 created two types of titles: customary rights of occupancy and granted rights of occupancy. The 1999 Village Land Act and the 2007 Land Use Planning Regulation guided implementation of the land titling program, called the Certificate of Customary Right of Occupancy (CCRO). In Chapter 2, we explore how land titling affected farm productivity. Since 2004, the Tanzanian government has implemented land reforms. The reforms aim to strengthen institutional arrangements to safeguard the security of tenure, facilitate economic use of rural land as collateral to access credit, and enhance property transactions (Sanga, 2009).

Land in Tanzania falls into three categories. The first category is customary rights of occupancy, which refers to the village land. About 70% of the land in Tanzania is customary land, which supports about 80%of the population for their livelihoods. The second category is reserved land for conservation and other areas. Almost 28%is reserved land comprising forests, national parks, game reserves, river basins, and land for public infrastructure and services. Finally, there are granted rights of occupancy (the general land), mainly urban land covering only 2% of the surface and supporting almost 20% of the population. The CCRO program concerns village land. However, only 3% of village land and 20% of urban land carry titles or have the potential to be titled (Massay, 2016). A large proportion of the rural population is therefore without land titles, implying that they lack the security to access credit from financial institutions. The lack of titles may also discourage long-term investments by farmers, such as in land productivity, and may imply that land markets do not function well, with the result that land does not end up in the hands of the most productive farmers. The perceived positive effects of formalizing secure land-property rights on improvements in agricultural productivity may contribute to attaining Sustainable Development Goal (SDG) 2: end hunger, achieve food security and improve nutrition and promote sustainable agriculture (Kehinde et al., 2021).

The rationale for the impact assessment in this thesis relates to the recent Agriculture and Livestock policy of 2013, which reiterates the limitations of the still prominent informal land tenure system and stresses implementation of existing policies, such as CCRO, to increase land tenure security and thus agricultural investments and productivity. It remains an open policy question how successful these land reforms were boosting agricultural productivity in rural households. The study seeks to evaluate the impact of land tenure on agricultural investment and productivity. An important caveat is that land titling in the context of Tanzania did not involve land redistribution.

1.2.2 Does crop diversity matter to rural household dietary diversification?

In sub-Saharan Africa, addressing hunger, food insecurity and malnutrition remains a primary challenge. The number of undernourished people is steadily increasing. Since 2006, Tanzania has engaged in several initiatives to reduce malnutrition rates in Tanzania. Some of those initiatives are (i) promoting crop diversification, (ii) developing the National Nutrition

Strategy 2011-16, and (iii) integrating food and nutritional issues in the second Five-Year Development Plan 2016-2021 (FYDP11). In Chapter 3, I focus on the relationship between crop diversity in the field and nutrition diversity on the plate. This is a complex and presumably context-specific relation. If farmers eat crops they produce, then increasing crop diversity is likely to increase dietary diversity. However, if farmers produce for the markets and consume food that is bought at the markets, then specialization in a small number of cash crops may promote dietary diversity.

Several studies have examined the association between agricultural production diversity and dietary diversity (Bellows et al., 2020; Chegere and Stage, 2020; Kissoly et al., 2018; Lovo and Veronesi, 2019; Madzorera et al., 2021). Some empirical studies find that factors such as household socioeconomic status and market access mediate the association between production diversity and dietary diversity. Madzorera et al. (2021) examined the association between food crop diversity and women's income-earning activities with women's diet quality, as mediated by access to markets. The findings show that food crop diversity affects women's income and diet quality. An empirical study by Lovo and Veronesi (2019) concluded that crop diversity is positively associated with child nutrition in households with limited access to markets. Literature by Kissoly et al. (2018) concludes that the relation between crop and dietary diversity is context-specific; a positive and significant association was found for households residing in remote rural areas, not for households in peri-urban areas. Given the variation in findings, it is useful to add a new case study to the literature to explore how crop diversity and market access are associated with household food security and dietary diversity.

1.2.3 Impact of modern maize seeds on technical efficiency

Efficiency means realizing the highest quantity of goods and services per unit of input. Technical efficiency explains how well a firm performs using a specified set of inputs to produce maximum outputs given the available technology relative to a standard (frontier) production (Battese and Coelli, 1992; Fried et al., 2008; Ogundari, 2014). Three forms of efficiency exist; technical efficiency, allocative efficiency, and economic efficiency (Kumbhakar and Wang, 2015). Given the available technology, a technically efficient firm aims to produce the maximum output using the level of a specified set of inputs (Kumbhakar and Lovell, 2003). On the other hand, the allocative efficiency of a firm aims at choosing an optimal combination of inputs with a given set of input prices (Daraio and Simar, 2007).

Economic efficiency is the product of technical and allocative efficiency when a firm combines the inputs in the least possible combination to produce an output (Maina et al., 2006). The neoclassical economic theory assumes that every producer is fully efficient. However, in real life, producers are hardly fully efficient. Theoretically, modern seeds are highly responsive to other inputs in the production process. On the one hand, if farmers use authentic modern seeds, fertilizers, labour, and other agronomic practices such as herbicides at an optimal level, we expect a higher level of TE. On the other hand, if farmers use counterfeit modern seeds, then production will be lower.

The Green Revolution of the 1970s and 1980s in India provides evidence that more extensive use of modern inputs can contribute to a process of agricultural transformation. Policies that foster increased use of modern seeds may also increase productivity and food security in sub-Saharan Africa, and reduce poverty. In recent decades, seed sectors in most African countries have been liberalized, motivating private seed enterprises to participate in production, marketing, and distribution of modern seed varieties, typically hybrids. In Tanzania, formal and informal seed systems coexist. Since 1973, the public seed program has dominated the formal seed systems. TANSEED, the government parastatal organization, is responsible for seed production, marketing and distribution (USAID, 2017). The public research institutes and the Agricultural Seed Agency (ASA) play a key role in producing certified seeds. The Tanzania Official Seed Certification Agency (TOSCI) certifies the quality of seeds before releasing them to the market (USAID, 2017). The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) observes that the use of certified seeds is most pronounced in the production of maize, sorghum, sunflower, and to a lesser extent wheat ASARECA (2014). However, the formal seed system constitutes only 25% of the overall seed supply, leaving a 75% share of informal or traditional seeds comprising farmer-saved seed, local exchanges, and local seed businesses (Moore, 2019).

For many crops, farmers retain seeds from the previous season. This includes priority crops for food security and nutrition, such as grain, legumes, millet, cassava, and sweet potatoes. One possible reason for the dominance of the informal system is widespread concerns and doubts about the quality of seeds provided through formal market channels. Specifically, farmers are concerned about the presence in stores of counterfeit seed and low-quality seed in general, which in their opinion is the result of poor handling and storage.

Perceptions of seed quality affect not only adoption rates of modern seed, but also the allocation of complementary inputs, as the marginal value product of such inputs depends on seed quality. Variation in seed quality also increases variation in productivity across farms. Farmers with the good fortune to buy good modern seed will experience higher productivity, ceteris paribus, than farmers who bought low-quality modern seed. In Tanzania, the National Agriculture Policy promotes the use of modern maize seeds, but there is considerable variation in efficiency across farmers who adopt them. One may ask whether some of this variation is caused by the prevalence of low-quality seeds in the market. Chapter 4 analyzes technical efficiency among subsamples of farmers using modern and traditional seeds, and considers whether there are patterns in the data that are consistent with the assumption that the performance of modern seed farmers is variable because of an underperforming formal seed market.

1.2. 4 Impact of off-farm employment on rural household food and nutrition security

Work outside the farm is a potential source of rural household income. Off-farm employment accounts for one-third to one-half of rural household income in developing countries, and is increasing over time (El-Osta et al., 2008; Hazell et al., 2007). Wage employment outside the farm household and running a non-farm enterprise can be an income diversification strategy for supplementing and stabilizing farm household income and enhancing household welfare (Davis et al., 2017; Khan and Morrissey, 2019). Nevertheless, how does increased off-farm employment affect agricultural productivity? On the one hand, reallocating labor to off-farm activities should logically reduce agricultural production. However, the expansion of off-farm activities may also relax capital constraints, thereby promoting investment and improving farm productivity (Babatunde and Qaim, 2010). In rural economies, credit markets are either absent or not functioning (Diiro, 2013; Ellis and Freeman, 2004). Therefore, off-farm income could be part of a strategy for overcoming credit constraints (Reardon et al., 2007). It provides farmers with liquid capital for purchasing productivity-enhancing inputs such as improved seeds and fertilizers (Diiro, 2013). Moreover, there may be other positive spillover effects between the farm and off-farm sectors of the rural economy (Babatunde, 2013), including knowledge spillovers. In Chapter 5, I aim to further explore the role of off-farm work on household welfare, specifically regarding agricultural productivity, food security and household income.

1.3 Knowledge gaps and contribution to literature

This thesis considers smallholder farmers in Tanzania, which provides a novel context to revisit some contested issues in the literature. Some of the ambiguity that exists in the literature is also present in my Tanzanian samples, and where possible I will use theory-informed additional analysis to probe this heterogeneity. For example, I study the impact of formal titling on productivity and how its impact varies across different types of farmers. In another chapter, I look at how crop diversity affects dietary diversity, and how the nature of this relationship depends on access to markets. A third chapter builds on the recent insight that some inputs traded via formal markets are of low quality. I explore variation in production efficiency by comparing two groups of farmers, those using modern seed and those using traditional seed of more predictable quality. A final chapter looks at the association between off-farm employment and nutrition security. This work is a complement to the emerging literature on food system transformation in low-income countries.

1.4 Objectives and research questions

This thesis aims to contribute to a better understanding of how key policy interventions and market developments are associated with food and nutritional security situations of rural households in Tanzania. Specifically, my thesis addresses 1) the impact of formal land titling on agricultural productivity, 2) the association between crop diversity and dietary diversity, 3) the impact of using modern maize seeds on technical efficiency, and 4) the impact of off-farm employment on households' food and nutritional security.

Specifically, this thesis addresses four research questions, one in each of in four subsequent chapters.

1. What are the effects of formal land titling on rural household's agricultural productivity, and how do these impacts vary across different types of households? (Chapter 2)
2. How does crop diversity affect dietary diversification in rural households and how is this effect mediated by rural markets? (Chapter 3)
3. What is the level of technical efficiency users of modern and traditional seeds, and is there reason to believe that low-quality seed from the formal seed system affects efficiency of modern seed users? (Chapter 4).
4. What is the impact of off-farm employment on rural household food and nutrition security? (Chapter 5).

1.5 Conceptual framework

Separable and non-separable models provide a useful framework for thinking about integrating household production and consumption decisions (Singh et al., 1986). The two types of models are widely used to explain the economic behavior of rural farm households in developing countries which are engaged in subsistence and commercial farming systems, and to analyze how various policy issues affect agricultural production. These models have also been used to study technology adoption, income distribution, and off-farm labor supply (Taylor and Adelman, 2003). However, such models typically ignore the complex inter-linkages between land tenure security, crop diversity, technical efficiency, and off-farm income.

Separable and non-separable models provide a useful framework for thinking about integrating household production and consumption decisions (Singh et al., 1986). The two types of models are widely used to explain the economic behavior of rural farm households in developing countries which are engaged in subsistence and commercial farming systems, and to analyze how various policy issues affect agricultural production. These models have also been used to study technology adoption, income distribution, and off-farm labor supply (Taylor and Adelman, 2003). However, such models typically ignore the complex inter-linkages between land tenure security, crop diversity, technical efficiency, and off-farm income (Figure 1.1).

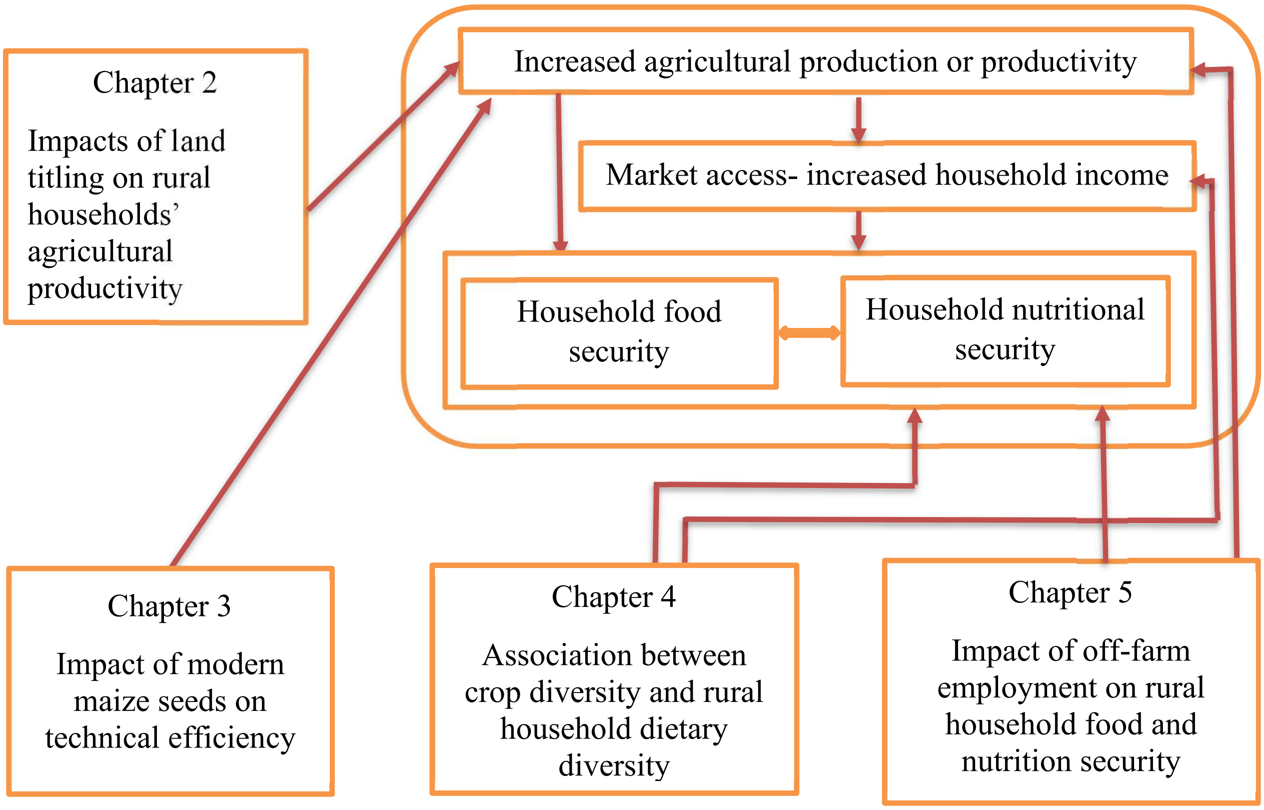

Figure 1.1: A conceptual framework for agricultural productivity, crop diversity and nutritional security in Tanzania

1.6 Methodology

1.6.1 Research areas, sampling strategies and data collection

Tanzania is an East African country located just south of the equator. The Tanzania mainland is bordered by Uganda, Lake Victoria, and Kenya in the north, the Indian Ocean to the east, Mozambique, lake Nyasa and Zambia to the south, and Lake Tanganyika, Burundi and Rwanda to the west. The Tanzanian economy is mainly agricultural. Export cash crops are a source of foreign exchange for the country. Coffee and cotton are the most important crops in this respect, but other export crops include cashew nuts, tea, tobacco, and sisal. The primary food crops include maize, rice, sorghum, millet, bananas, cassava, sweet potatoes, potatoes, and wheat. The country is divided into five geographical zones: the northern zone, the southern zone, the central zone, the eastern zone, and the western zone. We conducted our research in the southern highland zone.

The study covered three regions: Mbeya, Songwe, and Ruvuma. Purposive sampling was used to select these regions based on three considerations. First, agriculture is the main economic activity in the three regions, and they are among the leading food-producing areas. Second, the level of malnutrition is high in the southern highland regions, and literature is available to explain the challenge of malnutrition. Third, the CCRO was initially implemented in Mbeya Region. We used a similar purposive sampling approach to choose districts within regions: Mbeya rural, Mbarali and Rungwe in Mbeya Region, Mbozi and Momba in Songwe Region and Mbinga in the Ruvuma region (Figure 1.2). Random sampling was used to select wards and households for participation in the survey. This research mainly draws on evidence from primary data collected from the southern regions of Tanzania in 2014 and 2016 using household surveys. Structured questionnaires were the primary tool for data collection, and the questionnaires were pre-tested to check their validity and reliability. The household survey covered 1,425 households. The survey covered socioeconomic characteristics, land owned, land size cultivated, household crop production and livestock owned, inputs used, food consumption, credit access, and distance to markets. Most of the interviewed households were smallholder farmers who grew food and coffee as cash crops in the area and were members of farmer organizations. However, maize and rice were grown in the area for household consumption and the market.

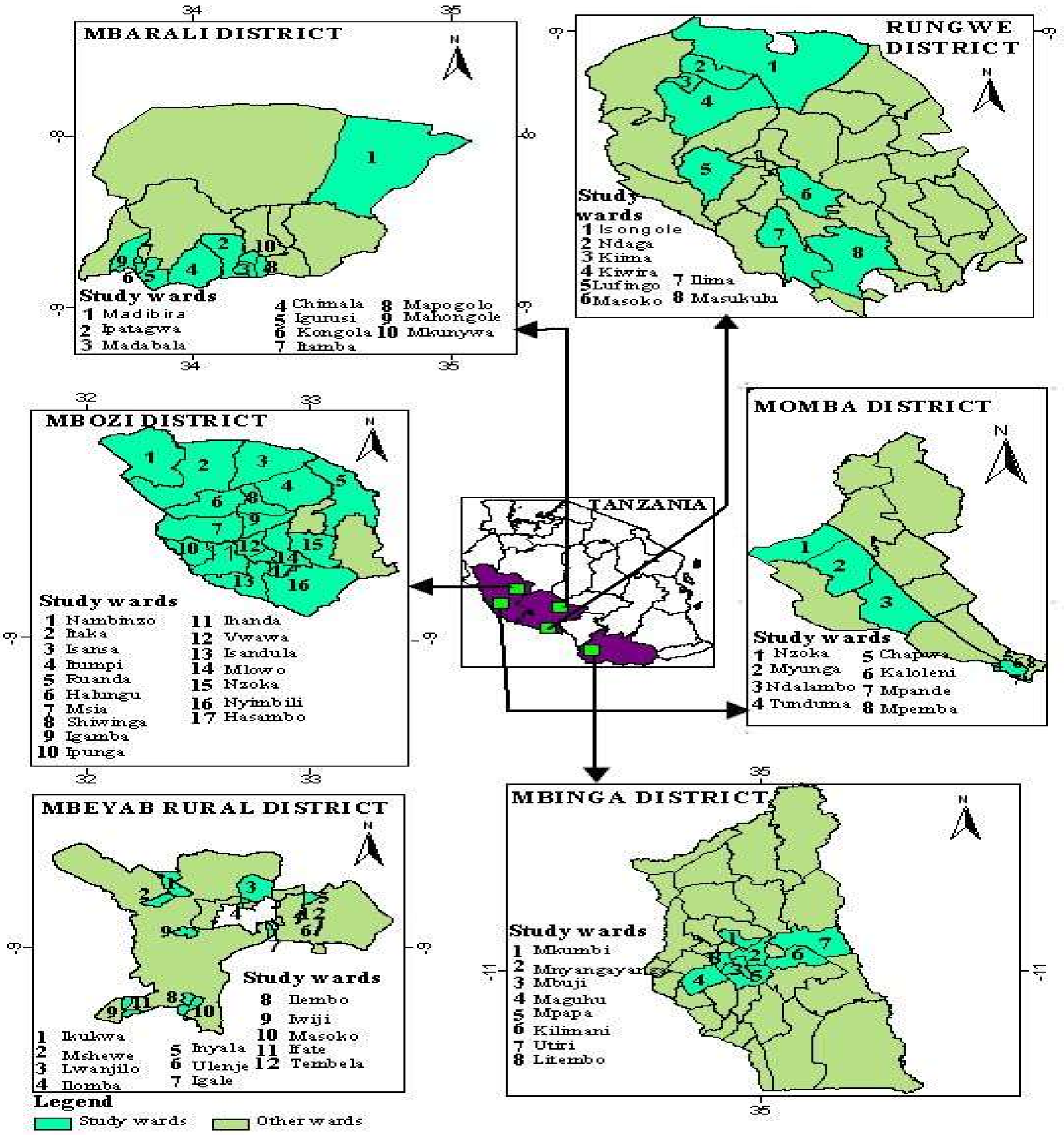

Figure 1.2: Map of Tanzania showing the study areas (painted green)

1.6.2 Overview of research methods

All chapters are based on household survey data. Because households self-selected into activities (such as off-farm employment) and voluntarily chose whether to join a titling program, purchase modern seeds, or plant multiple crops on their plot, it is extremely challenging to identify causal relationships. Since the analyses in this thesis are not based on experimental (exogenous) variation, identification of causal relations rests on some untested assumptions. This is an important caveat.

In Chapter 2, we use propensity score matching (PSM) to create a counterfactual for the group of titled households (Blundell and Costa Dias, 2000). We use cross-section data, which is a limitation (Ravallion, 2001). This chapter is based on three districts with different levels of land titling: Mbozi, where the land titling program was completed; Rungwe, where the land-titling program was ongoing, and Mbinga, which had not yet received the program. This strategy assured sufficient availability of both titled and untitled plots, which were needed to identify the counterfactual; what would have happened if the land titling program was not implemented?

In Chapter 3, a multivariate regression model is used to examine the correlation between crop diversity and different measures of household dietary diversity. The analysis uses ordinary least squares (OLS) regression to estimate a set of equations for the full sample of households, using a crop diversity index (CDI) as the main explanatory variable. Subsequently, I re-estimate the model using a median split for the variable distance to the market to enhance our understanding of how crop diversity relates to households' dietary diversification. The analysis is based on a cross-sectional sample of households. As robustness checks, I substituted the crop count for the CDI and I re-estimated the models employing a Poisson estimator with a maximum likelihood procedure.

In Chapter 4, I use stochastic frontier analysis (SFA) to estimate technical efficiency (TE) of modern maize seed users and traditional seed users. The analysis uses a linearized Cobb-Douglas production function, using maximum likelihood to estimate separate production functions for traditional seed users and modern seed users. This chapter is also based on cross-section household survey data. In Chapter 5, I had access to panel data on food and nutrition security, which enabled me to estimate a difference-in-differences model, combined with PSM, to estimate impacts.

1.7 Outline of the thesis

Each of the core chapters addresses one specific research question, as outlined above. Chapter 2 evaluates the effects of land titling on rural households' agricultural productivity. We critically assess how titling impacts the use of modern seeds, fertilizer and organic manure, and how this impact varies across different types of households. Chapter 3 examines the association between crop diversity and rural households’ dietary diversity. We focus on how this association is mediated by access to rural output markets. In Chapter 4, we assess the quality of seeds available in the rural market by considering variations in the TE of modern and traditional seed users. We compare the productivity and TE of smallholder farmers who used modern seeds with the productivity and TE of farmers who used traditional seeds. Chapter 5 uses panel data to assess the impact of off-farm employment on food security. We study drivers of households' decisions to participate in off-farm work and evaluate whether off-farm activities have the potential to improve rural households' food and nutritional security. Chapter 6 summarizes and integrates the main empirical findings. I discuss the theoretical and policy implications of the research and recommend strategies for promoting agricultural productivity and improving rural household food and nutritional security. In conclusion, I offer a few recommendations for policymakers and future researchers.

Chapter 2

Estimating heterogeneous effects of land titling on rural household's agricultural productivity: Evidence from Tanzania

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Abstract

This study evaluates the impact of land titles on agricultural productivity in Tanzania. We used household survey data collected in three southern highland districts of Mbozi, Rungwe, and Mbinga in 2013/14 to study the impact of land titles on agricultural productivity in Tanzania. The main objective was to evaluate changes in the level of agricultural productivity attributed to the land titling program. We find that land titles have a statistically significant positive effect on productivity. This can at least partially be explained by an increase in credit access for titled households. Our results further suggest heterogeneous effects of titles, which vary with age of the head of household and size of land being cultivated.

Key words: *land titles, productivity, input use, credit, heterogeneous effects*

2.1 Introduction

The land is a key economic resource for rural inhabitants in most parts of sub-Saharan Africa (Cotula and Chauveau, 2007; Obeng-Odoom, 2012). It is crucial for economic development and contributes to household food security and opportunities to make productive use of family labor (Kassie et al., 2013). Land titles may encourage rural households to undertake land-related investments, serve as collateral, and facilitate the transfer of land to the most productive farmers, all of which could increase agricultural productivity (Besley, 1995). Over the past decades, there has been a rapid increase in demand for agricultural land, largely driven by increasing global demand for food and biofuel crop production (Behrman et al., 2012; Kimaro and Hieronimo, 2014; Pedersen, 2012; Toulmin, 2009). The customary land tenure system is also under pressure because of urbanization, livelihood diversification and cultural change. Increased pressure on land in rural areas may threaten rural livelihoods (Behrman et al., 2012) and invite conflicts within and between local communities (e.g. crop growers and livestock keepers), between local communities and investors, and between communities and the state.

Theory predicts that secure property rights are key to economic development, especially in determining the functioning of credit markets (North, 1990). While there are good reasons to believe that customary tenure security can also be secure, the evidence increasingly supports the idea that formalization matters (Besley, 1995; Markussen, 2008). This conclusion is related to the increasing importance of the collateralization effect of land titles in facilitating credit access (Dower and Potamites, 2014).

Tanzania is a particularly interesting place to study the effect of land titling, as the government of Tanzania started to implement a new wave of land reforms in 1999. In line with theory, the government explicitly intended to stimulate agricultural investments and productivity by increasing farmers' tenure security, reducing land conflict and enabling farmers to use land as collateral for credit access (Pallotti, 2008; Pedersen, 2012). The idea was not to redistribute land; rather, the arrangement involved registering existing customary land rights as formal rights (Wily, 2008).

The agricultural sector remains the mainstay of Tanzania's economy. The sector employs over 75 % of the labor force. The sector is dominated by small-scale farmers, who are the main producers of both food and cash crops (Kimaro and Hieronimo, 2014). Despite the fact that the agricultural sector contributes about 25 % of Tanzania's gross domestic product, evidence suggests it is underperforming (Kassie et al., 2013). A number of factors contribute to this situation. In the first place, farmers face imperfect markets. As in many developing countries, credit markets are not well established in Tanzania, and rationing of credit to farmers is therefore frequently reported (Asfaw et al., 2012; Weber and Musshoff, 2012). A study by Kimaro and Hieronimo (2014), which examined challenges and opportunities in relation to agricultural land in Tanzania, found that productivity in the country is declining. To overcome such trends and encourage productivity as well as resilience-enhancing investment, formal titling might help.

While several studies have studied the effects of land rights in urban areas of Tanzania (Kombe, 2005; Magigi and Majani, 2006), little is known about the impact of rural land reforms under the village land act. Pallotti (2008) investigated the relationship between decentralization of the reforms and implementation of the 1999 land laws and concluded that land reforms play a crucial role in facilitating land markets. Kassie et al. (2013) investigated the adoption of sustainable agricultural practices in smallholder systems and found that investments in sustainable agriculture were mainly influenced by tenure status of the plot, plot size and household assets. Yet, there is still limited information on the impact of land titling reforms on agricultural production.

In this paper, we study the effect of land titles on agricultural productivity in Tanzania and assess the potential mediating effect of access to credit. As our study is based on observational data, we employ propensity score matching to determine the land titling effects. The contribution of this paper to the existing literature is threefold. First, we contribute to the general literature on the impact of land titling on agricultural performance. Second, we investigate whether access to credit is an important mediating variable. Third, we assess whether households respond differently depending on farmer and land characteristics. The remainder of the paper is organized as follows. The next section presents the theoretical framework. Section 3 presents a review of empirical studies about land titling. Materials and methods are presented in Section 4, and Section 5 presents the results. Our discussion and conclusion are presented in the last section of the paper.

2.2 The evolution of land rights in Tanzania

Historically, landholding in Tanzania was based on customary laws of almost 120 ethnic groups. Land ownership was communal, owned by families, clans or ethnic groups, and the power of land administration lay with chiefs, headmen and adults trusted by the community. The German rule interrupted the system in 1884, later on followed by British rule (Tsikata, 2003), which declared land to be public. After the First World War, Tanganyika, as Tanzania was still known, became a trust territory under the British, who passed their major land tenure registration in 1923. The so-called Land Ordinance Cap 123 stipulated that all occupied and unoccupied land was public.

After independence in 1961, the Tanganyikan/Tanzanian government inherited the colonial land tenure system with some minor modifications. The basic principle of customary land policy continued to exist where occupants continued to use, maintain and control land.

However, after 1963 the chiefs and elders were gradually replaced by elected village councils, and in 1995, land came under control of the president. For both economic and social reasons, the government realized it needed a land policy to define land tenure. The process was initiated taking into consideration both urban and rural land and the role of customary land tenure. Currently, the fundamental title is vested in the president as the trustee on behalf of all citizens. The commissioner for land is the sole authority responsible for overall administration of all land. However, the power has been delegated to authorize land officers at district/municipal level. The village councils manage all village lands with advice from the commissioner for lands, while reserved lands are managed by statutory bodies (United Republic of Tanzania, 1999).

Since 2004, the government has implemented land reforms as part of the land policy of 1999. Important components of these reforms are the land certificates of customary right of occupancy (CCRO). The CCRO is effected under the property and business formalization program. Before villagers are entitled to acquire land titles, two important conditions must be met. First, the village land use plan needs to be in place. Second, a land registry needs to be available. The land use plan is prepared in a participatory manner, involving a team of expert land officials or surveyors and the villagers. This is a document that defines land use categories and ownership within the village boundaries (Kironde, 2009). The planning process regulates the land use plan by accommodating the needs of the community. During the planning process, conservation of natural resources is given priority. Land, water potential, economic and social conditions are systematically assessed to determine the best land-use options. A land use plan document indicates three categories. The first category is communal village land. In this category, the villagers set aside land for social services such as schools and dispensaries. Land for agriculture and grazing land is clearly specified, while protecting natural resources such as water sources. About 50 meters toward the riverbanks, the area is considered as reserved land. The second category is individual and family land. The third category is reserved land within the village. This land is set aside for future use.

The land titling process is executed in a participatory way involving the village government officials, land committee and the district land department. The process begins at the village level. The village executive officer (VEO) provides the applicant with a standard form to fill in. Details regarding the name of the applicant and names to appear in the land title need to be indicated. Photos must be attached to the application form, and particulars on plot size and location are also specified. Moreover, names of neighbors bordering the applicant's plot are specified as witnesses to verify whether the applicant is the real owner of the plot and whether land is free from conflicts (Pedersen, 2012). The next step is that the VEO includes the list of applicants as an agenda point in the village meeting. The village meeting is the organ responsible for approving the names of applicants as stipulated in the village land policy. Afterwards, the VEO submits the documents to the land department at the district office. Then the district land officer instructs the trained personnel to record the coordinates for the title preparation. Three copies are produced: one is for the owner, and the other two copies are kept by the village government and by the district land registry.

Ideally, the village government is responsible for preparing land titles for its farmers. To maintain standards of the certificate, preparation is done at the district level. It was reported that a title costs about 15-20 US dollars and the survey costs about 15 US dollars, which adds up to 30-35 US dollars per plot (Swagile, 2014). The cost of acquiring land titles in Tanzania is thus higher compared to what has been reported in Ethiopia, where it costs one US dollar to obtain a land title (Melesse and Bulte, 2015), but is lower than in Madagascar, where a title costs 350 US dollars on average (Jacoby and Minten, 2007).

2. 3 Theoretical framework and hypotheses

Similar to the situation in Tanzania, customary land tenure systems are still prevalent in many developing countries. A customary land tenure is a system of land ownership whereby chiefs, clans, or family heads own the land. How the system exactly operates is context-specific, depending on cultural, ecological, socioeconomic and political factors (Cotula and Chauveau, 2007). Under the customary tenure system, inheritance is the most important form of land acquisition (Kalabamu, 2000). In most African societies, a patriarchal system dominates, and men are privileged in terms of land ownership. The system provides limited opportunities for women to own land, despite the fact that they are highly involved in agricultural activities (Cotula and Chauveau, 2007; Kalabamu, 2006).

To overcome perceived limitations of the customary system, many countries have implemented land reforms to introduce formal land titles. The theoretical foundations of these policies are based on property rights theory. Groenewegen et al. (2010) describe property rights as 'the bundle of rights protected by law', comprising the right to use the asset, earn income from it and transfer ownership rights of the asset to others. As explained by Deininger and Feder (2009a), formal land titles (1) can affect agricultural investment (5), productivity (6) and thus income (7) through three main channels: the assurance effect (2), the collateralization effect (3) and the realizability effects (4) (see Figure 2.1). The assurance effect suggests that land titles reduce the risk of land expropriation, and increase the chances of receiving compensation when land is acquired for other uses (Beekman and Bulte, 2012). They may improve the security of farmers by reducing land conflict and serving as a guarantee in court cases. The realizability effect refers to the prospects for collecting future returns. In addition, land titles facilitate allocative efficiency by transferability of land to the hands of those who value it most, for example through leasing (Deininger and Feder, 2009a). The collateralization effect predicts that the use of land title as collateral reduces credit rationing and therefore broadens access to formal credit for more investment and productivity.

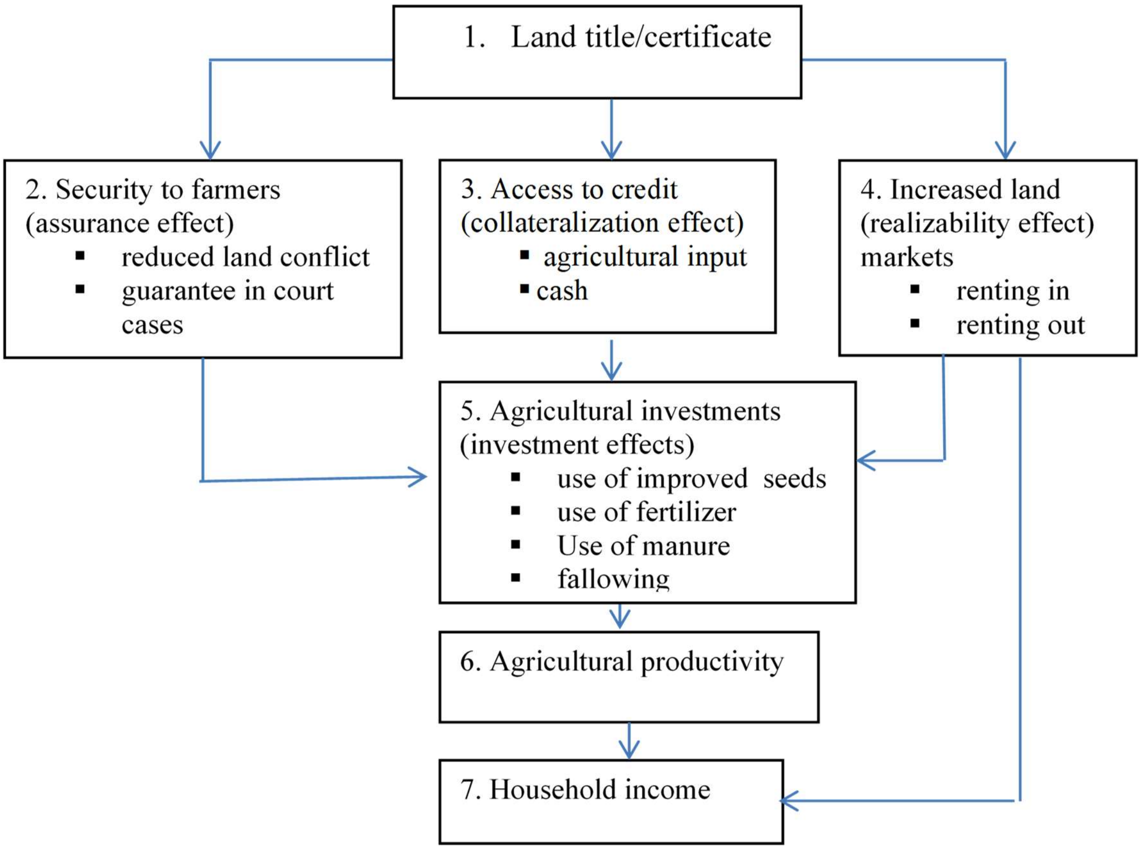

Figure 2.1: Conceptual Framework based on Deininger and Feder (2009a)

Despite these positive theoretical predictions, a review paper by Place (2009) on property rights in African agriculture concludes that effects are heterogeneous across countries and across households within the countries. The effects vary based on the existing institutional environment within the specific country implementing the reform, and two opposing categories of empirical evidence exist. The first category of empirical evidence comes from papers which hold that formal land titles improve land security and increase agricultural investments and productivity (Melesse and Bulte, 2015; Place, 2009). Evidence on the importance of property rights in contributing to long-term investment includes the planting of perennial crops, for example cocoa in Ghana and trees in Uganda and Zambia (Besley, 1995; Deininger and Jin, 2006; Do and Iyer, 2008), or leaving land fallow to improve soil fertility (Goldstein and Udry (2008). Apart from the effect of land title on productivity, Markussen (2008) suggests a positive association between land title and increasing land value. Beekman and Bulte (2012) examine the relationship between measures of institutional quality and existing links between land tenure security, social norms, and investments in land in Burundi. The authors suggest that erosion management is positively influenced by land tenure security. Evidence gathered by Yegbemey et al. (2013) and de Jalón et al. (2015) indicate the link between property rights to farmers' decisions in adapting to climate change in Benin. (Melesse and Bulte, 2015) show that the appearance of the names of both husband and wife on the land title exerts an additional positive impact on agricultural productivity.

The second category of studies finds that formal land titles have limited or no impact on investment. For example, Deininger and Jin (2006) find that land titles have no effect on terracing investments in Ethiopia. This could be because customary land tenure is relatively efficient, as it measures efficiency in terms of land access and conflict resolution within communities. Furthermore, there may be distributional issues. Deininger and Feder (2009b) report that formal tenure security outweighs secondary rights such as firewood collection by the poor. Finally, land titling is not costless. Deininger and Feder (2009a) and Jacoby and Minten (2007) indicate that the efficiency gains from formalization may be outweighed by the costs –depending on the nature of the formalization procedures.

To contribute to the evidence on the impact of land titling, we test the following hypotheses:

In the southern highlands of Tanzania, the productivity of the titled plots is higher than the productivity of the untitled plots (H1).
This is the result of higher agricultural investments in seeds, fertilizers, and manure (H2)

To explore potential underlying mechanisms, we look into the role of credit. As explained above, the introduction of formal land titles may increase access to credit (collateralization effect). Several empirical studies have found a positive impact of land titling on credit access (e.g., Carter and Olinto (2003); Boucher et al. (2008); Piza and de Moura (2016); Goldstein and Udry (2008); and Deininger and Feder (2009a)). These studies suggest land titles can be pledged by farmers as collateral to access credit, thus promoting agricultural investment and increasing productivity. A study conducted by Dower and Potamites (2014) on the importance of land title on signaling creditworthiness in Indonesia concludes that land title not only affects credit access but also determines the size of the loan. However, in Tanzania, where the formal credit market is not well developed, formal loans may be inaccessible to farmers even with a formal land title. We therefore test the following hypothesis:

Households with titled plots in the southern highlands of Tanzania are more likely to use credit (H3).

The effects of land titling are likely to depend on the socioeconomic characteristics of the titled households. We therefore extended our analysis to ask who benefited most from land title ownership and by how much, using subsample analysis (Do and Iyer (2008) Melesse and Bulte (2015). Land titling will be most beneficial for those willing and able to invest in improved technologies. We expect this willingness to be greater for younger farmers, who have a longer time to profit from them. In addition, we expect willingness to invest to be greater for larger plots due to economies of scale.

The effects of land titling are greater for larger plots and for plots owned by households with older heads (H4).

2.4 Data and empirical strategy

2.4.1 Study area and sampling procedure

We conducted our study in the southern highland zone of Tanzania, in the Mbeya and Ruvuma regions. We employed a multi-stage sampling procedure. In the first stage, we selected three districts: Mbozi and Rungwe districts from the Mbeya region, and Mbinga district from the neighboring Ruvuma region. These three districts are among the most promising districts in terms of food and cash crops production in the country, and they produce similar crops, mainly coffee, maize and beans. The land titling program was initiated in 2004 and implemented in Mbozi before being up scaled to other districts. The land titling program was introduced to households in Rungwe as part of the program up-scaling in 2010 before we collected our data. By the time of the data collection, Rungwe was only partly titled. Mbinga district was selected because farmers were not exposed to land titling by the time of the survey in 2013/2014.

The second stage of the sampling procedure involved a random selection of villages. In total 34 villages were selected: 14 from the titled district (Mbozi), 8 villages from the partly titled district (Rungwe) and 12 villages from the non-titled district (Mbinga). We used simple random sampling to select households from the village register. The majority of households in Mbozi had titled their land, and we randomly selected 263 households from the subsample of titled households (covering 571 titled plots and 38 untitled plots). Random sampling was also employed to select 148 households in Rungwe: these households owned 67 titled and 138 untitled plots. In the Mbinga, 206 households were selected covering 538 untitled plots. In total, 1,352 plots were included in the analysis.

2.4.2 Data collection

We used structured questionnaires for data collection. We used local enumerators to interview household heads in Swahili, and collected information on household characteristics, plot characteristics, and tenure status. The data included information on total land in acres cultivated, plot size, and plot slope (flat, gently sloped, or steep). Moreover, information on production costs for seeds, labor, fertilizer, pesticides and herbicides were collected, as well as crop output and prices. Maize, beans and bananas were the main food crops. Maize and bananas are regarded as both staple and cash crops, while coffee is the major cash crop. We also collected information on whether the household had experienced land conflict.

Information on institutional arrangements and the implementation of the land titling program and its costs were collected at the village level. Focus group discussions were conducted, involving farmers, village leaders and village land committee members. We consulted land officials at ministry and district levels for more insight into the program. Consultative meetings with loan officers from financial institutions provided a broad picture of credit in relation to land titles.

2.4.3 Outcome indicators

Our first outcome variable is productivity. Place (2009) describes productivity as total output divided by land size. Other scholars consider total factor productivity. Chand and Yala (2009) measure agricultural productivity as the ratio of agricultural output to the input used in production. In this paper, we measure productivity as the final market value of output minus costs per acre.

Agricultural investment is measured by three indicators: the use of higher-yielding or improved seed varieties, the use of chemical fertilizers, and the use of manure. The use of improved seeds and chemical fertilizers is considered as a short-term investment. Both are measured as the logarithm of the value of purchases. The use of manure is considered a long-term investment to enhance soil fertility and productivity. It is measured as a binary variable: manure used or not used. The outcome variable is the use of credit. This indicator as well is used as a binary variable: use of credit, yes or no.

2.4.4 Summary statistics of the variables

Summary statistics of key variables are presented in Table 2.1. Titled and untitled households were similar in terms of age, education, and gender and conflict experience. However, other variables were different, which may reflect the non-randomness of land titles. Notably, titled plots were larger, more likely to be flat, and part of larger farms, somewhat closer to the market. We therefore controlled for these variables.

Table 2.1: Summary statistics of variables used in analysis

Variable	Titled (N=573)	Untitled (N=674)	Pr (|T|t)
Household and plot characteristics			
Age of household head (years)	52.00 (13.128)	51.003 (13.060)	0.299
Number of years of schooling of household head	7.120 (2.654)	7.145 (1.891)	0.847
Male head of household	0.948 (0.221)	0.952 (0.213)	0.505
Household size	5.853 (1.596)	5.266 (1.782)	0.000
Farming as a main economic activity	0.928 (0.258)	0.953 (0.213)	0.071
Total land cultivated (acres)	8.785 (4.978)	5.785 (4.194)	0.000
Plot size cultivated (acres)	3.597 (2.869)	2.226 (1.732)	0.000
Plot with flat slope	0.583 (0.494)	0.293 (0.456)	0.000
Distance to the market (km)	9.306 (8.438)	11.966 (11.624)	0.000
Household with experience in land conflict	0.140 (0.346)	0.160 (0.367)	0.311
Outcome variables			
Productivity (value of output minus costs per acre in TZS)	313014.2 (433300.1)	198835.5 (335922.1)	0.000
Use of improved seeds (value of seeds per acre in TZS)	5502.526 (10462.65)	3802.485 (10975.07)	0.000
Use of fertilizer (value of fertilizer per acre in TZS)	75071.48 (80075.79)	50176.84 (73529.51)	0.000
Dummy =1 if accessed credit	0.246 (0.431)	0.135 (0.342)	0.000
Dummy = 1 if used manure	0.887 (0.317)	0.921 (0.269)	0.036

Standard deviations are presented in parentheses *** p<0.01, ** p<0.05, * p<0.1

TZS =Tanzania Shilling (one dollar is equivalent 2200 TZS)

2.4.5 Land titling impact estimation methods

We used propensity score matching (PSM) as the primary estimation technique to measure the impact of land titling on productivity. The propensity score is based on the conditional probability of assignment to a particular treatment, given observed covariates Rosenbaum and Rubin (1983). PSM has two key assumptions. The first assumption is the conditional independence assumption (CIA). For a given set of observable characteristics that are unaffected by the treatment, the potential outcomes are independent of the treatment assignment. The second condition is a common support or overlap condition, represented by 0 <P (D=1|X<1). This is a region where the score has positive density for both the treatment and comparison group, so subjects have a probability of receiving either treatment (Rosenbaum and Rubin, 1983). Hence, the PSM technique controls for selection bias due to observable characteristics if the samples are sufficiently similar (Heckman et al., 1997). We employed a logit model to generate the propensity scores. We then used the scores for matching observations from titled and untitled plots. In this process, we followed (Heckman et al., 1997) and Austin (2011) who assume that potential confounders are associated with treatment assignment and the outcome variables. In our model, D*i* is a binary variable that takes the value 1 if plot *i* is titled, and 0 otherwise. Our outcome variable productivity is denoted as Y*i* (D*i*), where *i* = 1*;.....N,* and *N* indicates the total number of plots. The average treatment effect on the treated is specified as follows:

$$T_{ATT} = E\,(T|D=1) = E[Y(1)|D=1] - E[Y(0)|D=1] \,, \quad (1)$$

Where ATT is the average treatment effect on the treated, E[Y(1)|D=1] is an expected productivity for a titled plot and E[Y(0)|D=1] is the expected productivity for the counterfactual.

We performed our analysis by using nearest neighbor (n=3) matching techniques with replacement. The algorithm matches treated individuals with non-treated individuals based on the proximity of the propensity score (Kassie et al., 2013). The algorithm reduces bias in matching because untreated subjects can be matched to more than one treatment individual (Dehejia and Wahba, 1999). After matching, we employed bootstrapping to estimate the correct standard errors. Finally, we performed balancing tests to check for similarities in covariates between titled and untitled samples. The tests enabled us to determine whether the balancing requirements of the propensity scores were satisfied (Austin, 2011; Dehejia and Wahba, 2002; Rosenbaum and Rubin, 1983).

To assess heterogeneous treatment effects, we categorized household heads into two groups of comparable size for each characteristic of interest: household head younger or older than 50 years, and household head that cultivated an average of up to or above 2 acres.

2.5 Empirical results

2.5.1 Propensity scores and balancing tests

Our first step was to generate propensity scores. Table 2.2 presents the logit estimates. In agreement with the descriptive statistics, the factors that predict that households will be in the titled group are household size, total land cultivated, average plot size cultivated, flat slope plot, and distance to the market.

Table 2.2: Estimation of logit model (standard errors are in parentheses)

VARIABLES	scores Titled
Age of household head (years)	0.003
	(0.005)
Number of years of schooling of household head	-0.017
	(0.031)
Farming as a main economic activity	-0.098
	(0.286)
Male head of household	-0.360
	(0.298)
Household size	0.181***
	(0.039)
Total land cultivated (acres)	0.107***
	(0.020)
Average plot size cultivated (acres)	0.160***
	(0.040)
Plot with flat slope	1.154***
	(0.130)
Household experienced land conflict	-0.287
	(0.186)
Distance to input market	-0.038***
	(0.007)
Constant	-2.035***
	(0.633)
Observations	1,247

*significance at 10 %, ** significance at 5 % and *** significance at 1 %

To evaluate whether changes in agricultural productivity can be attributed to the titling program, we employed the nearest neighbor (n=3) matching algorithm to match the covariates. Matching was done only on plots found in the region of common support [0.07855379, 0.99586597]. Ten untitled plots and zero titled plots were off support and therefore dropped. Figure 2.2 shows the distribution of propensity scores on the region of common support.

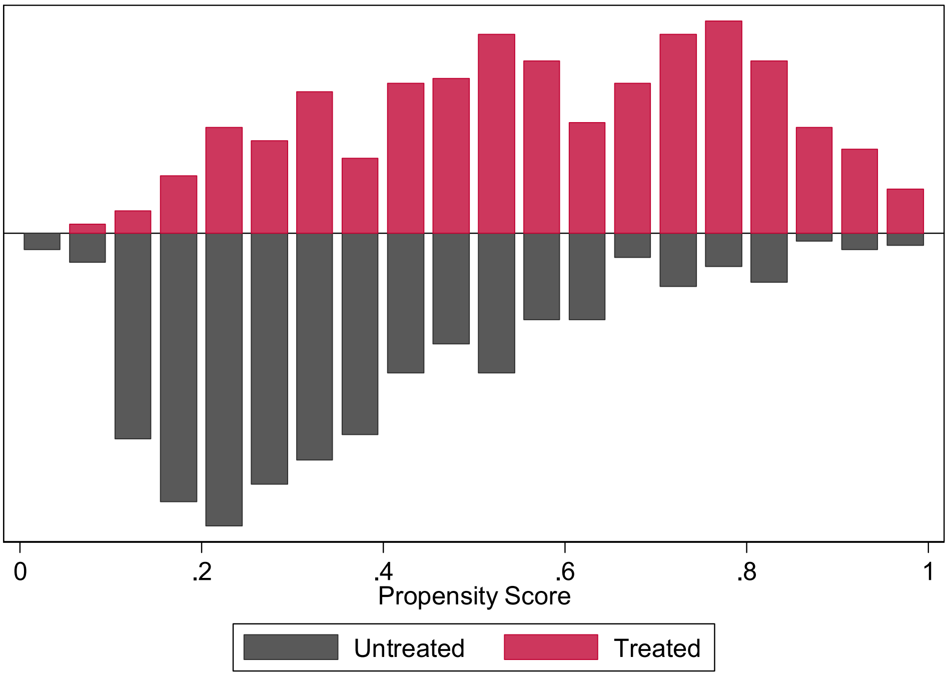

Figure 2.2: Histogram showing the distribution of propensity scores on the region of common support after matching

We employed two-sample t-tests involving all observables to check whether there was a significant difference between covariate means for titled and untitled plots (Rosenbaum and Rubin, 1985). We expected significant differences in covariate means before matching, while after matching covariates should be balanced (Caliendo and Kopeinig, 2008). The results in Table 2.3 show that matching has indeed solved the imbalances in the original sample.

Table 2.3: T-test for equality of means for individual variables before and after matching in full sample

Variable	Description	Mean treated	Mean control	% reduction bias	t-test P>(|t|)
Age of household head (years)	Unmatched	51.82	50.976		0.234
	Matched	51.476	52.665	-9.2	0.144
Years of schooling for household head	Unmatched	7.119	7.135		0.898
	Matched	7.113	6.947	7.1	0.271
Male head of household	Unmatched	0.948	0.951		0.830
	Matched	0.949	0.943	2.7	0.678
Household size	Unmatched	5.861	5.264		0.000
	Matched	5.855	5.840	0.9	0.883
Faming as a main economic activity	Unmatched	0.935	0.954		0.149
	Matched	0.927	0.939	-5.1	0.441
Total land cultivated (acres)	Unmatched	8.572	5.787		0.000
	Matched	9.900	8.813	1.8	0.802
Plot size cultivated (acres)	Unmatched	3.569	2.231		0.000
	Matched	3.689	3.593	3.9	0.588
Plot with flat slope	Unmatched	0.577	0.290		0.000
	Matched	0.579	0.577	0.4	0.957
Distance to the market	Unmatched	9.306	11.966		0.000
	Matched	9.471	9.031	4.4	0.389
Household never faced land conflict	Unmatched	0.131	0.157		0.182
	Matched	0.147	0.152	-1.5	0.812

Our covariance balance indicators before and after matching are identified. Sianesi (2004) suggests the importance of re-estimating propensity scores on the matched sample and comparing the pseudo R^2 of before and after matching. Results of the pseudo R^2 test for the joint significance estimated by the logit model are presented in Table 2.4. Before matching, our Pseudo R^2 was 0.1700 while after matching, it was low at 0.003. Moreover, after matching our chi square was 0.93.

Table 2.4: covariance balance indicators before and after matching

Before matching	**0.1700**
Pseudo R^2	0.0000
Kernel – based matching	
Pseudo R^2	0.003
LR χ^2 (p-value)	4.26 (0.935)

2.5.2 Land titling and productivity

Table 2.5 shows that the average treatment effect (ATT) of land titling on productivity is positive: Having a land title increases land productivity, as measured by value of produce minus costs per acre, by 100,493 Tanzanian Shilling (TZS) ($p<0.01$). Since untitled plots had a productivity of 198,836 TZS on average (Table 2.1), this implies that titled plots had 51 % higher productivity on average. This finding provides strong support for the hypothesis that productivity of the titled plots is higher than the productivity of the untitled plots (result 1).

Table 2.5: Average treatment effect: nearest neighbor matching

Variable	**ATT**	**Bootstrap standard error**	**P>|Z|**
Productivity	100492.8	34070.49	0.003

PSM assumes that all variables causing sample selection are controlled for. We adopt Rosenbaum rbounds to gauge deviations from the conditional independence assumption (CIA). For the analysis, we set a maximum value of ɼ to 1.5 with an increment of 0.1. Table 2.6 shows the gamma, which is the odds of the differential assignment to treatment due to unobserved bias. We found that our analysis is insensitive to a bias that would increase the odds of treatment by up to 20 %. We therefore conclude that our results are somewhat robust to hidden bias from unobserved confounders.

Table 2.6: Robustness of the ATT estimates to unobserved heterogeneity (rbound tests)

Gamma	sig+	sig-	t-hat+	t-hat-	CI+	CI-
1	0.00	0.00	50289.3	50289.3	21377.5	80750
1.1	0.01	0.00	35620.7	65412	7298.5	96790
1.2	0.06	0.00	22486.2	79393.6	-5262.5	111596
1.3	0.22	0.00	10692.7	92766.6	-16958.3	125940
1.4	0.49	0.00	229.167	104995	-27830	139113
1.5	0.75	0.00	-9717	116908	-37520.7	151846

gamma - log odds of differential assignment due to unobserved factors
sig+ - upper bound significance level
sig- - lower bound significance level
t-hat+ - upper bound Hodges-Lehmann point estimate
t-hat- - lower bound Hodges-Lehmann point estimate
CI+ - upper bound confidence interval (a= .95)
CI- - lower bound confidence interval (a= .95)

2.5.3 Mechanisms by which land titles improve productivity

We extended our analysis by investigating how land titles increase productivity (Table 2.7). First, we assessed the relationship between land titling and three indicators of agricultural investment: use of improved seeds, use of fertilizer, and use of manure. We found significant positive effects for all three indicators, though the effect on manure use was significant only at the 5 % level. Combining information from Table 2.1 and Table 2.7, we conclude that land titling increased expenditures on improved seeds by 39 % and expenditures on fertilizers by 49 %. Surprisingly, households with titled plots had a lower chance of applying manure to their plots. However, the effect is small: a decrease of 4 % from the high probability of 92 %. Hence, we find that farmers increase the use of short-term inputs (fertilizers) on their titled plots, but do not invest in long-term land productivity (manure) (result 2).

Table 2.7: Average treatment effect on the treated (ATT): Nearest neighbor matching on intermediate variables

Variable	ATT	Bootstrap standard error	P>|Z|
Use of improved seeds (value per acre)	1479.739	757.4546	0.051
Use of fertilizer (value per acre)	24369.5	6564.666	0.000
Use of manure in main plots	-0.04	0.022	0.043
Credit use	0.03	0.031	0.339

Second, we zoom in on the role of credit: did the increased use of inputs result from the collateralization effect? We find that the likelihood of using credit does not depend on the titling status of the plot. In conclusion, we find no evidence of the collateralization effect of land titling (result 3).

2.5.4 Heterogeneous treatment effects

We considered the effects of land titling on the mechanism variables when households were classified into groups according to age and farm size (Table 2.8). Younger farmers had the highest yield response, whereas older farmers surprisingly had the highest fertilizer response. These results seem contradictory. Contrary to expectations, we found a higher productivity response for smaller plots. This is attributable to a higher fertilizer response, as the seed response was higher for larger plots. These findings are the basis for result 4: the effects of land titling depend on the age of the farmer and the size of the plot.

Table 2.8: Heterogeneous treatment effects of land titles on the mechanism variables

	n	Productivity (value TZS)	Improved seeds (value TZS)	Fertilizer (value TZS)	Manure	Credit
Age head						
<50 years	606	137582***	991	14739*	-0.03	-0.03
		(44073)	(991)	(8806)	(0.03)	(0.05)
>= 50 years	641	52310	1461	31418	-0.04	0.02
		(37156)	(945)	(8278)***	(0.03)	(0.06)
Plot size						
=< 2 acres	696	142114***	1207*	15087*	-0.04	0.05
		(38855)	(726)	(8576)	(0.03)	(0.05)
>2 acres	551	52418	1808**	3095***	-0.03	0.01
		(48790)	(779)	(6817)	(0.04)	(0.05)

*significance at 10 %, ** significance at 5 % and *** significance at 1 %

2.6 Discussion and conclusion

In this paper, we test the relationships between land titles ownership and agricultural productivity. Four hypotheses guided this study: First, the productivity of the titled plots is higher than the productivity of the untitled plots. Second, this increased productivity is the result of higher investment in improved seeds, inorganic fertilizers, and manure. Third, land titles increase the use of credit (collateralization effect). Fourth, the effects of land titles depend on the age of the farmer and the size of the plot. We find evidence in support of only part of these hypotheses, as detailed below.

Conform hypothesis 1, we find that land titled plots had much higher productivity than untitled plots. The results for hypothesis 2 are mixed. The higher productivity was associated with a higher use of improved seeds and inorganic fertilizers but contrary to expectations, manure use was slightly lower for titled plots. This seems to suggest some substitution of organic for inorganic fertilizers. However, the effect was small and more than 90 percent of all farmers used manure. We reject hypothesis 3 that land titling would increase the use of credit. Conform the limited development of the formal credit market in Tanzania, land titling did not result in additional borrowing. This implies that the farmer responses that we observe resulted from the assurance and realizability effects of land titling and not from the collateralization effect. With higher potential access to formal credit, the effects of land titling would likely be higher.

We find support for hypothesis 4: the effect of land titling depended on age and plot size. Interestingly, productivity effects were largest for smaller plots, where farmers intensified fertilizer use more than on larger plots. Older farmers responded more to titling in terms of additional fertilizer use, but younger farmers achieved higher productivity responses. These sub-group findings are surprising and warrant more research.

This study has limitations. We use cross-sectional data from a non-randomized titling program. We employed propensity score matching to try to construct an artificial control group, but some bias may have remained. While randomized allocation of land titling may be unrealistic, with careful timing construction of a panel data set of land titling would be possible. Such data would allow analyses with lower risk of bias.

Chapter 3

Does crop diversity matter to rural household dietary diversification? Evidence from the southern highlands of Tanzania

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Abstract
This paper investigates the relation between crop diversity and dietary diversity in the southern highland regions of Tanzania and the moderating role of the market in this context. Our empirical analysis uses household survey data from 1,393 members of farmer organizations. We found that farm households with higher crop diversity also had higher dietary diversity, whereas farm households who lived farther from the market had lower dietary diversity. Interestingly, these conclusions hold for household-level dietary diversity indicators, which measure economic access to food, but not for the indicator of women's dietary diversity, which measures these diet quality. For rural farm households with better access to markets, crop diversity on the farm played a smaller role in dietary diversity**.**

Keywords: Crop diversity, Dietary diversity, Market access, Tanzania

3.1 Introduction

Food insecurity and undernutrition remain on the rise in many sub-Saharan African countries (Habtemariam et al., 2021; Usman and Callo-Concha, 2021). Over 204 million people in sub-Saharan Africa are undernourished (Bain et al., 2013; Koppmair et al., 2017). Food and nutrition security is influenced by the quantity of available foods and their diversity. Consequently, household food security is highly dependent on access to healthy, diverse and affordable food (Ruel et al., 2017).

While women play a substantial role in agricultural production in sub-Saharan Africa, a large proportion of them are affected by food and nutritional insecurity (Koppmair et al., 2017). A report on the State of Food Security and Nutrition in the World 2020 (SOFI) show that more than 30% of children under the age of five years in sub-Saharan Africa are chronically undernourished and lack access to micronutrients (FAO et al., 2020). Empirical findings suggest that less than half of women in parts of rural Tanzania consume enough food groups to meet minimum dietary requirements (Madzorera et al., 2021). Another vulnerable group is children. [1]The Tanzania Demographic and Health Survey of 2015 showed that 34% of children under five years of age are stunted (URT, 2016b). Starchy staples dominate the diets of most rural households (Fanzo et al., 2013), which are characterized by low intake of animal-protein source foods, fruits, and vegetables, with an accordingly poor micronutrient intake (Chatzivagia et al., 2019).

In order to improve the quality of rural diets, a number of studies have suggested the strategy of increasing crop diversity in agricultural production (Frison et al., 2011; Sibhatu et al., 2015b). There are at least three arguments for this approach. First, diversification stabilizes income if the returns for different crops are not perfectly covariate, which limits the need for precautionary savings. Second, farmers' own produce often makes up a considerable portion of their food consumption. A larger diversity of produce then may directly affect consumption diversity and diet quality. Finally, crop diversity may help to limit losses due to pests and diseases, and reduce risks of crop failures (Makate et al., 2016; Pellegrini and Tasciotti, 2014). This could result in higher income, which can be used to improve diets.

Yet the impact of the diversification strategy on diets is contested. Diet quality may instead improve if farmers specialize in the production of a small number of crops for the market. If specialization increases efficiency (and hence, income and purchasing power), specialized households would generate higher incomes which could be used to purchase components of a diverse diet. In this scenario, a negative association between crop diversity and dietary diversity could exist. The empirical evidence is mixed, with some studies showing a positive association between crop and dietary diversity (Arimond et al., 2011; Hoddinott, 2012; Jones, 2017; Jones et al., 2014; Malapit et al., 2015; Prize et al., 2015; Rajendran et al., 2014; Ruel et al., 2013; Sibhatu et al., 2015b) and others finding the reverse (Hirvonen et al., 2017; Sibhatu et al., 2015a; Stifel and Minten, 2017).

[1] Moreover, the Tanzania National Nutrition Survey (TNNS) (2018) reports that children aged between 6 and 23 months consume three food groups on average out of seven. These statistics highlight limited access to diversified diets.

Besides on-farm crop diversity, the development and proximity of food markets may substantially influence diet diversity. Proximity to consumer markets offering a diversity of foods ensures the availability of required foods. This is especially important food types that are not easily produced on farms, like certain animal-sourced foods. In addition, good access to markets facilitates the selling of produce and generation of cash income from agriculture, which then can be used to buy diverse foods. The degree of access to food markets may thus moderate the relationship between crop diversity and diet diversity: closeness to markets provides economic access to market-based diverse and healthy diets and decreases the need for production diversity. Put differently, for households close to well-developed food markets, production and consumption decisions may be separable, meaning that they cultivate the crops that generate the most income and subsequently allocate this income to various types of food and nonfood consumption to maximize utility. For households far from markets, production and consumption decisions may instead be non-separable: what they produce affects their consumption pattern. The diverging results from existing studies could therefore be at least partly explained by differences in market access.

The objective of this study is to assess the nexus between dietary diversity, crop diversity and market access in the southern highland regions of Tanzania. The paper extends the literature in two ways. First, we study not only how dietary diversity is related to farmers' own production and proximity to the market, but also the interaction between these two factors. By doing so, we hope to be able to shed light on a potential mechanism underlying the large differences in outcomes between existing studies. Specifically, we test the following hypotheses: 1) farm households with higher crop diversity also have higher dietary diversity; 2) farm households who live farther from the market have lower dietary diversity; and 3) the association between crop diversity and dietary diversity is stronger for households further from the market. Second, we extend the literature about crop and dietary diversity by complementing household-level measures of dietary diversity with an individual-based measure, which is rare in the empirical literature on the relation between crop and dietary diversity (with Koppmair et al. (2017) as the exception). We use the Women's Dietary Diversity Score (WDDS), which mainly reflects micronutrient adequacy for women, a relatively vulnerable group for malnutrition (Islam et al., 2018a; Rajendran et al., 2017) in addition to the commonly used Household Dietary Diversity Score (HDDS), a validated measure for economic access to food (Kennedy et al., 2011a), and the household-level Food Variety Score (FVS), an unvalidated measure of dietary diversity. Though each of these indicators measures a somewhat different aspect of food security, we have no reason to believe *ex ante* that the different measures will give different results. Hence, we hypothesize that the relationships between crop diversity, diet diversity and distance to the market are qualitatively the same for our different indicators of diet diversity.

The remainder of the paper is organized as follows. Section 2 presents our data and regression models. Section 3 presents the empirical results and discussion. Section 4 covers the conclusion and recommendations.

3.2 Materials and Methods

3.2.1 Data collection

Our empirical analysis is based on household survey data. We collected cross-section data in the regions of Mbeya and Songwe, Tanzania.[2] These are located in the southern highlands, which are Tanzania's food basket and produce most of its food crops, such as maize, rice, beans, groundnuts, and soybeans. In addition, coffee is grown as a cash crop by many farmers. The data was collected in October-November 2016, which was shortly after harvest. This is the period when the supply of food is relatively plentiful and people eat their "typical diet"

The sampling strategy followed a combination of methods. Two districts from each region were selected purposively: Mbozi and Momba from the Songwe region, and Mbeya rural and Mbarali districts from the Mbeya region. These districts were selected because of their potential for crop production. Then 51 farmer organizations were identified, and a random selection of their members was included in the study. In total, 1,393 households participated in the study.

The main tools of primary data collection were two pre-tested structured questionnaires: one for the household head, and another for the adult woman responsible for food preparation. When the household head was absent or the head was a woman, the adult woman filled out both questionnaires. If the adult woman mainly responsible for cooking was absent, we interviewed a knowledgeable household member who also participated in cooking and was well informed about the household's consumption expenditures. The household-head questionnaire aimed to capture information on agricultural production during the previous cropping season, such as land size, number, type of crops grown and access to extension

[2] The data is part of the impact evaluation of a program implemented by the Netherlands Development Organization (SNV) to increase agricultural productivity (IPIAP). Data was collected jointly by Wageningen University and Research Centre (WUR) in the Netherlands and Sokoine University of Agriculture (SUA).

services. Moreover, we collected data on the distance to agro-dealers, the market and tarmac roads. The adult woman questionnaire captured demographic and socioeconomic characteristics such as age, gender, educational level of all household members and whether a household engaged in off-farm employment. We also collected information on productive assets and total livestock owned and, importantly, on dietary patterns of the respondent and the household (see below).

3.2.2 Measuring dietary diversity and crop diversity

As indicated in the introduction, we used three complementary measures for diet quality and food security: WDDS, HDDS, and FVS. WDDS is significantly different from the other two: it is based on different data and has a somewhat different interpretation as explained below (also see Table 3.1).

WDDS is based on a qualitative 24-hour recall. Respondents were asked to recall all food items and beverages that they themselves consumed in the 24 hours before the interview (FAO, 2010). Based on this data, we computed the WDDS using the nine food groups recommended by the FAO (2010): (1) starchy staples, white roots, and tubers; (2) dark-green leafy vegetables; (3) vitamin-A rich fruits and vegetables; (4) other fruits and vegetables; (5) meat and fish; (6) eggs; (7) legumes, nuts, and seeds; (8) milk and milk products; and (9) organ meats. This choice of food has been tailored to reflect the quality of the individual's diet and the probability of micronutrient adequacy for women, and the measure computed with this procedure has been validated as such (FAO, 2010). FAO recommends the relatively short 24-hour recall period, because it is not so prone to recall errors, is less cumbersome for the respondent than larger recall periods, and has been applied in many studies e.g., Koppmair et al. (2017). As diets may differ from day to day, a single 24-hour recall WDDS may not provide an adequate measure at the individual level, but this disadvantage is canceled out at the group level. The Women's Dietary Diversity Project (WDDP) Study Group (Martin-Prevel et al., 2017) established that a cutoff of ≥ 5 reflects minimum required level of dietary diversity for women of reproductive age.

HDDS and FVS are frequently used indicators for dietary diversity in economic studies, as they can be easily calculated from standard food consumption modules in questionnaires, which ask questions on consumption of an extensive list of food items over the past seven days. We follow this convention as a point of comparison with the existing literature on the relationship between crop diversity and diet diversity. To calculate the HHDS, we classified the foods into 12 distinct food groups: (1) cereals; (2) roots and tubers; (3) vegetables; (4) fruits; (5) meat and poultry; (6) eggs; (7) fish and seafood; (8) pulses, legumes, and nuts; (9) milk and dairy products; (10) oils and fats; (11) sugar and honey; and (12) spices, condiments, and beverages (FAO, 2010). The HDDS is equivalent to the number of food groups consumed by a household in the past 7 days. This HDDS has been validated as an indicator of a household's economic ability to access a quantity, quality and variety of food that ensures better nutrition of all household members (FAO, 2010). There is no established cutoff point for adequate diversity in the HDDS (FAO, 2010). The FVS simply counts the number of food items from the list that have been consumed (Ruel, 2003). The FVS is not a validated measure.

Table 3.1: Comparison of the dietary diversity measures

	WDDS	**HDDS**	**FVS**
Target	Adult women	Household	Household
Recall period	24 hours	7 days	7 days
Level of aggregation	9 food groups based on all items consumed	12 food groups based on 47 items listed	47 food items
Intended indication	Quality of the individual diet, Probability of micronutrient adequacy (validated)	Household economic access to food (validated)	Not validated

Based on FAO, 2010

Our key indicator for crop diversity was the crop diversity index (CDI) based on the shares of land allocated to cultivating certain crops. The index was defined as a Simpson Index: 1-$\sum W_j^2$, where the Wj is the proportion of land allocated to crop j in the total land cultivated by the household in the previous cropping season. We computed the farm-level crop diversity index using the proportions of land for 24 crops commonly grown in the region. The index ranges between 0 and 1. A value of 0 means that a household grows only one crop. As the value of the index increases, production becomes diversified and more crops are cultivated and/or the amount of land used to grow each crop becomes more equal. As a robustness check, we also used a simple crop count measure as an alternative indicator for crop diversity.

3.2.3 Empirical strategy

We used a multivariate regression model to investigate the relationship between our dietary diversity indicators (*Y*) on the one hand and crop diversity (*CD*) and distance to markets (*DM*) on the other. We controlled for several demographic and socioeconomic variables (*X*). The model that we estimated reads as:

$$Y= \alpha_0 + \alpha_1 CD + \alpha_3 DM + \alpha_3 X + \varepsilon \quad (1)$$

We first used ordinary least squares regression to estimate this set of equations for the full sample using the CDI as the indicator for crop diversity. Next, we re-estimated the model using a median split for distance to the market. As the median split was only 10 walking minutes, we also estimated the model for households living farther than 30 walking minutes or 60 minutes from the market. As a first robustness check, we re-ran all estimates using the crop count as an indicator for crop diversity crop diversity indicator. Additionally, we estimated the models with CDI using a Poisson estimator with a maximum likelihood procedure.

3.3 Results and discussion

3.3.1 Descriptive statistics

Table 3.2 presents the summary statistics of our variables. On average, diet diversity for women is below the cutoff for adequacy of 5 at 3.4 out of 9 food groups. Low dietary diversity is common among female populations in developing countries, since their diets are mostly based on starchy staples, with little or no animal-sourced foods, fresh fruits and vegetables, which may be explained by socioeconomic status (Olabisi et al., 2021; Ruel, 2003). This finding is consistent with Madzorera et al. (2021), who find that only a minority of women in Tanzania's coastal district of Rufiji met the minimum dietary diversity of 5 food groups, see also (Bellows et al., 2020). The 7-day recall variable indicates that, on average, each household consumed 7.2 food groups out of 12. Considering individual food items, they consumed 11.8 on average.

The CDI and crop count reflect the level of diversification in crop production. Differences between households were quite substantial: some households specialized in the production of one crop, usually maize, rice, or beans, while others grew a variety of crops, up to maximum of eight. Such diversity is not uncommon in a smallholder setting. This heterogeneity allowed us to assess a potential relation between crop and diet diversity.

Market distance and farm size reflect the nature of the sample: members of farmer organizations, who tend to be relatively well-off compared to the average farmer in a high-potential agricultural area. Distance to the market ranged from 0 to 180 minutes, with an average of 24 minutes. This implies that the majority of farmers have relatively easy access to markets, with a smaller group living more remotely. The average farm size was 6.2 acres, compared to the average farm size of less than 2 ha approximately 5 acres (Julien et al., 2019). This implied that the majority of farmers in our sample would be considered medium farmers according to the threshold of 5 acres defined by (Jayne et al., 2016) and Sitko and Jayne (2014) for sub-Saharan Africa. The household size of 5.4 members is somewhat higher than the national average of 4.8 (United Republic of Tanzania, 2013).

Table 3.2: Summary statistics of variables (N=1347, except for WDDS[1])

Variable	Description	Mean	Std dev.	Min	Max
WDDS (N= 1300)	Women's dietary diversity score	3.409	0.990	1	7
HDDS	Household dietary diversity score	7.221	2.141	2	12
FVS	Food variety score	11.782	4.374	2	29
Distance to market	How long does it take you to go from your farm to the nearest agricultural output market (minutes)?	23.909	29.637	0	180
Crop diversity index	Simpson index based on land shares	0.473	0.229	0	0.879
Crop count	Number of crops out of a list of 24 grown by the household	2.754	1.092	1	8
Age of household head	Age in years	50.238	13.142	21	102
Gender of household head	Gender =1 female, 0 male head	0.154	0.361	0	1
Age of woman responsible for cooking	Age in years	43.559	12.483	15	100
Secondary school education of wife/adult woman responsible for food preparations	Education =1 if adult woman completed secondary school education1= Yes, 0= otherwise	0.10		0	1
Household size	Number of members	5.422	2.194	1	16
Dependency ratio		0.432	0.215	0	1
Total land owned (acres)	Number of land acres owned by the head of household	6.168	11.147	0.5	325
Household access to extension officer	Extension officer =1 if household had access, 0 = otherwise	0.394	-	0	1
Total livestock owned by the household[3]		1.733	3.082	0	38.18
Household head completed secondary school	Education =1 if household head completed secondary school education	0.10		0	1
Household head completed primary school education	Education=1 if household head completed primary school education	0.694	-	0	1
Household engaged in off-farm employment	Off-farm employment =1 if household engaged in working off-farm	0.268	-	0	1

[1] The sample size for WDDS is smaller, as in some cases the male household head answered the diet questions when his spouse was not present. Obviously, we can only use the 24-hour recall to calculate WDDS if the respondent was female.

[3] Total livestock calculated based on the tropical livestock unit (TLU) conversion factors (2005) cattle= 0.7, goat = 0.1, pig =0.2, chicken =0.01, rabbit=0.01

As background information, we calculated the percentage of consumption sourced from own produce consumed (Figure 3.1). The rest of consumption was purchased in the market. As expected in a major cereal-producing area, less than 25% of cereals consumed came from the market. The percentage of market foods was also low for two other food types: eggs; and pulses, legumes, and nuts. The percentages of purchased foods for the rest of the food groups were much higher, suggesting that access to the market substantially contributes to a household's dietary diversity (see also (Ochieng et al., 2017).

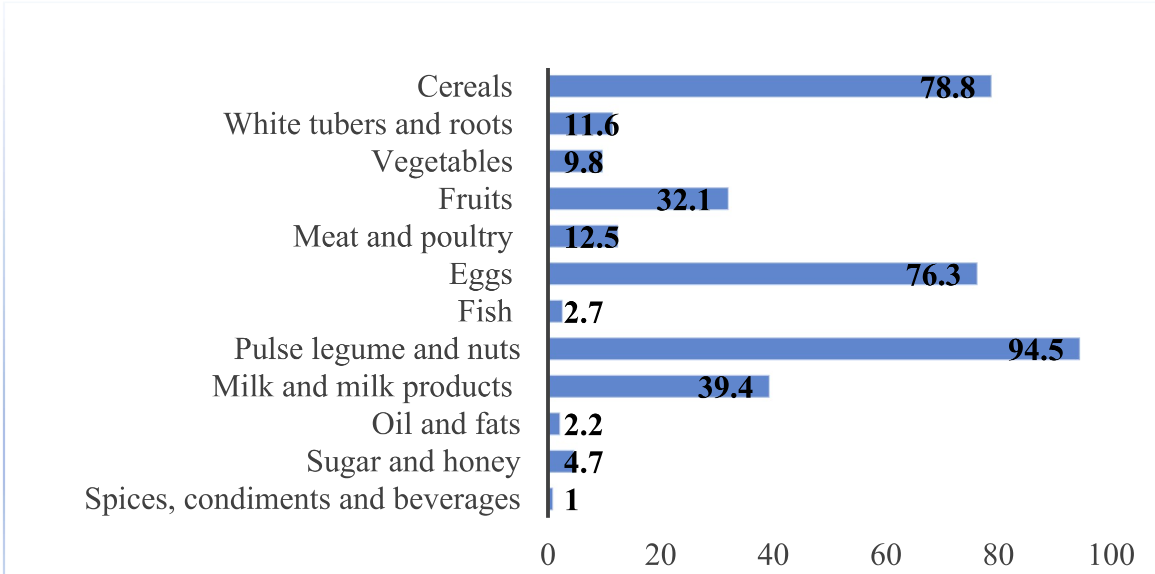

Figure 3.1: Percentages of self-produced foods in household consumption

3.3.2 Regression results

The results in Table 3.3, panel A reveal that a household with the maximum crop diversity observed in the sample (CDI=0.88) had consumed on average 1.1 food groups and 1.2 different food items more in the past 7 days than a household cultivating only one crop (CDI =0). This does not translate to a significantly higher dietary diversity for women in the past 24 hours. Hence, we find support for our first hypothesis at household level, although the effects are not very large, see also (Chegere and Stage, 2020). However, the hypothesis is not confirmed at the individual level: farm households with higher crop diversity have higher household-level dietary diversity, but do not have higher dietary diversity in women (Finding 1).

The results confirm our hypothesis that farm households who live farther from the market have lower dietary diversity (Finding 2). The size of the relation is 0.66 less food groups per hour distance to the market for HDDS (9 percentage points of the average); 1.2 less food items per hour distance for FVS (10 percentage points of the average); and 0.12 less food groups per hour distance for WDDS (4 percentage point of the average).

Comparing panels B-D, we find support for our hypothesis that the positive association between crop diversity and dietary diversity is stronger for households further from the market (Finding 3). For those households living less than 10 minutes from the market, we find no, or a small, only marginally significant effect of crop diversity on dietary diversity. For those living more than 10 minutes away or more than 30 minutes away, the size of the coefficient for market distance increases and becomes strongly significant for the household-level dietary diversity indicators (see also (Matita et al., 2021)). For a distance of more than 60 minutes (Panel E), the coefficients for crop diversity decrease again slightly and become only marginally significant for both HDDS and FVS. This could be due to the relatively small sample size for this subgroup of households. Surprisingly, we find a strong, positive relationship between crop diversity and women's dietary diversity for this small subgroup.

Based on the above findings, we reject our hypothesis that the effects of diet diversity and distance to the market are qualitatively the same for our different indicators of diet diversity (Finding 4). As indicated above, the rejection of the hypothesis could be due to the different nature of the indicators: HDDS (and probably FVS) reflect food access whereas WDDS reflects diet quality, and HDDS refers to the entire household whereas WDDS zooms in on one potentially vulnerable individual. We thus find that food security increases with crop diversity, but diet quality does not, at least not for women. This could result from the patriarchal culture in the study area, but we cannot be sure as we do not have sufficient information about individual dietary diversity for men. However, the finding could also originate from differences in the recall period and data collection process.

Table 3.3: Regression coefficient showing association between crop diversity index and dietary diversity (Standard errors in parentheses)

Variables	**WDDS measured using 24-hour recall**	**HDDS measured using 7-day recall**	**FVS measured using 7-day recall**
Panel A: Full sample			
CDI	0.042	1.217***	1.332***
	(0.142)	(0.337)	(0.641)
Distance to the market	-0.002*	-0.011**	-0.020***
	(0.001)	(0.004)	(0.006)
N	1,300	1,347	1,347
Panel B: distance to market ≤10 min			
CDI	0.059	0.806*	0.874
	(0.164)	(0.466)	(0.956)
Distance to the market (min)	0.010	-0.010	-0.010
	(0.016)	(0.033)	(0.071)
N	679	704	704
Panel C: Distance to market > 10 min			
CDI	0.071	1.633***	1.801**
	(0.242)	(0.377)	(0.699)
Distance to the market (min)	-0.002	-0.012***	-0.017***
	(0.002)	(0.004)	(0.010)
	621	643	643
Panel D: Distance to market > 30 min			
CDI	0.122	2.038***	2.728***
	(0.397)	(0.449)	(0.780)
Distance to the market	-0.002	-0.010	-0.010
	(0.003)	(0.010)	(0.010)
N	343	354	354
Panel E: Distance to market > 60			
CDI	0.749**	1.780*	2.382*
	(0.266)	(0.951)	(1.270)
Distance to the market	-0.002	-0.003	-0.001
	(0.004)	(0.010)	(0.012)
N	188	192	192

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
Full regression results in Appendix

As a robustness check, we also consider a simple crop count as our indicator for crop diversity. The results are presented in Table 3.4 and are largely consistent with the results using CDI. Surprisingly, the median split of 10 minutes gives a higher coefficient for number of crops for those living close to the market for WDDS and FVS, although only the latter coefficient is significantly different from 0.

Yet, the subgroup who lived more than 30 minutes from the market again gives the largest coefficients for HDDS and FVS. Panel E, where the distance from the market is more than 60 minutes, now reveals no significant relationship between crop diversity and diet diversity. This supports our assertion that the counterintuitive results for CDI for this subgroup are related to the relatively small sample size.

Table 3.4: Regression coefficient showing association between number of crops grown and dietary diversity (standard errors in parentheses)

Variable	WDDS measured using 24-hour recall	HDDS measured using 7-day recall	FVS measured using 7-day recall
Panel A: Full sample			
Number of crops	0.013	0.288***	0.359***
	(0.024)	(0.066)	(0.128)
Distance to the market (min)	-0.002*	-0.010**	-0.020***
	(0.001)	(0.004)	(0.006)
N	1300	1347	1347
Panel B: Distance to market ≤10 min			
Number of crops	0.027	0.255**	0.379*
	(0.030)	(0.097)	(0.195)
Distance to the market (min)	0.010	-0.010	-0.002
	(0.016)	(0.033)	(0.070)
N	679	704	704
Panel C: Distance to market >10 min			
Number of crops	0.005	0.308***	0.323**
	(0.040)	(0.063)	(0.127)
Distance to the market (min)	-0.002	-0.011**	-0.016**
	(0.002)	(0.004)	(0.022)
N	621	643	643
Panel D: Distance to market > 30			
Number of crops	0.017	0.354***	0.482***
	(0.061)	(0.081)	(0.148)
Distance to the market	-0.002	-0.010*	-0.010
	(0.003)	(0.010)	(0.010)
N	343	354	354
Panel E: Distance to market > 60			
Number of crops	0.088	0.326	0.451
	(0.067)	(0.221)	(0.295)
Distance to the market	-0.003	-0.003	-0.002
	(0.005)	(0.010)	(0.013)
N	188	192	192

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

As a further robustness check, the Poisson regression coefficients for all model variants are reported in the Appendix. The results are qualitatively very similar to those presented above, though the coefficients for the crop diversity indicators are consistently smaller.

3.4 Conclusions and recommendations

This study examined the nexus between crop diversity, dietary diversity, and market access. We find that crop diversity has a positive effect on household-level indicators of dietary diversity, but the effect is not very large and is not present for households who live close to the market. This supports the assertion of Kissoly et al. (2018) and Sibhatu and Qaim (2018) that crop diversity on the farm has a lesser effect on dietary diversity of rural farm households that have better access to the market.

Women's dietary diversity was not associated with crop diversity, except for the small subgroup of households living more than one hour from the market, and only for one of our two crop diversity indicators. These findings suggest that increased economic access to food, as measured by the household dietary diversity score, does not guarantee increased micronutrient intake in the diets consumed by women, as measured by the women's dietary diversity score, in the breadbasket of rural Tanzania. This contradicts the study by (Koppmair et al., 2017) in Malawi, which found that the effect for individual dietary diversity was similar to that for household dietary diversity, or even larger.

The effect size of one additional hour distance to the market on household-level dietary diversity was similar to the effect size of cultivating only one crop vs the maximum crop diversity observed in the sample. Interestingly, distance to markets was also negatively related to women's dietary diversity, though the size of the relation is relatively small. These results are consistent with the observation of Humphries et al. (2017) that access to the market is crucial for household consumption of quality diets (also see Dillon et al. (2015) and (Sibhatu et al., 2015a). In our case study, we found that a high proportion of household consumption for many food groups came from market purchases. Vicinity to the market may incentivize rural farming households to specialize in the production of the most profitable crops, participate in the markets, and enhance household income, which in turn could lead to increased ability to access quality diets and improve food security. Alternatively, better access to consumer food markets could be sufficient to improve food security.

Despite the relevance of the findings, this study has two key limitations. First, we cannot guarantee that the differences observed between the individual and household-level dietary diversity indicators are due to the differences between the concepts we measured. For WDDS, we used the conventional qualitative 24-hour recall, but we had only one data point available rather than the recommended three. In addition, we based the HDDS on a conventional 7-day consumption recall survey. This is common practice among economists, but it would be interesting to investigate whether a more nutrition-oriented approach using 24-hour recalls would give different results. Second, our data is observational and determines only associations. To address this issue, we recommend an impact assessment of the cause-effect relationship between crop diversity and household dietary diversity in rural Tanzania.

Appendix

Table A1: OLS regression model coefficients showing association between crop diversity and dietary diversity in full sample

VARIABLES	(1) WDDS, 24-hour recall	(2) HDDS measured using 7-day recall	(3) FVS measured using 7-day recall
Crop diversity index (CDI)	0.042	1.217***	1.332**
	(0.142)	(0.337)	(0.642)
Distance to market	-0.002*	-0.011**	-0.018***
	(0.001)	(0.004)	(0.006)
Age of adult woman responsible for cooking	0.009*	-0.010	-0.011
	(0.005)	(0.009)	(0.019)
Age of head of household	-0.008*	0.002	0.000
	(0.005)	(0.009)	(0.019)
Secondary school education of wife/adult woman responsible for food preparations	0.656***	-0.433	1.221*
	(0.148)	(0.342)	(0.666)
Household head completed secondary education	-0.516***	0.864***	0.047
	(0.117)	(0.241)	(0.410)
Gender of household head, 1= female, 0 otherwise	0.124	-0.268	-0.326
	(0.113)	(0.238)	(0.436)
Household size	0.033**	0.080*	0.177**
	(0.015)	(0.041)	(0.082)
Dependency ratio	-0.079	-0.330	-0.822**
	(0.127)	(0.227)	(0.395)
Total land owned (acres)	0.008***	0.012*	0.021*
	(0.002)	(0.007)	(0.011)
Household access to extension officer	-0.047	0.057	0.097
	(0.031)	(0.061)	(0.092)
Total number of livestock (owned)	0.027**	0.029	0.064
	(0.012)	(0.021)	(0.038)
Household engaged in off-farm employment	0.039	0.956***	1.720***
	(0.067)	(0.167)	(0.307)
Constant	3.210***	6.526***	10.655***
	(0.158)	(0.408)	(0.746)
Observations	1,300	1,347	1,347
R-squared	0.035	0.109	0.085

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A2: OLS regression model coefficients showing association between crop diversity and dietary diversity, distance ≤10 minutes

VARIABLES	(1) WDDS 24-hour recall	(2) HDDS 7-day recall	(3) FVS 7-day recall
Crop diversity index (CDI)	**0.059**	**0.806***	**0.874**
	(0.164)	**(0.466)**	**(0.956)**
Distance to market	**0.010**	**-0.010**	**-0.010**
	(0.016)	**(0.033)**	**(0.071)**
Age of adult woman responsible for cooking	0.012*	-0.019*	-0.032
	(0.007)	(0.010)	(0.022)
Age of head of household	-0.011*	0.006	0.011
	(0.006)	(0.012)	(0.025)
Secondary school education of wife/adult woman responsible for food preparations	0.173*	0.351	1.189
	(0.100)	(0.327)	(0.831)
Gender of household head, 1= female, 0 otherwise	0.100	-0.370	-0.192
	(0.156)	(0.273)	(0.572)
Household size	0.051***	0.039	0.153
	(0.017)	(0.058)	(0.120)
Dependency ratio	0.066	-0.156	-0.482
	(0.150)	(0.358)	(0.654)
Total land owned (acres)	0.010*	0.032*	0.061
	(0.005)	(0.019)	(0.038)
Household access to extension officer	-0.078**	0.052	0.172
	(0.036)	(0.095)	(0.113)
Total number of livestock (owned)	0.043**	0.061*	0.129*
	(0.018)	(0.035)	(0.070)
Household engaged in off-farm employment	0.046	0.880***	1.498***
	(0.080)	(0.255)	(0.492)
Constant	2.959***	6.965***	10.888***
	(0.282)	(0.612)	(1.179)
Observations	679	704	704
R-squared	0.050	0.086	0.070

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A3: OLS regression model coefficients showing association between crop diversity and dietary diversity, distance >10 minutes

VARIABLES	(1) WDDS 24-hour recall	(2) HDDS 7-day recall	(3) FVS 7-day recall
Crop diversity index (CDI)	**0.071**	**1.633*** **	**1.801** **
	(0.242)	**(0.377)**	**(0.699)**
Distance from farm to output market	**-0.002**	**-0.012*** **	**-0.017*** **
	(0.002)	**(0.004)**	**(0.006)**
Age of adult woman responsible for cooking	0.003	0.003	0.017
	(0.009)	(0.017)	(0.031)
Age of head of household	-0.004	-0.005	-0.018
	(0.009)	(0.016)	(0.031)
Secondary school education of wife/adult woman responsible for food preparations	0.112	0.571*	1.428**
	(0.128)	(0.287)	(0.581)
Gender of household head, 1= female, 0 otherwise	0.150	-0.175	-0.544
	(0.172)	(0.350)	(0.678)
Household size	0.014	0.130***	0.211**
	(0.020)	(0.045)	(0.100)
Dependency ratio	-0.246	-0.450	-1.127*
	(0.220)	(0.386)	(0.668)
Total land owned (acres)	0.008***	0.007	0.014*
	(0.002)	(0.004)	(0.007)
Household access to extension officer	-0.008	0.048	-0.008
	(0.047)	(0.060)	(0.127)
Total number of livestock (owned)	0.014	-0.001	0.004
	(0.011)	(0.020)	(0.044)
Household engaged in off-farm employment	0.032	0.980***	1.859***
	(0.105)	(0.187)	(0.384)
Constant	3.397***	6.021***	10.175***
	(0.238)	(0.592)	(1.218)
Observations	621	643	643
R-squared	0.031	0.148	0.111

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A4: OLS regression model coefficients showing association between crop diversity and dietary diversity, distance > 30 minutes

VARIABLES	(1) WDDS 24-hour recall	(2) HDDS 7-day recall	(3) FVS 7-day recall
Crop diversity index (CDI)	0.122	2.038***	2.722***
	(0.397)	(0.449)	(0.780)
Distance from farm to output market	-0.002	-0.008	-0.008
	(0.003)	(0.007)	(0.009)
Age of adult woman responsible for cooking	-0.016*	-0.035**	-0.074**
	(0.008)	(0.016)	(0.028)
Age of head of household	0.016*	0.030	0.070**
	(0.009)	(0.019)	(0.034)
Secondary school education of wife/adult woman responsible for food preparations	0.221	0.690*	1.283
	(0.234)	(0.359)	(0.832)
Gender of household head, 1= female, 0 otherwise	-0.127	-0.306	-0.755
	(0.176)	(0.482)	(0.980)
Household size	0.029	0.102	0.166
	(0.028)	(0.061)	(0.133)
Dependency ratio	-0.333	-0.427	-1.020
	(0.305)	(0.540)	(0.900)
Total land owned (acres)	0.002	0.041**	0.067**
	(0.011)	(0.015)	(0.026)
Household access to extension officer	-0.077	0.031	0.036
	(0.051)	(0.061)	(0.130)
Total number of livestock (owned)	0.001	-0.003	-0.012
	(0.021)	(0.037)	(0.079)
Household engaged in off-farm employment	-0.167	0.643***	1.210***
	(0.112)	(0.162)	(0.424)
Constant	3.545***	5.925***	9.595***
	(0.317)	(0.672)	(1.398)
Observations	343	354	354
R-squared	0.032	0.132	0.093

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A5: OLS regression model coefficients showing association between crop diversity and dietary diversity, distance >60 minutes

VARIABLES	(1) WDDS 24-hour recall	(2) HDDS 7-day recall	(3) FVS 7-day recall
Crop diversity index (CDI)	0.749**	1.780*	2.382*
	(0.266)	(0.951)	(1.270)
Distance from farm to output market	-0.002	-0.003	-0.001
	(0.004)	(0.006)	(0.012)
Age of adult woman responsible for food preparations	-0.019**	-0.035	-0.072
	(0.009)	(0.022)	(0.042)
Age of head of household	0.015	0.030	0.055
	(0.011)	(0.023)	(0.051)
Secondary school education of wife/adult woman responsible for food preparations	0.426	0.831	1.394
	(0.406)	(0.658)	(1.553)
Gender of household head, 1= female, 0 otherwise	-0.084	0.087	0.224
	(0.268)	(0.813)	(1.543)
Household size	0.040	0.160**	0.265
	(0.039)	(0.075)	(0.181)
Dependency ratio	-0.378	0.068	-0.470
	(0.440)	(0.602)	(1.222)
Total land owned (acres)	0.005	0.015	0.044
	(0.014)	(0.024)	(0.041)
Household access to extension officer	-0.196***	-0.063	0.117
	(0.037)	(0.134)	(0.426)
Total number of livestock (owned)	0.049*	-0.041	-0.111
	(0.025)	(0.044)	(0.072)
Household engaged in off-farm employment	-0.232	0.514	0.719
	(0.178)	(0.322)	(0.600)
Constant	3.347***	5.154***	8.990***
	(0.310)	(1.052)	(2.113)
Observations	188	192	192
R-squared	0.081	0.101	0.086

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A6: OLS regression model coefficients showing association between number of crops grown and dietary diversity using full sample

VARIABLES	(1) WDDS 24-hour recall	(2) HDDS 7-day recall	(3) FVS 7-day recall
Total number of crops grown	0.013	0.288***	0.359***
	(0.024)	(0.066)	(0.128)
Distance from farm to agricultural markets	-0.002*	-0.010**	-0.018***
	(0.001)	(0.004)	(0.006)
Age of adult woman responsible for food preparations	0.009*	-0.008	-0.009
	(0.005)	(0.009)	(0.019)
Age of head of household	-0.008*	0.001	-0.001
	(0.005)	(0.009)	(0.019)
Secondary school education of wife/adult woman responsible for food preparations	0.661***	-0.230	1.427**
	(0.149)	(0.345)	(0.678)
Household head completed secondary education	-0.522***	0.655***	-0.160
	(0.117)	(0.233)	(0.398)
Gender of household head, 1= female, 0 otherwise	0.126	-0.240	-0.290
	(0.113)	(0.238)	(0.438)
Household size	0.033**	0.079*	0.176**
	(0.015)	(0.041)	(0.082)
Dependency ratio	-0.078	-0.300	-0.794**
	(0.128)	(0.224)	(0.393)
Total land owned (acres)	0.008***	0.009*	0.018*
	(0.002)	(0.005)	(0.010)
Household access to extension officer	-0.047	0.060	0.099
	(0.031)	(0.056)	(0.091)
Total number of livestock (owned)	0.027**	0.029	0.064
	(0.012)	(0.021)	(0.039)
Household engaged in off-farm employment	0.039	0.949***	1.722***
	(0.066)	(0.164)	(0.306)
Constant	3.193***	6.292***	10.272***
	(0.160)	(0.417)	(0.777)
Observations	1,300	1,347	1,347
R-squared	0.035	0.114	0.088

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A7: OLS regression model coefficients showing association between number of crops grown and dietary diversity, distance ≤ 10 minutes

VARIABLES	(1) WDDS 24-hour recall	(2) HDDS 7-day recall	(3) FVS 7-day recall
Total number of crops grown	0.027	0.255**	0.379*
	(0.030)	(0.097)	(0.195)
Distance from farm to agricultural markets	0.008	-0.008	-0.002
	(0.016)	(0.033)	(0.070)
Age of adult woman responsible for food preparations	0.013*	-0.019*	-0.031
	(0.007)	(0.010)	(0.021)
Age of head of household	-0.012*	0.005	0.011
	(0.006)	(0.012)	(0.025)
Secondary school education of wife/adult woman responsible for food preparations	0.171*	0.337	1.169
	(0.100)	(0.330)	(0.834)
Gender of household head, 1= female, 0 otherwise	0.103	-0.343	-0.145
	(0.154)	(0.271)	(0.568)
Household size	0.051***	0.040	0.155
	(0.017)	(0.058)	(0.120)
Dependency ratio	0.065	-0.148	-0.486
	(0.152)	(0.356)	(0.655)
Total land owned (acres)	0.010*	0.025	0.052
	(0.005)	(0.018)	(0.035)
Household access to extension officer	-0.078**	0.053	0.171
	(0.036)	(0.087)	(0.108)
Total number of livestock (owned)	0.043**	0.061*	0.128*
	(0.018)	(0.035)	(0.069)
Household engaged in off-farm employment	0.050	0.898***	1.550***
	(0.078)	(0.247)	(0.479)
Constant	2.909***	6.647***	10.216***
	(0.273)	(0.596)	(1.164)
Observations	679	704	704
R-squared	0.050	0.094	0.076

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A8: OLS regression model coefficients showing association between number of crops grown and dietary diversity, distance > 10 minutes

VARIABLES	(1) WDDS 24-hour recall	(2) HDDS 7-day recall	(3) FVS 7-day recall
Total number of crops grown	0.005	0.308***	0.323**
	(0.040)	(0.063)	(0.127)
Distance from farm to agricultural markets	-0.002	-0.011**	-0.016**
	(0.002)	(0.004)	(0.006)
Age of adult woman responsible for food preparations	0.003	0.007	0.022
	(0.009)	(0.017)	(0.031)
Age of head of household	-0.004	-0.008	-0.021
	(0.009)	(0.016)	(0.031)
Secondary school education of wife/adult woman responsible for food preparations	0.110	0.557*	1.408**
	(0.128)	(0.289)	(0.581)
Gender of household head, 1= female, 0 otherwise	0.151	-0.153	-0.519
	(0.172)	(0.342)	(0.671)
Household size	0.015	0.128***	0.210**
	(0.020)	(0.044)	(0.099)
Dependency ratio	-0.244	-0.410	-1.081
	(0.221)	(0.388)	(0.677)
Total land owned (acres)	0.008***	0.005	0.011*
	(0.002)	(0.003)	(0.006)
Household access to extension officer	-0.008	0.057	0.003
	(0.047)	(0.062)	(0.131)
Total number of livestock (owned)	0.014	-0.000	0.005
	(0.012)	(0.021)	(0.045)
Household engaged in off-farm employment	0.031	0.966***	1.841***
	(0.104)	(0.187)	(0.386)
Constant	3.415***	5.868***	10.052***
	(0.259)	(0.626)	(1.313)
Observations	621	643	643
R-squared	0.031	0.143	0.109

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A9: OLS regression model coefficients showing association between number of crops grown and dietary diversity, distance >30 minutes

VARIABLES	(1) WDDS 24-hour recall	(2) HDDS 7-day recall	(3) FVS 7-day recall
Total number of crops grown	0.017	0.354***	0.482***
	(0.061)	(0.081)	(0.148)
Distance from farm to agricultural markets	-0.002	-0.007	-0.007
	(0.003)	(0.007)	(0.010)
Age of adult woman responsible for food preparations	0.016*	0.035*	0.076**
	(0.008)	(0.020)	(0.035)
Age of head of household	-0.016*	-0.037**	-0.076**
	(0.008)	(0.016)	(0.028)
Secondary school education of wife/adult woman responsible for food preparations	0.218	0.657*	1.241
	(0.233)	(0.355)	(0.833)
Gender of household head, 1= female, 0= otherwise	-0.124	-0.279	-0.722
	(0.181)	(0.471)	(0.972)
Household size	0.030	0.115*	0.182
	(0.027)	(0.058)	(0.129)
Dependency ratio	-0.334	-0.415	-1.004
	(0.305)	(0.555)	(0.930)
Total land owned (acres)	0.001	0.029**	0.051**
	(0.010)	(0.013)	(0.024)
Household access to extension officer	-0.078	0.030	0.035
	(0.052)	(0.062)	(0.131)
Total number of livestock (owned)	0.001	-0.003	-0.012
	(0.021)	(0.038)	(0.080)
Household engaged in off-farm employment	-0.167	0.663***	1.238***
	(0.113)	(0.161)	(0.426)
Constant	3.553***	5.763***	9.346***
	(0.283)	(0.733)	(1.461)
Observations	343	354	354
R-squared	0.031	0.123	0.089

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A10: OLS regression model coefficients showing association between number of crops grown and dietary diversity, distance >60 minutes

VARIABLES	(1) WDDS 24-hour recall	(2) HDDS 7-day recall	(3) FVS 7-day recall
Total number of crops grown	0.088	0.326	0.451
	(0.067)	(0.221)	(0.295)
Distance from farm to agricultural markets	-0.003	-0.003	-0.002
	(0.005)	(0.006)	(0.013)
Age of adult woman responsible for food preparations	0.019	0.039	0.067
	(0.011)	(0.028)	(0.056)
Age of head of household	-0.022**	-0.041	-0.080*
	(0.009)	(0.026)	(0.046)
Secondary school education of wife/adult woman responsible for food preparations	0.400	0.773	1.318
	(0.414)	(0.670)	(1.572)
Gender of household head, 1= female, 0 otherwise	-0.086	0.049	0.169
	(0.276)	(0.848)	(1.579)
Household size	0.045	0.166**	0.271
	(0.041)	(0.072)	(0.177)
Dependency ratio	-0.381	0.081	-0.450
	(0.437)	(0.621)	(1.246)
Total land owned (acres)	0.003	0.006	0.032
	(0.013)	(0.023)	(0.038)
Household access to extension officer	-0.191***	-0.054	0.128
	(0.038)	(0.133)	(0.430)
Total number of livestock (owned)	0.049*	-0.041	-0.111
	(0.026)	(0.045)	(0.072)
Household engaged in off-farm employment	-0.225	0.530	0.739
	(0.184)	(0.320)	(0.600)
Constant	3.454***	5.140***	8.936***
	(0.290)	(1.043)	(2.069)
Observations	188	192	192
R-squared	0.069	0.094	0.083

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A11: Poisson regression coefficients showing association between crop diversity and dietary diversity in full sample

VARIABLES	(1) WDDS 24-hour recall	(2) HDDS 7-day recall	(3) FVS 7-day recall
Crop diversity index (CDI)	0.013	0.172***	0.116**
	(0.042)	(0.049)	(0.056)
Distance from farm to output market	-0.001*	-0.002**	-0.002***
	(0.000)	(0.001)	(0.001)
Age of adult woman responsible for food preparations	0.003*	-0.001	-0.001
	(0.002)	(0.001)	(0.002)
Age of head of household	-0.002*	0.000	0.000
	(0.001)	(0.001)	(0.002)
Secondary school education of wife/adult woman responsible for food preparations	0.198***	-0.067	0.085
	(0.042)	(0.047)	(0.053)
Household head completed secondary education	-0.157***	0.124***	0.015
	(0.034)	(0.035)	(0.036)
Gender of household head, 1= female, 0 otherwise	0.035	-0.039	-0.030
	(0.033)	(0.034)	(0.039)
Household size	0.010**	0.011**	0.015**
	(0.004)	(0.005)	(0.007)
Dependency ratio	-0.025	-0.049	-0.073**
	(0.037)	(0.032)	(0.035)
Total land owned (acres)	0.002***	0.001*	0.001*
	(0.000)	(0.001)	(0.001)
Household access to extension officer	-0.014	0.008	0.008
	(0.009)	(0.008)	(0.007)
Total number of livestock (owned)	0.008**	0.004	0.005*
	(0.003)	(0.003)	(0.003)
Household engaged in off-farm employment	0.012	0.129***	0.141***
	(0.019)	(0.023)	(0.025)
Constant	1.171***	1.882***	2.374***
	(0.046)	(0.059)	(0.065)
Observations	1,300	1,347	1,347

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A12: Poisson regression coefficients showing association between crop diversity and dietary diversity, distance ≤10 minutes

VARIABLES	(1) WDDS 24-hour recall	(2) HDDS 7-day recall	(3) FVS 7-day recall
Crop diversity index (CDI)	0.017	0.112*	0.075
	(0.047)	(0.065)	(0.080)
Distance from farm to agricultural output market	0.002	-0.001	-0.001
	(0.005)	(0.004)	(0.006)
Age of adult woman responsible for food preparations	0.004*	-0.003**	-0.003
	(0.002)	(0.001)	(0.002)
Age of head of household	-0.003**	0.001	0.001
	(0.002)	(0.002)	(0.002)
Secondary school education of wife/adult woman responsible for food preparations	0.050*	0.045	0.091
	(0.028)	(0.041)	(0.060)
Gender of household head, 1= female, 0 otherwise	0.028	-0.054	-0.018
	(0.044)	(0.041)	(0.051)
Household size	0.015***	0.006	0.013
	(0.005)	(0.008)	(0.009)
Dependency ratio	0.018	-0.025	-0.044
	(0.043)	(0.049)	(0.056)
Total land owned (acres)	0.003**	0.004*	0.005*
	(0.001)	(0.002)	(0.003)
Household access to extension officer	-0.024**	0.006	0.013
	(0.011)	(0.012)	(0.009)
Total number of livestock (owned)	0.011***	0.008*	0.010**
	(0.004)	(0.004)	(0.005)
Household engaged in off-farm employment	0.013	0.115***	0.119***
	(0.023)	(0.035)	(0.040)
Constant	1.099***	1.945***	2.398***
	(0.080)	(0.084)	(0.099)
Observations	679	704	704

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A13: Poisson regression coefficients showing association between crop diversity and dietary diversity, distance >10 minutes

VARIABLES	(2) WDDS 24-hour recall	(4) HDDS 7-day recall	(6) FVS 7-day recall
Crop diversity index (CDI)	0.022	0.237***	0.161**
	(0.072)	(0.056)	(0.063)
Distance to market	-0.001	-0.002***	-0.002***
	(0.001)	(0.001)	(0.001)
Age of adult woman responsible for food preparations	0.001	0.000	0.001
	(0.003)	(0.002)	(0.003)
Age of head of household	-0.001	-0.001	-0.002
	(0.003)	(0.002)	(0.003)
Secondary school education of wife/adult woman responsible for food preparations	0.033	0.078**	0.117***
	(0.037)	(0.038)	(0.045)
Gender of household head, 1= female, 0 otherwise	0.043	-0.026	-0.050
	(0.050)	(0.050)	(0.060)
Household size	0.004	0.018***	0.018**
	(0.006)	(0.007)	(0.009)
Dependency ratio	-0.074	-0.067	-0.102*
	(0.065)	(0.055)	(0.060)
Total land owned (acres)	0.002***	0.001*	0.001*
	(0.000)	(0.000)	(0.000)
Household access to extension officer	-0.002	0.007	-0.000
	(0.014)	(0.008)	(0.011)
Total number of livestock (owned)	0.004	-0.000	0.000
	(0.003)	(0.003)	(0.004)
Household engaged in off-farm employment	0.010	0.136***	0.157***
	(0.031)	(0.024)	(0.030)
Constant	1.224***	1.807***	2.329***
	(0.070)	(0.089)	(0.110)
Observations	621	643	643

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A14: Poisson regression coefficients showing association between crop diversity and dietary diversity, distance > 30 minutes

VARIABLES	(1) WDDS 24-hour recall, distance > 30 minutes	(2) HDDS 7-day recall, distance > 30 minutes	(3) FVS 7-day recall, distance > 30 minutes
Crop diversity index (CDI)	0.038	0.316***	0.260***
	(0.119)	(0.065)	(0.074)
Distance from farm to agricultural output market	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)
Age of adult woman responsible for food preparations	0.005*	0.004	0.006*
	(0.003)	(0.003)	(0.003)
Age of head of household	-0.005**	-0.005**	-0.007**
	(0.002)	(0.002)	(0.003)
Secondary school education of wife/adult woman responsible for food preparations	0.066	0.096**	0.108
	(0.066)	(0.049)	(0.068)
Gender of household head, 1= female, 0 otherwise	-0.039	-0.046	-0.070
	(0.052)	(0.069)	(0.087)
Household size	0.009	0.015*	0.015
	(0.008)	(0.009)	(0.012)
Dependency ratio	-0.101	-0.070	-0.099
	(0.090)	(0.080)	(0.084)
Total land owned (acres)	0.001	0.005**	0.005**
	(0.003)	(0.002)	(0.002)
Household access to extension officer	-0.024	0.004	0.003
	(0.016)	(0.009)	(0.011)
Total number of livestock (owned)	0.000	-0.000	-0.001
	(0.006)	(0.006)	(0.007)
Household engaged in off-farm employment	-0.051	0.091***	0.106***
	(0.034)	(0.021)	(0.035)
Constant	1.268***	1.787***	2.273***
	(0.095)	(0.103)	(0.129)
Observations	343	354	354

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A15: Poisson regression coefficients showing association between crop diversity and dietary diversity, distance > 60 minutes

VARIABLES	(1) WDDS 24-hour recall, distance > 60 minutes	(2) HDDS 7-day recall, distance > 60 minutes	(3) FVS 7-day recall distance > 60 minutes
Crop diversity index (CDI)	0.234***	0.291**	0.260***
	(0.084)	(0.146)	(0.074)
Distance to market	-0.001	-0.000	-0.001
	(0.001)	(0.001)	(0.001)
Age of adult woman responsible for food preparations	0.005	0.005	0.006*
	(0.004)	(0.004)	(0.003)
Age of head of household	-0.006**	-0.006*	-0.007**
	(0.003)	(0.003)	(0.003)
Secondary school education of wife/adult woman responsible for food preparations	0.126	0.120	0.108
	(0.109)	(0.090)	(0.068)
Gender of household head, 1= female, 0 otherwise	-0.028	0.008	-0.070
	(0.081)	(0.122)	(0.087)
Household size	0.012	0.024**	0.015
	(0.011)	(0.012)	(0.012)
Dependency ratio	-0.120	0.011	-0.099
	(0.129)	(0.095)	(0.084)
Total land owned (acres)	0.002	0.002	0.005**
	(0.004)	(0.003)	(0.002)
Household access to extension officer	-0.062***	-0.012	0.003
	(0.012)	(0.019)	(0.011)
Total number of livestock (owned)	0.015**	-0.007	-0.001
	(0.007)	(0.007)	(0.007)
Household engaged in off-farm employment	-0.073	0.078*	0.106***
	(0.055)	(0.046)	(0.035)
Constant	1.210***	1.656***	2.273***
	(0.092)	(0.168)	(0.129)
Observations	188	192	354

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A16: Poisson regression coefficients showing association between number of crops grown and dietary diversity in full sample

VARIABLES	(1) WDDS measured using 24-hour recall	(2) HDDS measured using 7-day recall	(3) FVS measured using 7-day recall
Total number of crops grown	0.004	0.040***	0.031***
	(0.007)	(0.009)	(0.011)
Distance to market	-0.001*	-0.001**	-0.002***
	(0.000)	(0.001)	(0.001)
Age of adult woman responsible for food preparations	0.003*	-0.001	-0.001
	(0.002)	(0.001)	(0.002)
Age of head of household	-0.002*	0.000	-0.000
	(0.001)	(0.001)	(0.002)
Secondary school education of wife/adult woman responsible for food preparations	0.199***	-0.038	0.103*
	(0.042)	(0.047)	(0.054)
Household head completed secondary education	-0.159***	0.094***	-0.003
	(0.034)	(0.034)	(0.035)
Gender of household head, 1= female, 0 otherwise	0.036	-0.035	-0.027
	(0.032)	(0.035)	(0.039)
Household size	0.010**	0.011**	0.015**
	(0.004)	(0.005)	(0.007)
Dependency ratio	-0.024	-0.044	-0.070**
	(0.037)	(0.032)	(0.035)
Total land owned (acres)	0.002***	0.001*	0.001*
	(0.000)	(0.001)	(0.001)
Household access to extension officer	-0.014	0.008	0.008
	(0.009)	(0.007)	(0.007)
Total number of livestock (owned)	0.008**	0.004	0.005*
	(0.003)	(0.003)	(0.003)
Household engaged in off-farm employment	0.012	0.128***	0.142***
	(0.019)	(0.022)	(0.025)
Constant	1.164***	1.851***	2.341***
	(0.046)	(0.060)	(0.068)
Observations	1,300	1,347	1,347

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A17: Poisson regression coefficients showing association between number of crops grown and dietary diversity, distance ≤10 minutes

VARIABLES	(1) WDDS 24-hour recall, distance > 30 minutes	(2) HDDS 7-day recall, distance > 30 minutes	(3) FVS 7-day recall, distance > 30 minutes
Total number of crops grown	0.008	0.035***	0.031**
	(0.008)	(0.013)	(0.016)
Distance from farm to output markets	0.002	-0.001	-0.000
	(0.005)	(0.004)	(0.006)
Age of adult woman responsible for food preparations	0.004*	-0.003*	-0.003
	(0.002)	(0.001)	(0.002)
Age of head of household	-0.003**	0.001	0.001
	(0.002)	(0.002)	(0.002)
Secondary school education of wife/adult woman responsible for food preparations	0.049*	0.043	0.090
	(0.028)	(0.041)	(0.061)
Gender of household head, 1= female, 0 otherwise	0.029	-0.050	-0.015
	(0.043)	(0.040)	(0.050)
Household size	0.015***	0.006	0.013
	(0.005)	(0.008)	(0.009)
Dependency ratio	0.018	-0.023	-0.044
	(0.044)	(0.049)	(0.056)
Total land owned (acres)	0.003**	0.003	0.004
	(0.001)	(0.002)	(0.003)
Household access to extension officer	-0.024**	0.007	0.013
	(0.011)	(0.011)	(0.008)
Total number of livestock (owned)	0.011***	0.008*	0.010**
	(0.004)	(0.004)	(0.005)
Household engaged in off-farm employment	0.014	0.118***	0.124***
	(0.022)	(0.034)	(0.039)
Constant	1.083***	1.902***	2.343***
	(0.078)	(0.083)	(0.098)
Observations	679	704	704

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A18: Poisson regression coefficients showing association between number of crops grown and dietary diversity, distance > 10 minutes

VARIABLES	(1) WDDS 24-hour recall	(2) HDDS 7-day recall	(3) FVS 7-day recall
Total number of crops grown	0.002	0.043***	0.029***
	(0.012)	(0.009)	(0.011)
Distance from farm to output market	-0.001	-0.002**	-0.001***
	(0.001)	(0.001)	(0.001)
Age of adult woman responsible for food preparations	0.001	0.001	0.002
	(0.003)	(0.002)	(0.003)
Age of head of household	-0.001	-0.001	-0.002
	(0.003)	(0.002)	(0.003)
Secondary school education of wife/adult woman responsible for food preparations	0.033	0.075**	0.115**
	(0.037)	(0.038)	(0.045)
Gender of household head, 1= female, 0 otherwise	0.043	-0.022	-0.047
	(0.050)	(0.049)	(0.059)
Household size	0.004	0.018***	0.018**
	(0.006)	(0.006)	(0.009)
Dependency ratio	-0.074	-0.061	-0.098
	(0.065)	(0.056)	(0.060)
Total land owned (acres)	0.002***	0.000	0.001*
	(0.000)	(0.000)	(0.000)
Household access to extension officer	-0.002	0.008	0.001
	(0.014)	(0.008)	(0.011)
Total number of livestock (owned)	0.004	-0.000	0.000
	(0.003)	(0.003)	(0.004)
Household engaged in off-farm employment	0.010	0.133***	0.156***
	(0.031)	(0.024)	(0.031)
Constant	1.227***	1.788***	2.319***
	(0.077)	(0.093)	(0.118)
Observations	621	643	643

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A19: Poisson regression coefficients showing association between number of crops grown and dietary diversity, distance > 30 minutes

VARIABLES	(1) WDDS 24-hour recall	(2) HDDS 7-day recall	(3) FVS 7-day recall
Total number of crops grown	0.005	0.052***	0.044***
	(0.018)	(0.011)	(0.013)
Distance from farm to output market	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)
Age of adult woman responsible for food preparations	0.005**	0.005*	0.007**
	(0.002)	(0.003)	(0.003)
Age of head of household	-0.005**	-0.005**	-0.007***
	(0.002)	(0.002)	(0.003)
Secondary school education of wife/adult woman responsible for food preparations	0.065	0.091*	0.104
	(0.066)	(0.048)	(0.068)
Gender of household head, 1= female, 0=otherwise	-0.037	-0.041	-0.066
	(0.053)	(0.068)	(0.086)
Household size	0.009	0.017*	0.017
	(0.008)	(0.009)	(0.012)
Dependency ratio	-0.102	-0.067	-0.098
	(0.090)	(0.083)	(0.087)
Total land owned (acres)	0.000	0.004*	0.004*
	(0.003)	(0.002)	(0.002)
Household access to extension officer	-0.024	0.004	0.003
	(0.017)	(0.009)	(0.011)
Total number of livestock (owned)	0.000	-0.000	-0.001
	(0.006)	(0.006)	(0.007)
Household engaged in off-farm employment	-0.051	0.095***	0.109***
	(0.035)	(0.021)	(0.035)
Constant	1.271***	1.771***	2.256***
	(0.085)	(0.113)	(0.135)
Observations	343	354	354

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A20: Poisson regression coefficients showing association between number of crops grown and dietary diversity, distance > 60 minutes

VARIABLES	(1) WDDS 24-hour recall	(2) HDDS 7-day recall	(3) FVS 7-day recall
Total number of crops grown	0.026	0.051	0.044
	(0.020)	(0.032)	(0.027)
Distance from farm to output market	-0.001	-0.000	-0.000
	(0.002)	(0.001)	(0.001)
Age of adult woman responsible for food preparations	0.006*	0.006	0.006
	(0.004)	(0.004)	(0.005)
Age of head of household	-0.007**	-0.007*	-0.008*
	(0.003)	(0.004)	(0.004)
Secondary school education of wife/adult woman responsible for food preparations	0.117	0.110	0.112
	(0.112)	(0.092)	(0.134)
Gender of household head, 1= female, 0 otherwise	-0.028	0.002	0.011
	(0.084)	(0.127)	(0.146)
Household size	0.014	0.025**	0.025
	(0.012)	(0.011)	(0.016)
Dependency ratio	-0.120	0.014	-0.044
	(0.128)	(0.098)	(0.121)
Total land owned (acres)	0.001	0.000	0.002
	(0.004)	(0.003)	(0.003)
Household access to extension officer	-0.061***	-0.011	0.008
	(0.012)	(0.018)	(0.036)
Total number of livestock (owned)	0.015**	-0.007	-0.011
	(0.008)	(0.007)	(0.007)
Household engaged in off-farm employment	-0.071	0.081*	0.067
	(0.057)	(0.045)	(0.053)
Constant	1.248***	1.660***	2.210***
	(0.086)	(0.164)	(0.194)
Observations	188	192	192

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Chapter 4

Using production frontiers to assess quality differences of modern seeds: Evidence from maize farming households in the southern highlands of Tanzania

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Abstract

The present study proposes a new measure for assessing the quality of seeds used by farmers and applies it to Tanzania. We use stochastic frontier analysis to estimate separate production frontiers for modern and traditional seed users. We argue that differences in seed quality will lead to higher levels and variance of technical efficiency (TE) for modern seeds users, with likely a bimodal distribution. Our results provide weak evidence for the presence of quality differences among modern seeds, at best. TE levels do not differ between the two seed types, and the variance of TE is higher for modern seeds, this variance is associated not with a bimodal distribution, but rather with a large share of farmers producing at high levels of TE.

Keywords: Maize, Seeds Quality, Stochastic Frontier, Technical Efficiency, Tanzania

4.1 Introduction

Africa's population is growing, and the continent already has pressing problems of food insecurity and poverty. It is therefore vital to use the continent's resources as efficiently as possible; yet, agricultural production systems in most sub-Saharan African (SSA) countries are far from reaching their full potential. Crop productivity has largely remained stagnant over the past five decades, with cereal productivity ranging between 1.2 to 1.7 metric tons per hectare (Belete, 2020; Michelson et al., 2018). These low productivity levels are in part attributable to failure to adopt modern inputs such as seeds and inorganic fertilizers (Ashour et al., 2019; Michelson et al., 2021; Sheahan and Barrett, 2017). The use of modern inputs was the key driver of the Asian Green Revolution, and a similar strategy could boost agricultural production across SSA countries, thereby stimulating economic growth and transforming semi-subsistence economies into productive middle-income countries (Bulte et al., 2014).

Yet, the use of modern inputs in Africa is limited. To explain this phenomenon, recent research has focused on the presence of low quality inputs in markets. Responding to farmer complaints about low quality and adulterated inputs in African markets, Bold et al. (2017) tested modern inputs in Ugandan markets in a seminal paper. They found that urea lacked 30% of nutrients and hybrid maize seed contained less than 50% authentic seeds. Bold et al. see this as evidence of counterfeiting on the part of traders, who exploit noisy agricultural yields that limit farmers' ability to learn. The end result of this process is a market equilibrium with low quality inputs and a limited share of farmers using these.

Although farmers' distrust of traders is genuine, their suspicions of foul play are not always justified. The presence of large scale counterfeiting has been questioned by a number of more recent papers. Michelson et al. (2021) found that urea purchased in markets in Tanzania was of sufficiently high quality. While local tests indicated considerable nitrogen deficiencies, these were not observed in a random subsample double tested at a US-based lab and in the local labs after instrument calibration and reduction of other error sources. Other studies come to similar conclusions for Uganda: their samples of urea were shown to contain the required amount of nitrogen after proper testing (Ashour et al., 2019; Sanabria et al., 2018). This implies that the results of Bold et al. (2017), who tested in a single lab, are an outlier in the literature and that the urea available in East African markets is generally of good quality. Perhaps this is not surprising, as urea is a stable molecule which does not deteriorate easily, and intentional dilution of this fertilizer is unlikely to be profitable.

In contrast to the debate concerning quality of urea, it seems generally agreed that there are problems with seed quality in Africa. Uganda's 2018 National Seed Policy indicates that an estimated 30-40% of seed traded in the market is counterfeit. Similarly, local experts estimated almost 30 % of the seeds traded in the rural market outlets to be inauthentic (CPRA, 2016; Marechera et al., 2016). However, the validity of these estimates may be questioned. Varietal purity can only be assessed through genetic fingerprinting and comparison with reference genetic material, and this is rarely done (Beegle et al., 2021). Besides, overall seed quality, as measured by characteristics such as germination rate and vigor, requires lab testing, which is not often used in economic development studies. An exception is the study by (Barriga and Fiala, 2020), who tested seeds along the maize supply chain in Uganda. They found good quality seeds on average, though increasing variation in quality further down the supply chain. As the genetic fingerprint of the seeds was uniform, Barriga and Fiala conclude that these quality differences were due to mishandling and poor storage, not to counterfeiting. However, more research is needed before a definite answer can be given about the quality of seeds and the extent of counterfeiting.

The present study uses an innovative approach to look into the issue of seed quality: we compare the productivity and technical efficiency (TE) of smallholders who used modern seeds with the productivity and TE of farmers who used traditional seeds. The farm-level production frontier, which represents the maximum production that can be generated for each combination of resources, is higher for genuine, non-deteriorated modern seeds than for traditional seeds. Hence, estimating separate production frontiers for modern and traditional seeds for each crop gives an indication of the quality of the modern seeds: if the modern seed frontier is substantially higher than the traditional seed frontier, a decent share of the modern seeds used must have been genuine and of sufficient quality. In the case of quality differences in the modern seed market there will be lower average levels and higher variance of TE for users of modern seed than for users of traditional seed: some farmers will purchase high quality seeds and can produce close to the modern seed frontier, while others who unknowingly purchase low quality seeds will produce well below this frontier, even with perfect management.

To our knowledge, we are the first to use production frontiers to study seed quality. The main advantage of this indirect approach is that it only requires relatively standard survey data and is easily reproducible. We therefore think that it is a useful complement to lab testing, which is still indispensable to distinguish between different sources of low quality: counterfeiting or mishandling.

The paper is structured as follows. Section two elaborates on the use of the production frontier to assess seed quality and derives hypotheses for testing. Section three introduces the study area, materials, and methods, while section four presents the results. The last section concludes the paper.

4.2 Theoretical Framework

Modern seeds tend to have a higher production potential than traditional seeds as well as a higher responsiveness to other inputs like fertilizers. Hence, farmers benefit most from purchasing expensive seeds when they also increase their application of complementary inputs. This means that we expect higher yields for farmers using modern seeds due to both the nature of the seeds and the use of additional inputs. Mistrust in the quality of seeds may suppress this behavioural response: some farmers are insecure about seed quality and may undersupply other inputs (Bulte et al., 2014). However, they would still achieve higher yields than farmers planting traditional seeds. This leads to the following hypothesis:

Farmers using modern seeds have higher yields than those using traditional seeds (H1).

As indicated, part of this expected yield difference would be attributable to higher use of complementary inputs. However, we also expect that with proper management, modern seeds will give higher yields given the amount of inputs used. Put differently, we expect that the production frontier for modern seeds exceeds the production frontier for traditional seeds:

Modern seeds have a higher production frontier than traditional seeds (H2).

Other than yields, a difference in the production frontier can be directly attributed to differences in seed quality, as behavioral responses imply a shift along the frontier and not a change of the frontier. In addition, as long as sufficient farmers have purchased high quality modern seeds, the presence of low quality seeds will not affect the estimates of the frontier, which by definition is based on best practice, which in this case includes best seeds.

Adulterated or maltreated seeds are associated with a lower production frontier than high quality seeds. However, as seed quality is unobserved by buyers, all farmers purchasing modern seeds are judged against the benchmark of the modern seed frontier. Hence, low seed quality is measured as technical inefficiency, which is the failure to produce the maximum output given the use of inputs and the available technology (Kumbhakar and Lovell, 2003). This adds to the standard causes of technical inefficiency that affect both users of traditional and modern seed, such as suboptimal timing of input applications. The extent of additional TE depends on the specific quality of seeds, which is likely to differ from farmer to farmer. These observations lead to the following two hypotheses:

Modern seed users have a lower average TE than traditional seed users (H3).

The variance of TE is higher for modern seed users than for traditional seed users (H4).

It is probable that a substantial group of farmers using modern seeds will plant unadulterated, non-deteriorated seeds whereas other farmers will plant seeds that are adulterated/ deteriorated and of a similar low quality. In this case, we would expect the first group of farmers to produce relatively close to the production frontier, whereas the latter group would produce at much lower levels of efficiency. This leads to our final hypothesis:

The TE of modern seed farmers has a bimodal distribution (H5).

4.3 Material and Methods

4.3.1 Data

The data used for this paper were collected from smallholder farming households in Mbeya and Songwe regions in the southern highlands of Tanzania in 2016. The two regions are among the leading food-producing regions in the country. The annual rainfall in both regions ranges from 650mm to 2,600mm. Two districts from each region were purposively selected based on the importance of maize, rice and bean cultivation by smallholder farmers. All wards in these districts with high potential for the target crops were subsequently selected for data collection, which amounted to 41 wards. In these wards, 51 farmer organizations were identified, and survey participants were stratified randomly selected from the membership lists, aiming for similar shares of members selected per organization.

For our analysis, we limited the sample to farmers cultivating maize on 15 acres or less, thus eliminating the largest maize growers with plots up to 75 acres, who constitute only 1 % of total growers. This resulted in a sample containing complete maize production data on 1,304 farmers. We focused on maize because of its importance in Tanzania and the rest of eastern Africa. Maize is the main cereal crop in Tanzania in terms of production, food security, and rural household income (Kassie et al., 2014; Shiferaw et al., 2011). The crop occupies almost 45 % of the land under cultivation, and accounts for nearly 75 % of all cereals consumed in the country. The annual per capita consumption of maize in Tanzania is estimated at 112.5 kg, implying that three million tons are consumed annually (Degraeve et al., 2016; Temu et al., 2011). As a staple food, maize is grown for household consumption and for markets in all of Tanzania's agro-ecological zones, but the main production areas are in the southern highlands.

We interviewed the selected households using structured questionnaires. The household head was asked detailed questions on crop production. The information collected included maize output (kg), maize inputs, and distance to key markets. Key inputs were land cultivated (acres), labor use (person-days), value of inorganic fertilizers (TZS), quantity of seeds (kg), and value of herbicides (TZS). The main adult woman in the household, generally the spouse of the household head or the head herself, was interviewed on household demographic factors, asset ownership, consumption and food security. For this study, we mainly used the information from the crop production questionnaire.

4.3.2 Estimation of technical efficiency

We used stochastic frontier analysis (SFA) to estimate TE. SFA was developed based on the pioneering work of Farrell (1957) and transformed into production function analysis by Aigner et al. (1977). Contrary to the non-parametric approach of data envelopment analysis, SFA takes into account the stochastic nature of production: the disturbance term captures both a noise and an inefficiency component, thus allowing for variation in agricultural production attributed to randomly distributed factors beyond the farmers' control (Coelli and Battese, 1996). This comes at the cost of having to specify a functional form.

The stochastic frontier production function is specified as follows:

$$Y_i = f\ (X_i\,, \beta)\ \exp\ (\varepsilon_i)\ \ i=1, 2...N, \tag{1}$$

where Y is production, X is use of inputs for household i, and ε is a composite error term. This error term is defined as

$$\varepsilon_i = v_i - u_i \tag{2}$$

where v_i is the disturbance term, which is assumed to be independently and identically distributed (*iid*) with mean zero and constant variance. v_i captures the random variation in output due to factors outside farmers' control, including unpredictable events such as bad weather. u_i is a one-sided *iid* error that reflects efficiency (Aigner et al., 1977; Meeusen and van Den Broeck, 1977). It measures the distance of the producer from the production frontier: the potential production level given the amount of inputs used. TE efficiency is calculated as e^{-u_i}, which theoretically ranges between 0, for farmers not producing at all ($u_i = \infty$), and 1, for technically efficient farmers operating on the frontier ($u_i = 0$).

For the analysis, we used a linearized Cobb Douglas function:

$$lnY_i = \beta_0 + \sum_{j=1}^{5} \beta_j\ lnx_{ji} + \sum_{k=1}^{2} \gamma_k\ D_{ki} + v_i - u_i, \tag{3}$$

where x_j are the five key inputs: land, labour, seeds, fertilizers, and herbicides. As not all households use fertilizers and herbicides, we defined ln(0) = 0 and added dummies for use/no use of these inputs to avoid sensitivity of the estimates to scaling of the respective input variables.

We estimated (3) separately for traditional seed users and modern seed users using maximum likelihood estimation (Coelli and Battese, 1996; Kumbhakar and Lovell, 2003; Wang and Schmidt, 2002). Each different type of seed implies a different technology and thus separate production functions: the productivity of inputs may be different for traditional and modern seed users. This is obvious for seeds, and other modern inputs are generally considered complements to modern seeds, which could result in higher input elasticities in the modern seed frontier. We used a Chow test to test for significant differences between the two frontiers and also for differences at the coefficient level.

4.4 Results

4.4.1 Maize production and yields

Table 4.1 presents descriptive statistics for maize production by seed type. Sixty two percent of farmers used modern seeds. In agreement with hypothesis 1, these farmers obtained higher yields: yields were no less than 90% higher on average. This suggests that modern seed users take advantage of the high-yielding potentials of modern seeds to enhance farm output. In order to achieve the higher yields, they used more fertilizers and herbicides, while using slightly less labor and seeds. Based on the descriptive statistics alone, it is not possible to say what portion of the higher yields, if any, results from using higher quality seeds. To give a general idea of the producers in the study, Table 4.1 also presents some farm household characteristics. The average household head was a 50-year-old man with primary education. Households using modern seeds had larger maize plots, more cattle, and larger households than those using traditional seeds. This agreed with our expectations that wealthier farmers would make more use of modern inputs.

Table 4.1: Characterization of maize production and farm households

Variable	Traditional seeds (N= 490) Mean (SD)	Modern seeds (N=814) Mean (SD)	Pr (|T|>|t|)
Maize production			
Maize yield (kg/acre)	564.206	1065.63	0.000
	(449.51)	(676.10)	
Land cultivated (acres)	2.01	2.46	0.000
	(1.58)	(2.18)	
Labour (days/ha)	23.16	21.59	0.082
	(17.48)	(14.58)	
Fertilizers (TZS/ha)	50633.72	119859.60	0.000
	(66898.21)	(82951.06)	
Seeds (kg/ha)	10.55	8.43	0.000
	(6.39)	(7.12)	
Herbicides (TZS/ha)	3218.84	10116.64	0.000
	(7374.00)	(11842.19)	
Farm household characteristics			
Age of household head	50.98	50.16	0.280
	(13.48)	(13.07)	
Gender of head, 1= female 0= male	0.19	0.12	0.001
	(0.39)	(0.33)	
Head completed primary education	0.69	0.70	0.774
	(0.46)	(0.46)	
Household size (number)	5.14	5.51	0.004
	(2.22)	(2.21)	
Livestock ownership (TLU)	1.56	1.89	0.012
	(2.98)	(3.03)	

4.4.2 The production frontiers

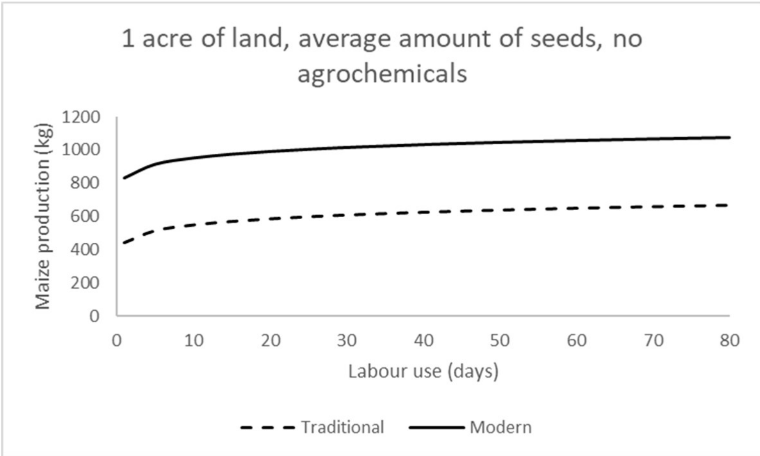
We used production frontier estimates to shed more light on the productivity effects of modern seeds. Table 4.2 presents the maximum likelihood estimates of the stochastic frontiers for both types of seeds. All coefficients have the expected sign and most are statistically significant at the 1 % level. As anticipated, jointly the coefficients were significantly different between the two seed types, indicating that they indeed represent different technologies with separate frontiers. Looking at the individual coefficients, only the elasticities for land and seeds differed between the seed types. As expected, the seed elasticity of production was much higher for modern seed users. However, land elasticity was higher for traditional seed users. This reflects the nature of the technologies: when using traditional seeds, a larger share of production is generated from the land itself, while a larger share is generated from the seeds when using modern seeds. The seed effect is sufficiently large to result in increasing returns to scale for the modern seed technology compared to constant returns to scale for the traditional seed technology.

Table 4.2: Maximum livelihood estimates for parameters of the Cobb Douglas stochastic frontier

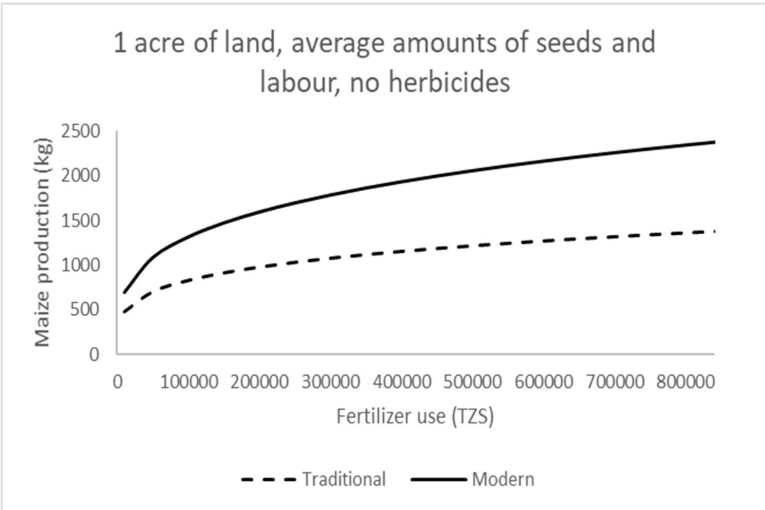
	Traditional (N=490)	Modern (N=814)	Pr(|Z|>|z|)	
Land	0.581***	0.434***		0.044
	(0.071)	(0.050)		
Labour	0.094	0.058		0.772
	(0.060)	(0.040)		
Fertilizers	0.237***	0.278***		0.357
	(0.049)	(0.036)		
Seeds	0.096*	0.331***		0.000
	(0.054)	(0.038)		
Herbicides	0.118	0.055		0.632
	(0.103)	(0.036)		
Fertilizer dummy	-2.386***	-2.927***		0.339
	(0.571)	(0.437)		
Herbicides dummy	-0.817	-0.419		0.768
	(1.011)	(0.357)		
Constant	5.863***	6.022***		0.962
	(0.226)	(0.156)		
sigma_u	0.503***	0.535***		
sigma_v	0.556***	0.392***		
Lambda	0.905***	1.336***	Chow test	
Economies of scale[a]	0.13	0.16***	Prob>chi2	0.000

Notes: Standard error in parentheses. Significant at *** p<0.01, ** p<0.05, * p<0.1; [a] b(land)+b(labour)+b(fertilizer)+b(seed)+b(herbicides)-1

To test our hypothesis 2 that the production function of modern seeds is higher than the production frontier for traditional seeds, we use Table 4.2 in combination with graphical representations of the production functions. First, we plotted the frontier as a function of labor use, assuming a plot size of one acre, average seed quantities for both types, and no use of other inputs (Figure 4.1, panel A). The modern seed frontier is consistently higher than the traditional seeds frontier. This implies that even without complementary modern inputs, the modern seeds are more productive than traditional seeds. This is contrary to the common belief that fertilizers and other agrochemicals are needed to derive benefit from modern seeds. Second, we plotted the frontier as a function of fertilizer use, again assuming a plot size of one acre and no use of other inputs than labor, but now assuming average labor use of the pooled sample. Logically, the modern seed function is again higher than the traditional seed function over the full range of fertilizer applications. Because of the higher fertilizer elasticity for modern seeds, the frontier has a higher slope. However, remember that the difference in fertilizer elasticities was not statistically significant when tested in isolation. In conclusion, the production frontier is consistently higher for modern seeds than for traditional seeds, providing support for hypothesis 2.



A: Labour use



B: Fertilizer use

Figure 4.1: Maize production frontier

Summarizing the results so far, the higher yields observed for modern seeds are the result of a combination of two factors. First, the production frontier is higher, so that with the same amounts of inputs used, farmers using modern seeds can achieve a higher level of output. Second, modern seed farmers apply higher levels of variable inputs, which increases productivity even more.

4.4.3 *Technical efficiency*

To test our other hypotheses, we needed to analyse our efficiency estimates. The inefficiency component of the disturbance term (u) was significantly different from zero for both sub-samples, indicating that there was indeed technical inefficiency. We used the models to estimate the TE for each individual farmer. Table 4.3 summarizes the results and Figure 4.2 presents the full distribution.

Table 4.3: Distribution of technical efficiency scores by technology

	Traditional seeds users (N=490)	Modern seeds users (N=814)	Prob>0
Mean	0.64	0.63	0.8235[1]
Standard deviation	0.16	0.19	0.0004[2]
Minimum	0.07	0.02	
Maximum	0.89	0.91	
Percentiles			
25%	0.56	0.52	
50%	0.68	0.68	
75%	0.76	0.78	

Notes: [1] p-value for T-test for equality of means; [2] p-value for variance ratio test.

We reject our hypothesis 3 that TE was generally lower for modern seed users: on average, traditional and modern seed users produced at an efficiency of 64 and 63 % of their respective frontiers (Table 4.3). These figures are similar to the average TE level of 57 % for maize production in the East African region in literature as reviewed by Kibirige et al. (2014). Interestingly, Ngango and Hong (2021) found an average TE of 62 % for maize cultivated with traditional seeds, which is almost identical to our estimate, but an average as high as 75-80 % for modern seeds, depending on the type of seeds.

To gain additional insights, we looked further into the distribution of the TE scores. Interestingly, we found that the standard deviation was 19 % higher for modern seeds than for traditional seeds, which provides support for hypothesis 4. This seems indicative of heterogeneous seed quality. Going beyond the second moment of the distribution, the kernel density plot clearly shows a unimodal, left-skewed distribution of TE for modern seed users and a slightly more uniform distribution with a peak at a somewhat lower score for traditional seed users (Figure 4.2). We therefore reject hypothesis 5, which predicted a bimodal distribution of TE for modern seed users. The relatively high density at high levels of efficiency for modern seed users could be an indication that it is the better farmers who purchase improved seeds, but we cannot exclude other possible explanations.

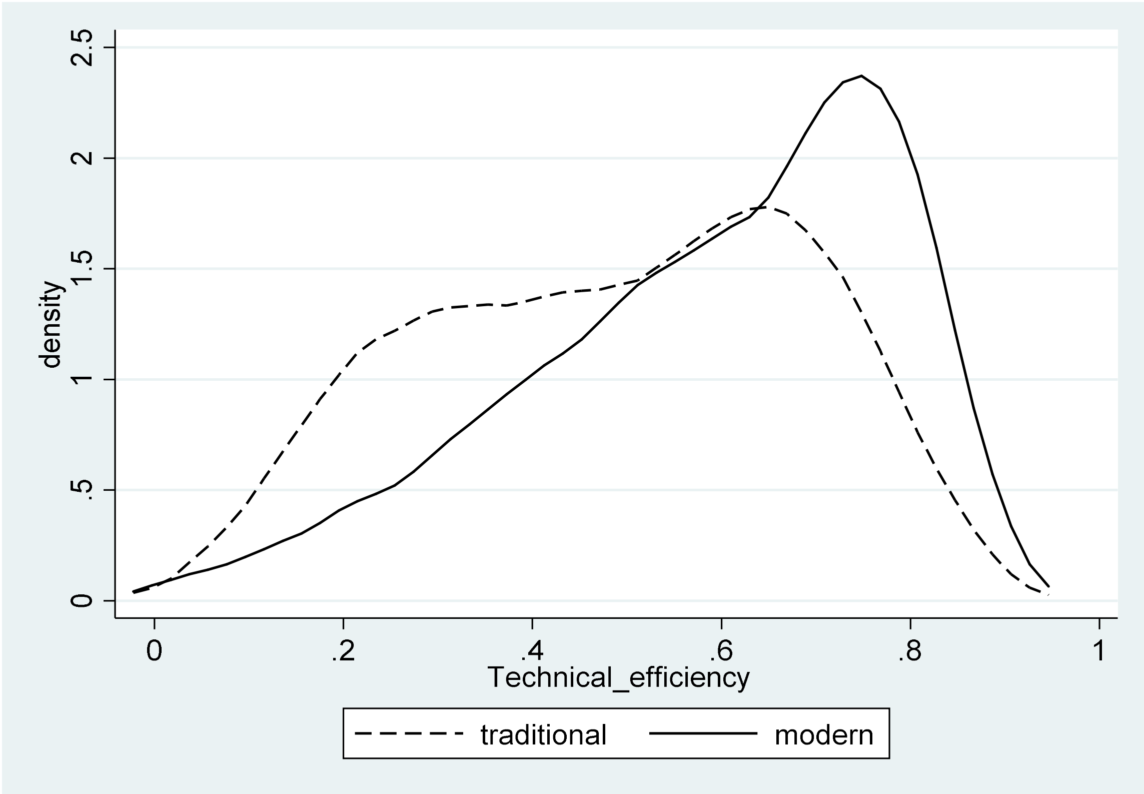


Figure 4.2: Kernel density plot for technical efficiency

Taken together, our findings provide limited evidence to support the perception that a substantial share of the modern maize seeds available in rural markets in Tanzania are either counterfeit or heavily deteriorated. The use of modern seeds results in higher productivity with similar average levels of TE compared to traditional seeds, and we find a unimodal distribution of TE with a larger density at high efficiency levels for modern seeds. Yet, the variance for TE is substantially higher for modern seeds, which could be an indication of differences in seed quality.

4.5 Conclusion

We used an innovative method to study the current issue of the quality of modern seeds in African markets. Instead of using laboratory research to directly assess seed quality, we used stochastic frontier analysis to compare the productivity of modern and traditional seeds and to assess the distribution of TEs, which we believe can be an indirect indicator of heterogeneous seed quality. The advantage of our method is that it provides insights into seed quality without the need for expensive and complicated laboratory testing. The downside is the indirectness of the approach, which leaves room for differences in interpretation.

Overall, our results show that farmers who purchased modern seeds obtained much higher yields on average than farmers who used traditional seeds. While this result was partly due to the higher use of complementary inputs, such as fertilizers and herbicides, it was also attributable to a high production frontier for modern seeds. On average, TE efficiency was not different for modern and traditional seeds, but its variance was higher for modern seed users. This could be the result of the presence of low quality seeds, which prevents some farmers to produce at the high TE efficiency levels observed for the bulk of modern seed producers. However, the absence of a bimodal distribution contradicts the assumption that some farmers are buying unadulterated, undeteriorated seeds, whereas other farmers are buying relatively low-quality seeds. Our results, however, do not exclude the possibility of a sliding scale of seed quality, on which a substantial group of farmers receive good quality seeds, as reflected in the high density of farmers producing at high levels of TE, and another group purchases seeds whose level of quality shows a relatively uniform distribution. This distribution seems more likely for deteriorated seeds than for adulterated seeds, which would likely have a bimodal or multimodal distribution. Hence, while our results do not reveal evidence of seed adulteration, we cannot rule out the presence of seeds whose lower quality is due to mishandling.

Chapter 5

Impact of off-farm employment on rural household food and nutrition security: Evidence from the southern highland regions of Tanzania

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Abstract

Food insecurity is a serious problem in Tanzania that could be decreased by engagement in the off-farm economy. This study addresses two objectives: (i) to examine the drivers of households' decision to participate in off-farm employment in Tanzania, and (ii) to evaluate the impact of off-farm activities on rural households' food security and nutritional security. We used household survey data from the southern highland districts of Mbeya and Songwe regions collected in 2014 and 2016. We employ difference-in-difference and propensity score matching techniques to evaluate the impact of participation in off-farm employment on household food security using three indicators with different recall periods. We find that more adults per household and a larger farm size stimulated participation in off-farm activities, while farming experience and livestock ownership had a limiting effect. Participation had a significant effect on food security, but the strength of the effect depended on the specific indicator selected.

Keywords: Off-farm work, Drivers, Food Security, Southern Highland, Tanzania

5.1 Introduction

Food and nutritional insecurity remain the most serious global health challenges of our time (FAO, 2019). Estimates show that more than 820 million individuals worldwide are food insecure (FAO, 2019). The causes of food insecurity include low adoption of modern farm technologies, inadequate infrastructures for irrigation and reliance on rain-fed cropping methods. In addition, food insecurity is being increased by rapid population growth coupled with low agricultural productivity. Projections have shown that 1.3 billion people of the world's population lacks access to sufficient or suffers from poor nutrition. In Africa, the number of undernourished people increased from 181 million in 2010 to 236 million in 2017 (FAO, 2018). Achieving food security thus remains a key development challenge in most sub-Saharan African (SSA) countries. Farm households are key to this challenge, not only as the main producers of food but also because a substantial share of the food-insecure population depends for the most part on agriculture for food, nutritional security, and income (Dzanku, 2019).

One country that is highly representative of food insecurity issues in SSA is Tanzania. The Tanzania Household Nutrition Survey of 2015–2016 indicates that the stunting rate in children under the age of 5 years was 35%. Wasting was about 5% (too thin for their age), while 4% were overweight and 14% were underweight. Surprisingly, all three nutritional indicators are highest in children in the major food production areas of the southern highlands, an observation that requires investigation. While the agricultural sector remains the primary employer in rural Tanzania and the major source of income for rural households, its contribution to household food security has declined over time. As a result, farming as the primary source of income fails to furnish a sufficient livelihood to many rural farming households in Tanzania, and households are being forced to look for alternative means of coping with the problem of low and variable income.

One strategy for countering food insecurity is the object of growing interest: rural off-farm employment. Increasingly, engaging in off-farm activities is being seen as a crucial pathway towards mitigating the income shocks and risks associated with farming in rural areas where agriculture is vulnerable to weather **(**Duong et al., 2020**)**. Rural households can decide to participate in off-farm activities for various reasons: excess labor in the family, seasonality of crop production, and demand for more income. In all cases, off-farm income may provide farmers with enough financial resources to purchase farm inputs which can boost agricultural production, finance household expenditures on food, and increase food security. On the other hand, liquidity constraints could force farmers to supply off-farm labor at the cost of their own farm production (Dzanku, 2019). In addition, moving away from agriculture makes households more dependent on food purchased at the market, with its fluctuating prices which could potentially harm their food security (Rahman and Mishra, 2020). The relationship between off-farm employment and food security is therefore anything but clear-cut.

The current study explores the issue of off-farm employment by addressing two objectives: (i) to examine drivers predicting households' decision to participate in off-farm employment in a high-potential agricultural zone in Tanzania and (ii) to evaluate the impact of off-farm activities on rural households' food security. Several studies have analysed the impact of off-farm employment on food security in SSA (e.g., (Babatunde and Qaim, 2010; Duong et al., 2020). We contribute to these studies in two ways. Our first contribution is the use of food security indicators with different recall periods: (i) the household dietary diversity score for the past 7 days (7 days HDDS); (ii) the household food insecurity access scale (HFIAS) for the past month; and (iii) a binary indicator for whether a household reported facing food insecurity in the past year. While previous literature has used many different indicators for food security, these are generally so-called objective measures based on similar household-level food consumption data with a 7-day recall period (Kuwornu, Owusu, Tsiboe, Zereyesus). Exceptions are Babatunde and Qaim (2010), who complemented 7-day consumption data with child anthropometric data, and (Dzanku, 2019), who calculated annual potential food supply and asked whether households had reduced the number of meals eaten during the lean season due to lack of food, which is a more subjective measure of food security. Our study uses both objective and subjective indicators with different recall periods to provide additional insights into the intricacies of the relationship between off-farm employment and food security.

Our second contribution to previous literature involves the use of panel data. Generating unbiased estimates of the impact of off-farm employment is complicated due to self-selection of households, especially when only cross- sectional data is available. To the best of our knowledge, the only study using panel data to assess the relationship between off-farm employment and food security for SSA is (Dzanku, 2019). However, the use of panel data provides a number of significant advantages. It offers the additional option to control for time-invariant differences between participants and non-participants. Also, it enables the use of baseline characteristics in matching. Our study therefore uses panel data for 1,411 farm households in the southern highlands of Tanzania.

The findings of this study are central for making evidence-based policymaking concerning the rural economy, where people are often more nutritionally susceptible and have a greater risk of micronutrient deficiencies. The results of the study will guide strategies to reduce food insecurity and boost the nutritional status of rural households.

The remaining part of this chapter is structured as follows. Section 2 describes the material and methods, section 3 is about results and discussion, and section 4 presents the conclusion and recommendations.

5.2 Material and methods

5.2.1 Data

This paper used panel household survey data from the southern highland districts of the Mbeya and Songwe regions. The first round of data was collected in December 2014-January 2015. This coincided with a peak in the production season with farmers preparing their fields and planting an assortment of crops. However, some locations were difficult to access due to the rains, which caused severe delays in the data collection process. The second round was collected almost two years later. While we originally intended to collect the second round data exactly two years after the first round, we opted against this to avoid the complications encountered in the first round. Instead, we collected the data in October-November 2016.

Multistage sampling was used to select the households. First, we sampled four districts: Mbeya Rural and Mbarali from the Mbeya region and Mbozi, and Momba from the Songwe region. These districts were selected for their potential to produce crops such as maize, paddy and beans. In the second stage, we selected 41 wards using the same criteria. In the third stage, we selected 51 farmer organizations spread over the wards. Finally, we randomly selected farming households from each of the membership lists of the farmer organizations for the interviews.

We used two pre-tested structured questionnaires to gather primary data through face-to-face interviews. The trained enumerators used the Swahili language to interview the respondents. The first questionnaire was used to interview household heads. Information collected included socioeconomic data on agricultural production of the previous cropping season, such as land size, total land owned, land cultivated, and input used in agricultural production. Moreover, we collected information on access to institutional factors such as distance to output markets. The second questionnaire was administered to the main female adult, often the spouse of the household head. In a situation where the spouse was absent, we interviewed a knowledgeable household member engaged in cooking and well informed on consumption expenditures. In the case of female-headed households, the woman had to answer both questionnaires. Using the female questionnaire, we collected demographic data such as age, gender, marital status, education level, and main occupations of all household members. The occupations included participation in any off-farm income-generating activities, i.e., wage labor or self-employment, such as petty trading. As these questions did not refer to a specific time period, we do not expect the difference in timing between the first and second survey round to have affected the answers to these questions. Moreover, we collected information on total livestock owned by the households, as well as household consumption and food security. As the data on these last two items partly refer to a shorter time period, the timing of the survey may have affected some of the answers, as we will discuss in detail below.

5.2.2 Measuring food security

The Food and Agriculture Organization (FAO) defines food security as a ‘‘situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life’’ (Kennedy et al., 2011b). Due to the complex nature of the concept, we used three indicators. Each indicator referred to a different time period: a week, a month, or the year before the survey. The most food-insecure period in the research area is February-March, just before the main harvest. Both our surveys rounds took place before this. However, the households interviewed in January in the first round may have already experienced some seasonal food insecurity, which would mean that levels of food security for the indicators with a short reference period were lower in the first round than in the second round.

The first indicator was the Household Dietary Diversity Score (HDDS), which measures economic access to a food. The HDDS was calculated based on household consumption data for the 7 days before the survey. All food items in the questionnaire are classified in 12 food group using FAO guidelines (2011). These food groups are 1) cereals; 2) roots and tubers; 3) vegetables; 4) fruits; 5) meat/poultry; 6) eggs; 7) fish and seafood; 8) pulses/legumes/nuts; 9) milk and dairy products; 10) oils/fats; 11) sugar/honey; and 12) spices, condiments, and beverages. HDDS is then the number of food groups consumed in the reference period. For more detailed information on HDDS, see Chapter 4.

The second indicator is the Household Food Insecurity Access Scale (HFIAS). The HFIAS is constructed from a short questionnaire that captures behavioral and psychological manifestations of insecure food access (see Appendix 1). The reference period was the 30 days before the survey date (Coates et al., 2007). For each of nine items, the HFIAS questionnaire asks how often a situation occurred: never, rarely (once or twice), sometimes (three to ten times) or often (more than ten times). A score of 0 was recorded for never, 1 for rarely, 2 for sometimes, and 3 for often. The sum of HFIAS points can thus range from 0 for fully food-secure to 27 for maximum food-insecure households, with 0-2 indicating food security, 3-10 moderate food insecurity, and 11-27 severe food insecurity (Coates et al., 2007).

Measure three reflects food security on an annual basis: the female questionnaire contained questions on whether the household had experienced food insecurity in the past twelve months. The indicator is simply the binary variable indicating whether this was the case or not. We also asked in which months the household experienced food insecurity. Based on this information, we calculated the number of months that each household faced food insecurity. However, as only 21 % of survey households reported food insecurity, the results for this variable were very similar to the results for the binary variable and we decided to report the latter only.

5.2.3 Data analysis

To make optimal use of the panel nature of our data, we built on two different approaches to deal with the probable endogeneity of off-farm employment, borrowing heavily from impact assessment methodology. First, we used a first difference approach for the full sample of households. The model was estimated using linear regression and can be expressed as:

$$\Delta Y_i = \beta_0 + \beta_1 \Delta OF_i + \beta_2 X_i + \varepsilon_i, \qquad (1),$$

where ΔY_i is a vector measuring the change in food security between the two survey periods for household *i*. ΔOF is the change in off-farm employment status and *X* is a set of controls from period 1, including the lagged outcome indicator. (See Table 5.1 for a description of the variables.) This approach gives unbiased estimates of the effect of ΔOF on ΔY if cov(ΔOF, ε_i), *i.e.*. there are no unobserved characteristics that affect both ΔY and ΔOF. Potential seasonal differences in food security between baseline and endline are expected to be averaged out.

Table 5.1: Definition of control variables

Variable	**Variable type**	**Description**
Off-farm participation	Binary	A treatment variable whether the household participated working off-farm 1 = participant, 0 = non-participant
Age of household head	Continuous	Age of household head in years
Gender head	Binary	Dummy = 1 if female head of household, 0= Male head of household
Secondary education complete	Binary	Dummy = 1 if the head completed secondary school education, 12 years of schooling, 0 = otherwise
Household size	Continuous	Total number of household members
Dependency ratio	Continuous	The ratio of total inactive labour <15 years of age and >60) and the active working age i.e. between 15 and 60 years
Livestock owned	Continuous	Total number of livestock estimated in Tropical Livestock Unit
Region of respondent	Binary	Dummy = 1 if respondent resided in Songwe region, 0= Mbeya region
Subsistence farming as main occupation	Binary	Dummy = 1 if subsistence farming the main occupation
Farming experience	Continuous	A number of years a household head has engaged in farming activities. This acts as proxy for experience in farming
Land owned	Continuous	Size of land owned by the household in acres
Distance to market	Continuous	Distance in kilometres of a household from the agricultural market

The second approach is propensity score matching (PSM). This approach focuses on food security in period 2. Households in period 2 were divided into two groups, those with and those without off-farm employment. Then, we compared food security between these two groups after matching the households using the propensity score, which is the probability of engaging in off-farm employment using a probit model with period 1 characteristics as independent variables. The key underlying assumption is that there are no unobservable characteristics affecting both period 2 off-farm employment and period 2 food security. These estimates will not be affected by potential seasonal differences in food security between baseline and endline.

Whereas estimating the effects of off-farm employment on the full sample has the advantage of using all available information and, in the case of first differences, accounting for both loss and gain of off-farm income, households who already engaged in off-farm activities in

2014 may be inherently different from those who did not. This would cast doubt on the validity of the underlying assumptions of the two models. We therefore performed a second set of analyses for those households that did not have off-farm employment in period 1. Interpreting engagement in off-farm employment as a non-randomized treatment, we can now make full use of quasi-experimental methods.

The first difference model now reverts to a standard difference-in-differences estimator (DID). DID relies on the availability of data for two groups: the treatment group that receives treatment (Zi=1) and the control group that does not (Zi=0). The intervention is not available in the first period for either group (Di,t=0 = 0|Zi = 1, 0), and it is available for the treated group in the follow-up period (Di,t=1 |Zi = 1) (Villa, 2016). The DID treatment effect is then defined as the difference in the outcome for treated and control units before and after controlling for period 1 characteristics (*X*) and can be expressed as:

$$DID = E\{ (Y_{it,=1}|D_{it=1} = 1, Z_i = 1, X_i) - E(Y_{it=1}|D_{it=1} = 0, Z_i = 0, X_i)\} - \{E\ (Y_{it=0}|D_{it=0} = 0, Z_i = 1, X_i\ ) - E(Y_{it=0}|D_{it=0} = 0, Z_i = 0, X_i)\} \qquad (2).$$

The regression model used to estimate this equation equals (1), the only difference being that households with off-farm employment in period 1 are excluded.

The key assumption of DID is that, although treatment and comparison groups may have different levels of the outcome prior to the start of treatment, their trends in pre-treatment outcomes are the same. Unfortunately, this assumption can only be tested when more than one observation before treatment is available, which is why we did not rely on this approach alone. As a second approach we again used PSM, but now for the restricted sample.

As a third model, we combined DID and PSM (PSM-DID). PSM-DID controls for both observed covariates and time-invariant unobserved characteristics that may affect both the treatment and the outcome variables (Dehejia, 2005; FAO and OECD, 2016; Villa, 2016). The propensity score from the probit model is used to weigh observations in the DID regression. Econometrically the model is expressed as follows:

$$DID = \{E(Y_{it,=1}D_{it=1} = 1, Z_i = 1) - w_i X\ E(Y_{it,=1}|D_{it=1} = 0, Z_i = 0)\} - w_{it=0}^{t}\ X \left\{E(\ Y_{it=0}|D_{it,=0} = 0, Z_i = \ 1\right) - w_i X\ E\left(Y_{it,=0}|D_{it=0} = 0, Z_i = 0\right)\} \qquad (4),$$

where

w_i are the kernel weights.

As a third set of analyses, we intended to calculate DID, PSM and PSM-DID for those farmers who had off-farm activities at baseline. The treatment would then be the loss of off-farm income. Comparing the results for farming gaining off-farm employment in period 2 with those losing off-farm employment in that same period would give an additional robustness check. However, the number of farmers engaging in off-farm employment in period 1 was relatively small and the number of these losing their employment in period 2 was too small for DID and PSM-DID to be taken into further consideration. We did, however, estimate the PSM model for this subset of farmers.

5.3 Results and discussion

5.3.1 Summary statistics

Two thirds of the survey households did not engage in off-farm employment in either of the two survey periods (Table 5.2), and 12 % participated in both periods. Fifteen percent participated only in period 2 (2016), whereas no more than 7 % participated only in period 1 (2014). This implies that there was a substantial increase in off-farm participation between the two years. Restricting the sample to only those households not participating in off-farm activities thus amounts to excluding 19 % of the sample.

Table 5.2 Number of households participating in off-farm employment per survey year

	Off-farm 2016		
Off-farm 2014	**No**	**Yes**	**Total**
No	936 (66%)	205 (15%)	1,141 (81%)
Yes	97 (7%)	173 (12%)	270 (19%)
Total	1,033 (73%)	383 (27%)	1,411 (100%)

Tables 5.3a and 5.3b compare the 2014 characteristics of households with and without off-farm employment in 2016. Looking at the full sample (Table 5.3a), we see that the group without off-farm employment had higher food security status as measured by all three indicators. This group also had a higher human capital endowment: household heads were more likely to have completed secondary education and had more farming experience, even though they were younger on average. The households with off-farm employment in 2016 owned more land but less livestock on average and were somewhat less likely to define themselves as subsistence farmers, a label deemed appropriate by 96 % of respondents.

Restricting the sample to those households who did not have off-farm employment in 2014 made the two groups more comparable, as expected. Of the three food security indicators, only HFIAS showed a statistically significant difference between the two groups: those who had off-farm employment in 2016 were more food-secure in 2014. Additionally, differences in capital endowments decreased substantially, and the only significant differences remaining were in livestock owned (higher for those without off-farm employment) and farming experience (higher for those with off-farm employment). On the other hand, in 2016 the with and without off-farm groups are again relatively dissimilar when one considers only those that had off-farm income in 2014. However, this observation is based on a relatively small group of households.

Table 5.3a Descriptive statistics 2014 (Full sample)

	All		**No off-farm 2016**		**Off-farm 2016**		**Comparison**
Variable	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Pr(|T|>|t|)**
Food security							
HDDS	7.43	1.53	7.30	1.50	7.78	1.56	0.00
HFIAS	4.18	4.49	4.33	4.58	3.76	4.23	0.03
Food insecurity	0.21	0.41	0.22	0.41	0.17	0.38	0.03
Other							
Off-farm	0.19	0.39	0.09	0.29	0.46	0.50	0.00
Region	0.49	0.50	0.45	0.50	0.60	0.49	0.00
Age head	48.50	13.10	50.26	13.56	43.68	10.33	0.00
Gender head	0.14	0.34	0.13	0.34	0.16	0.37	0.13
Head secondary education	0.10	0.30	0.07	0.26	0.17	0.38	0.00
Head married	0.82	0.38	0.83	0.38	0.82	0.39	0.61
Household size	5.36	2.21	5.30	2.21	5.52	2.19	0.10
Land owned (acres)	6.46	12.79	5.90	10.03	7.99	18.25	0.04
Farming experience	20.07	13.45	22.10	13.82	14.53	10.55	0.00
Dependency ratio	42.42	21.67	43.21	22.34	40.26	19.57	0.02
Livestock (TLU)	0.54	0.58	0.56	0.51	0.50	0.72	0.15
Subsistence farmer	0.96	0.19	0.98	0.14	0.91	0.28	0.00
Distance to market	23.36	32.22	22.79	31.86	24.94	33.19	0.28
Number of observations	1411		1033		378		

Table 5.3b Descriptive statistics 2014 (No off-farm in 2014)

Variable	All Mean	Std. Dev.	No off-farm 2016 Mean	Std. Dev.	Off-farm 2016 Mean	Std. Dev.	Comparison Pr(|T|>|t|)
Food security							
HDDS	7.27	1.52	7.24	1.49	7.40	1.63	0.19
HFIAS	4.23	4.50	4.37	4.60	3.58	3.92	0.01
Food insecurity	0.22	0.41	0.22	0.42	0.20	0.40	0.38
Other							
Region	0.48	0.50	0.46	0.50	0.55	0.50	0.03
Age head	49.57	13.46	50.70	13.68	44.42	11.06	0.00
Gender head	0.13	0.34	0.13	0.33	0.16	0.36	0.28
Head secondary education	0.07	0.25	0.07	0.25	0.06	0.24	0.63
Head married	0.82	0.38	0.83	0.38	0.79	0.41	0.20
Household size	5.33	2.17	5.28	2.18	5.56	2.13	0.10
Land owned (acres)	6.21	12.51	5.92	10.20	7.52	19.89	0.26
Farming experience	21.56	13.71	22.65	14.01	16.62	11.04	0.00
Dependency ratio	42.59	22.36	42.97	22.68	40.87	20.83	0.20
Livestock owned (TLU)	0.54	0.53	0.56	0.51	0.47	0.59	0.03
Subsistence farmer	0.98	0.13	0.98	0.13	0.98	0.14	0.82
Distance to market	22.66	31.49	22.82	31.75	21.94	30.34	0.71
Number of observations	1141		963		205		

Table 5.3c Descriptive statistics 2014 (Off-farm in 2014)

Variable	All Mean	Std. Dev.	No off-farm 2016 Mean	Std. Dev.	Off-farm 2016 Mean	Std. Dev.	Comparison Pr(|T|>|t|)
Food security							
HDDS	8.10	1.39	7.88	1.44	8.23	1.35	0.05
HFIAS	3.94	4.47	3.87	4.31	3.98	4.58	0.84
Food insecurity	0.16	0.37	0.21	0.41	0.14	0.35	0.17
Other							
Region	0.57	0.50	0.40	0.49	0.67	0.47	0.00
Age head	43.97	10.32	46.02	11.61	42.82	9.36	0.02
Gender head	0.16	0.37	0.16	0.36	0.17	0.38	0.78
Head secondary education	0.23	0.42	0.09	0.29	0.31	0.46	0.00
Head married	0.83	0.38	0.79	0.41	0.84	0.36	0.32
Household size	5.49	2.33	5.52	2.46	5.47	2.26	0.89
Land owned (acres)	7.53	13.87	5.74	8.27	8.54	16.13	0.06
Farming experience	13.79	10.09	16.88	10.60	12.05	9.38	0.00
Dependency ratio	41.68	18.47	45.49	18.78	39.54	18.00	0.01
Livestock owned (TLU)	0.53	0.76	0.51	0.56	0.54	0.85	0.78
Subsistence farmer	0.87	0.34	0.94	0.24	0.83	0.38	0.01
Distance to market	26.33	35.04	22.46	33.01	28.50	36.05	0.17
Number of observations	270		97		173		

5.3.2 Determinants of households' participation in off-farm employment

Table 5.4 presents the estimates for participation in off-farm employment in 2016 as a function of 2014 characteristics. Households from Songwe, one of the two districts, had a higher probability of participating, as did households with more members and a lower dependency ratio. This may reflect the secondary status of off-farm employment in relation to farming: only when sufficient adults are available do the households engage in off-farm activities. Yet, the coefficient of land owned is positive, indicating that, *ceteris paribus,* a larger farm size is associated with higher off-farm employment. The effect is very small though: less than a one percentage point increase per acre owned. The effect of livestock is more substantial; an additional livestock unit is associated with a 13 (full sample) or 25 percentage point decrease in the probability that a household engages in off-farm employment. In addition, households with older heads or heads with more farming experience are less likely to participate in off-farm activities. Secondary education decreases participation, but only for the restricted sample. For the full sample, households with female and married heads were more likely to participate. The same gender effect was observed in Tanzania by (Dzanku, 2019). In our sample, it seems to be driven by those households who already had off-farm employment in 2014, as the effects disappear in the restricted sample. Contrary to the findings of Beyene (2008) for Ethiopia and Nazir et al. (2018) for Pakistan, we found no or negligible effects of distance to the market.

Table 5.4: Probit model for Off-farm employment in 2016

Variables	Full sample	No off-farm in 2014
Region of respondent, 1= Songwe, 0= Mbeya	0.489***	0.293**
	(0.125)	(0.128)
Age of household head (years)	-0.017***	-0.017***
	(0.004)	(0.004)
Gender of head, 1= female, 0= Male	0.335**	0.066
	(0.146)	(0.136)
Marital status, 1= married, 0 =otherwise	0.467***	-0.108
	(0.132)	(0.144)
Secondary school education of household head	-0.068	-0.271**
	(0.142)	(0.127)
Household size (number)	0.056***	0.063***
	(0.015)	(0.022)
Land owned (acres)	0.007**	0.007**
	(0.003)	(0.003)
Farming experience (years)	-0.020***	-0.013***
	(0.004)	(0.005)
Dependency ratio	-0.005**	-0.004*
	(0.002)	(0.002)
Livestock owned (TLU)	-0.134*	-0.247**
	(0.072)	(0.099)
Subsistence farmer	-1.023***	-0.178
	(0.167)	(0.284)
Distance to market	-0.001	-0.002*
	(0.001)	(0.001)
Constant	1.159***	0.341
	(0.292)	(0.312)
Number of observations	1,411	1,141

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

5.3.3 Impact of off-farm employment on rural households' food security

The estimation results are qualitatively robust between estimation methods and subsamples, suggesting that participation in off-farm employment significantly improves food security (Table 5.5). HDDS increased by 0.4 to 0.7 food groups for the full sample and the no off-farm at baseline sample, depending on the estimation method. This is an increase of 6 to 10 %. For our preferred estimates, the PSM-DID for the restricted sample, the increase is 8 %. We found no significant effect of off-farm income for those households who were already engaged in off-farm employment in period 1. This could be due to the small sample size or because these households were better off on average. HFIAS decreased by -0.6 to -1.9, 14 to 45 % (25 % for our preferred estimates). These differences are related to the choice of estimation method, with PSM giving the highest estimates, but also to the choice of sample. In this case, it is perhaps surprising that farmers with off-farm income at baseline show the largest effect. When non-significant estimates are included, the probability of being food insecure decreases by 2-8 percentage points, which is substantial at a food insecurity rate of 22 %. However, the coefficient is only marginally significant for two out of six estimates and not for our preferred estimates, so we must be very careful when drawing conclusions from these numbers. The lack of significance could be due to the very rough nature of the indicator. Replacing it by the more detailed number of months that households were food insecure gave very similar results due to the relatively small share of non-zero values. Yet, alternative annual indicators, for example based on HFIAS, could potentially give stronger results.

Table 5.5: The effect of off-farm employment on food security

VARIABLES	N	HDDS	HFIAS	Food insecure
Full sample	1,411			
First difference		0.440***	-0.629**	-0.024
		(0.140)	(0.310)	(0.034)
PSM		0.696***	-1.519**	-0.062*
		(0.165)	(0.772)	(0.033)
No off-farm at baseline	1,141			
DID		0.596***	-0.943*	-0.078*
		(0.182)	(0.477)	(0.127)
PSM		0.699***	-1.480**	-0.030
		(0.187)	(0.660)	(0.045)
DID with propensity score weights		0.579***	-1.078**	-0.069
		(0.197)	(0.472)	(0.041)
Off-farm at baseline	270			
PSM		0.241	-1.870***	-0.067
		(0.194)	(0.657)	(0.058)

Inference: *** p<0.01; ** p<0.05; * p<0.1(standard errors in parentheses)

In conclusion, while the overall effect of off-farm employment on food security is clearly positive, the strength of the effect depends on the specific measure selected. We find the largest effects for our monthly measure HFIAS. This could be due to the recall period selected, but also to the subjective nature of this indicator compared to the more objective HDDS.

5.3.4 Matching quality assessment

The reader may recall that period 1 characteristics differed substantially between farmers engaging in off-farm employment in period 2 and those who did not (Tables 5.3a-c), especially for the full sample, and that we applied matching procedures to overcome these differences. The question is how well these procedures have worked: are the covariates balanced after matching? We tested this problem using a T-test on the weighted covariates (Rosenbaum and Rubin, 1985). We assumed that after matching, covariates would be balanced (Caliendo and Kopeinig, 2008).

Table 5.6 indicates that matching was very effective for all characteristics, except for the baseline food security indicators. Remember that for the full sample, all three indicators were significant at the <1 % or 3 % level. After balancing, balancing of HFIAS was still rejected, but only at 7 %, whereas balancing for the other two indicators was rejected at the <1 % level. On the other hand, for the restricted sample, only HFIAS was significantly different between the two groups without weighting. This did not change after weighting, though the significance level decreased from 1 % to 7 %. Hence, matching has significantly improved balancing, though perhaps not as much as desired for the lagged outcome indicators. Based on these results, we would credit the estimates with the restricted samples as having the lowest chance of bias, as anticipated.

Table 5.6: Balancing of baseline characteristics after weighting

	Full sample Mean			No off-farm at baseline Mean		
Weighted Variables	**Control**	**Treated**	**Pr(|T|>|t|)**	**Control**	**Treated**	**Pr(|T|>|t|)**
HDDS	7.357	7.792	0.000	7.314	7.406	0.414
HFIAS	4.322	3.827	0.072	4.230	3.594	0.068
Months food insecurity	0.612	0.385	0.002	0.551	0.459	0.191
Region	0.517	0.558	0.412	0.530	0.546	0.784
Age head	43.706	44.205	0.542	44.475	44.432	0.959
Gender head	0.152	0.161	0.735	0.155	0.155	0.978
Head secondary education (yes=1)	0.152	0.154	0.956	0.061	0.058	0.816
Head married (yes=1)	0.805	0.808	0.902	0.784	0.787	0.917
Household size	5.465	5.504	0.807	5.503	5.551	0.756
Land owned (acres)	6.554	7.489	0.504	5.736	7.468	0.327
Farming experience	15.184	15.142	0.956	16.675	16.705	0.973
Dependency ratio	41.12	41.246	0.938	41.179	40.768	0.822
Livestock (TLU)	0.499	0.499	0.980	0.480	0.462	0.639
Subsistence farmer	0.921	0.917	0.851	0.986	0.976	0.336
Distance farm to market	23.306	24.382	0.696	21.762	21.834	0.973
Numbers of observations	1033	378		963	205	

5.4 Conclusion and policy recommendations

This study has investigated the impact of participation in off-farm activities on improving household food and nutritional security. The analysis relied on the panel data collected in 2014 and 2016 in the southern highlands regions of Songwe and Mbeya in Tanzania. Despite the strong agricultural character of the regions, 33 % of survey households engaged in agriculture in either or both of the two years. More adults and a larger farm size stimulated off-farm activities, while farming experience and livestock ownership had a limiting effect. This participation had a significant effect on food security, the strength of which depended on the specific indicator selected. HFIAS was most affected, followed by HDDS. The effects on the very rough annual indicator for food insecurity were mostly insignificant. On the basis of these findings, we suggest that development of policies and programs that pay more attention to off-farm work can boost rural household income, and thus promote food security and nutritional security.

Appendix 1: Household food insecurity access scale

For each of the following questions, consider what has happened in the past month. Please answer whether this happened never, rarely (once or twice), sometimes (3-10 times), or often (more than 10 times) in the past month?

1. Did you worry that your household would not have enough food?
2. Were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources?
3. Did you or any household member eat a limited variety of foods because of a lack of resources?
4. Did you or any household member eat food that they did not want to eat because a lack of resources for obtaining other types of food?
5. Was there ever no food at all in your household because there were no resources for getting more?
6. Did you or any household member go to bed at night hungry because there was not enough food?
7. Did you or any household member go a whole day without eating anything because there was not enough food?
8. Did anybody in your household eat a smaller meal than you felt they needed because there was not enough food?
9. Did anybody in your household eat fewer meals on one day because there was not enough food?

Chapter 6

Synthesis

6.1 Introduction

Agricultural productivity in most developing African countries remains low. Increasing the productivity of smallholder crop production is therefore considered a priority in alleviating poverty. While food and nutritional insecurity remain a global challenge, the situation is worst in developing countries with low productivity, traditional technology, imperfect market institutions, and limited off-farm employment opportunities. Several reasons explain low productivity in smallholder farming. Lack of land titles is sometimes considered one of these reasons, as it hinders farmers from accessing credit and restricts their access to modern technologies such as improved seed varieties. Because of low productivity, many African countries have food shortages and experience malnutrition. More information is needed about whether existing policies need to be promoted or changed. In relation to this topic, this thesis considers several relevant issues.

Rural households and women in Tanzania are most vulnerable to malnutrition despite existing policies and programs that target increasing agricultural productivity. Some initiatives include a land titling program intended to improve the security of tenure and facilitate credit access for productivity improvement, while at the same time promoting crop diversity to influence dietary diversity, and the use of modern seeds to increase productivity. For instance, the primary documents which regulate the agricultural sector are the Tanzanian National Land and Agricultural Policy of 1997 and the agricultural policy of 2013. The main goals of these policies are to promote food and nutritional security by increasing crop production and productivity and to stimulate economic development by increasing the output, availability, and quality of food products (Mkonda and He, 2018). The policy objectives acknowledge the importance of land tenure security in increasing productivity. However, there is little empirical evidence that shows these policies alleviate the problem of rural households' food and nutritional insecurity.

Several essential theories are central to the thesis chapters. In Chapter 2, I apply property rights theory to address the impact of land titles on agricultural productivity. In Chapter 3, I emphasize the difference between separable and non-separable household models. In separable models, production and consumption decisions are integrated. If markets in rural areas function well, then production and consumption are expected to be separable, providing a pathway to food and nutritional security by maximizing the income of rural households. This can be achieved by specializing in the most profitable activities and using income to purchase nutritious food. However, since markets in most rural areas do not function well, rural households should consume whatever they produce. Next, production theory guided us to estimate technical efficiency and productivity using a stochastic frontier model. I interpret the results of the efficiency analysis in light of recent concerns about low-quality inputs in rural markets. Chapter 5 evaluates the impact of off-farm employment on rural household food and nutrition security.

This synthesis chapter is organized as follows. Section 6.2 provides the main results of the four research questions and discusses some key findings. Section 6.3 reflects on the methodology and the data needs. Section 6.4 discusses the implications of my findings, and Section 6.5 contains concluding remarks and some insights for future research.

6.2 Major findings

Chapter 2 estimates the effects of formal land titling on rural households' agricultural productivity and examines how its impact varies across different types of households. Different groups are compared on the basis of age and plot size. The findings of the study provide strong evidence to support the hypothesis that agricultural productivity of the titled plots is higher than that of the untitled plots: productivity was 51 % higher on average.

The higher productivity of titled plots was associated with increased agricultural investment. Households who possessed titled plots increased short-term investments, as measured by the use of fertilizers and improved seeds, but had slightly lower chances of using manure, a long-term investment in land productivity. More specifically, land titling increased expenditures on improved seeds by 39 % and on fertilizers by 49 %. The probability of accessing credit did not depend on the titling status of the plot. The effects of land titling depended on the age of the farmer and the size of the plot cultivated. Younger farmers showed the highest yield response, while older farmers had the highest fertilizer response. These results seem inconsistent. In addition, we found a higher productivity response for smaller plots than for larger plots, which contradicted our expectations. This discrepancy is attributable to a higher fertilizer response, as the seed response was higher for larger plots. These findings suggest that strengthening land tenure security will lead to increased investments in fertilizer and improved seeds, which are crucial to increase agricultural productivity.

Chapter 3 assesses how crop diversity affects dietary diversification in rural households and how rural markets mediate these effects. The findings show that a large share of household consumption comes from farmers' own production for 3 food groups out of 12: (1) cereals; (2) eggs; and (3) pulses, legumes, and nuts. For the other food groups, the percentage share of purchased food was 60% or higher. These results suggest that access to the market substantially contributes to households' dietary diversity, and suggests some specialization whereby farmers produce the most profitable crop and sell it to earn income that facilitates access to nutritious foods, see also Ochieng et al. (2017). The findings do not provide evidence to support an association between crop diversity and individual-level dietary diversity for women in the past 24 hours prior to their interviews. On the contrary, results confirm that crop diversity relates to dietary diversity, as found by using the 7-day recall technique and the household-level indicators Household Dietary Diversity Score (HDDS) and Food Variety Score (FVS). However, the effect size is small, which is consistent with the findings of a study by Chegere and Stage (2020). For households located more than 10 and those more than 30 walking minutes from the market, the size of the coefficient for CDI increases and becomes strongly significant for the household-level dietary diversity indicators. These findings are consistent with Matita et al. (2021). Crop diversity substantially contributes to a household's dietary diversity when the household is located far from the market. These differences in dietary diversity at individual and household levels provide an understanding of why measuring dietary diversity at the household level does not guarantee the same results as for women's dietary diversity. These findings suggest the importance of strengthening rural markets to improve rural household income and increase their purchasing power, thus providing access to nutritious foods from the market.

Chapter 4 assesses farm-level technical efficiency and distinguishes between farmers using modern and traditional seeds. The results show that modern seed users obtained much higher yields on average than farmers who used traditional seeds, which is consistent with Westengen et al. (2019). We show that the level of technical efficiency in the two groups is comparable. On average, efficiency scores for traditional and modern seeds users were 64 % and 63%, respectively. These efficiency levels are similar to the average efficiency level in maize production in east Africa as a whole (Kibirige et al., 2014; Ngango and Hong, 2021). Interestingly, the standard deviation of our efficiency variable was higher for modern seeds users than for traditional seeds. These results suggest that modern seed quality may be heterogeneous in quality, as discussed extensively in recent academic and popular media.

However, the kernel density plot shows a unimodal distribution, which does not support the belief that a considerable share of the modern maize seeds sold at rural markets in Tanzania are either fake or heavily deteriorated.

In Chapter 5, I look at the determinants and implications of engaging in off-farm employment. Geographical location is an essential factor. Households from the Songwe region had a higher likelihood of participating in off-farm work. Higher participation in off-farm employment was also predicted by increased household size and amount of land owned, as well as a decreased dependency ratio. Babatunde and Qaim (2010) show that excess labor motivates household members to engage in off-farm work. Owning livestock had a negative relationship with participation in off-farm employment. This implies that more labor is allocated to the farm as the number of livestock increases. The older household heads or heads with more experience in farming were less likely to participate in off-farm activities. Our findings indicate a higher likelihood of young household heads engaging in off-farm employment, also see Astatike and Gazuma (2019). However, the findings are inconsistent with Block and Webb (2001), who state that income diversification is positively associated with the age of household heads because adult heads have accumulated capital for a long time and can therefore afford the initial cost of engaging in off-farm employment. Considering all households in the sample, households with female heads and married heads were more likely to participate. A similar gender effect was noted in Tanzania by Dzanku (2019) and in Ghana by Anang et al. (2020), who noted that involvement in off-farm work is higher for women who complement their household income by engaging in petty trading, arts, and crafts.

The empirical findings suggest that participation in off-farm employment improves food security. Participation in off-farm work significantly increased dietary diversity scores. This finding of positive impact of off-farm employment on food security is in line with Babatunde and Qaim (2010) and Kuwornu et al. (2018), who found that participation in off-farm work significantly increased household intake of daily calories. Similarly, our findings are consistent with those of Islam et al. (2018b) and Seidu et al. (2019) that income diversification toward off-farm sources significantly contributes to household dietary diversity.

These results suggest that to narrow the gap in food insecurity between participants and non-participants in off-farm work, interventions should consider empowering youth and women by connecting them to the market. Employment opportunities may be created along the agricultural value chain to generate more income. Initiatives to promote rural women's engagement in off-farm employment should be designed to increase their income and improve rural household food and nutritional security. These opportunities have the potential to reduce the effects of low agricultural productivity and income, which exacerbate poverty in rural areas, can improve rural household food and nutritional security and can promote the rural economy as a whole.

6.3 Reflections on data needs and methodology

This thesis used two main types of data collected from the southern highlands. First, cross-sectional data were used to gain insight into the association between land titles and productivity, crop diversity and dietary diversity, the quality of modern maize seeds and technical efficiency (Chapters 2, 3 and 4). I also used panel data to assess the impact of off-farm employment on household food and nutritional security (Chapter 5).

I used different econometric techniques to address the research questions formulated in each chapter. The choice of appropriate data analysis techniques was motivated by the concern for attenuating methodological problems, such as endogeneity of key explanatory variables. The propensity score matching (PSM) technique was employed to compare what would have happened to the treatment group if the land-titling program had not been implemented (Chapter 2). The average difference in outcome across the two groups was compared using the average treatment effect (ATE). Chapter 3 used ordinary least squares (OLS) to study the association between crop diversity and dietary diversity. In Chapter 4, we used the stochastic frontier model to assess variations in the level of technical efficiency and productivity of modern seeds users and traditional seeds users. In Chapter 5, the difference-in-differences model and propensity score matching were combined to evaluate the impact of off-farm employment on rural household food security. Limitations of the data, however, imply that we should be very careful not to interpret the associations as causal relationships. This is particularly true for Chapters 2, 3 and 4, based on cross-sectional data, where a causal interpretation of the results requires that we satisfy a number of additional assumptions which, however, cannot be tested.

6.3.1 Limitations

1. In Chapter 2, we faced a selection bias problem, common in observational studies, since the decision to join the land-titling program was non-random. To overcome the stated problem, we relied on data from three districts, Mbozi, Rungwe and Mbinga. During

data collection, upscaling of the land-titling program was starting in Rungwe, and Mbinga was yet to receive the program. We used the Rungwe sample to generate propensity scores to predict land titling in Mbozi (titled) and Mbinga (untitled) districts. This strategy enabled us to create counterfactual that, to some extent, mitigate the causal inference problem. We used a PSM estimator (Blundell and Costa Dias, 2000), to estimate the average treatment effect on the treated (ATT). For a causal interpretation of the estimates, we needed to make the following assumptions. First, since we could observe only one potential outcome and one treatment possibility for each person, we relied on the stable unit treatment value assumption (SUTVA) (Popova, 2020). This implies that the treatment assignment of one unit should not affect the outcome of another unit and that there are no spillover effects. Second, conditional on some observable characteristics, untreated units can be compared to treated units. Put differently, there is no selection on unobservable characteristics.

2. The collection of food consumption recall data (Chapter 3) was somewhat problematic regarding memory issues. However, we minimized the problem by using well-trained enumerators to interview the wife or the most knowledgeable household member who was involved in cooking. In addition, we were not able to make causal inferences because crop diversity and dietary diversity are both household decisions and we had no suitable instrumental variables.

3. In computing WDDS, we used a single qualitative 24-hour recall instead of the recommended three repeated 24-hour recalls. Moreover, the HDDS was measured using a 7-day consumption recall survey (Chapter 3). It would be interesting to investigate whether using 24-hour recalls to measure HDDS would give different results. In addition, our data is observational by nature and determines only associations between crop diversity and dietary diversity.

4. The cross-sectional data used in Chapter 4 were limited to an aggregate farm-level maize production function. This strategy can provide only limited understanding at the plot level. Farmers may knowingly plant modern and traditional seeds at the same time. This should provide results similar to those for the presence of low-quality improved seeds, but we found no evidence of this.

5. In Chapter 4, we compared two groups of farmers: those using modern maize seeds and those that do not. Based on this comparison, we drew conclusions about seed quality.

However, the two groups most likely differed in other ways as well, not all of which we were able to control for. This makes our conclusions somewhat speculative.

6. In Chapter 5, the parallel trend assumption is the most critical assumption to ensure internal validity of difference-in-difference models, but it is difficult to fulfill. The assumption requires that in the absence of treatment, the difference between the 'treatment' and 'control' group is constant over time. Violation of parallel trend assumption will lead to biased estimation of the causal effect. Unfortunately, we could not test the validity of the assumption because we had only a two-year panel. As we were aware of this, our analysis did not rely on this approach alone. As a second approach, we used the propensity score matching (PSM) technique, but now for the restricted sample.

6.4 The policy implications of research findings

The findings of this research are assessed in line with existing policies: the land, agricultural and nutritional policies currently implemented in Tanzania. These findings have both societal and policy relevance. To society, the results in Chapter 2 show that land titling increases expenditures on fertilizers and improved seeds which improve agricultural productivity. This in turn may improve rural household food availability and income, and access to nutritious food. However, land titling is unlikely to enhance soil fertility by increasing use of manure. Younger farmers with land titles had higher agricultural productivity than older farmers. Farmers with cultivated land of no more than two acres showed higher productivity responses than farmers with larger plots. Productivity of title plots thus depends on farmers' age and land size cultivated.

The findings of this study have two major policy implications. First, the results of the study provide empirical evidence to support the theory that strengthening land tenure security is crucial to boosting agricultural productivity. Second, access to modern seeds and fertilizers should be promoted by the formulation of policies aiming to boost agricultural productivity.

In Chapter 3, we found that crop diversity is related to household dietary diversity for households far from the market. The finding confirms that in a situation of missing markets, households' production and consumption decisions are closely interrelated (non-separable). To enhance women's dietary diversity and households' access to nutritious foods, rural markets should be strengthened by policies and programs focusing on reducing food and nutritional insecurity. This would enable farmers to specialize in producing the most profitable crops and purchase food at the market.

Our findings suggest that a separable model is confirmed for households closer to markets. In this case, the market is the preferred way of providing dietary diversity. Rather than being self-sufficient in producing all nutritious food resources, households can choose to specialize their production, at least in part.

The findings of the study of chapter 4 are relevant for policymakers because they reveal that overall increases in technical efficiency are possible for farmers using modern seeds as well as farmers using traditional seeds. This suggests that extension interventions could be intensified or scaled up. The results contradict the hypothesis that a large share of the modern seeds in rural Tanzania is of low quality (counterfeit or degraded). However, in light of evidence from other sources about variable input quality, future policies should probably pay more attention to promoting and safeguarding the quality of modern seed and fertilizer sold at local markets.

Chapter 5 provides insights into determinants of household participation in off-farm income. The findings support the theory that households allocate labor depending on the expected returns. We observe that off-farm work activities strongly influence household food and nutritional security. The findings have important implications for rural transformation in Tanzania. While crop production and off-farm employment coexist in rural areas, their interaction is vital to the policy recommendations. In cases where the two have complementary effects on each other, rural policies may focus on how to maximize their synergies. What are the implications of our results for policy? Rural development policies in most developing countries tend to be biased toward promoting the agriculture sector because the rural population largely depends on agriculture for its livelihood. Instead, more attention should be devoted to implementing policies and programs that create an enabling environment with remunerative off-farm employment opportunities for rural households. This too would reduce food insecurity and improve nutritional security.

6.5 General conclusion

The findings of my study provide some evidence for the theory that the productivity of titled plots is higher than the productivity of untitled plots. Households with land titles invest more in fertilizers and modern seeds. The heterogeneous effect of land title shows that younger farmers and households with smaller plots benefit the most. Access to fertilizer and seeds for young farmers and those who cultivate small plots is crucial to increasing productivity and income. This will, in turn, increase food availability for Tanzania's growing population.

We also studied the association between crop diversity, dietary diversity, and market access. The findings of the study show that crop diversity has a positive effect on household-level dietary diversity indicators. Still, the effect is small and is not present for households close to the market. Again, heterogeneity matters. We found that a high proportion of household consumption for many food groups came from market purchases. We recommend that the government focus on policies and programs that promote rural output markets, with a view to enhancing economic access to nutritious foods through the income pathway. We recommend that future studies consider the cause-effect relationship between crop diversity and household dietary diversity in rural Tanzania.

Our third research topic was the efficiency of farmers who use modern and traditional seed. On average, farmers who bought modern seeds obtained much higher yields than farmers who used traditional seeds. However, technical efficiency levels did not differ between the two groups, and the absence of a bimodal distribution for our efficiency variable for the subsample of modern seed farmers contradicts the common belief that some farmers bought unadulterated seeds while other farmers bought relatively low-quality seeds. Nevertheless, the supply chain of modern maize markets remains an area for future research. Moreover, future studies can use panel data to explore the uncertainty about the presence of counterfeit modern seeds.

Finally, we assessed the impact of participation in off-farm activities on improving household food and nutritional security. Results reveal that off-farm employment positively affects food security, but the exact result varied across the food and nutrition indicators. This leaves open important areas for future research. The development of programs that pay more attention to off-farm work can boost rural household income and thus promote food security and nutritional security. Moreover, policies that promote the synergy between on-farm agriculture production and off-farm employment may improve productivity and income, with increased food and nutritional security as the result.

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Summary

This PhD thesis contributes to understanding the key factors that shape productivity, the level of TE and income of rural Tanzania, and their implications for rural household food and nutrition security. The analysis employed mixed methods to answer important research questions that arise from specific objectives. In the individual chapters, I assessed the impacts of land title on productivity; the nexus between crop diversity, market access, and dietary diversity at an individual and household level; quality differences in modern seeds on productivity and TE; and off-farm employment on household food and nutritional security. The assessment of these relationships may hold policy implications for improving rural household food and nutritional security.

In Chapter 2, I examined some key aspects that are believed to shape the productivity of the agricultural sector in Tanzania and explored some implications for household food and nutrition security. We hope that having secure land rights is an economic development that can facilitate access to credit for short-term and long-term investments and productivity. I used propensity score matching as the primary estimation technique to measure the impact of land titling on productivity. Results showed that productivity of titled plots is higher than that of untitled plots, with an ATT of 100,493 TZS. Assessment of heterogeneity of treatment effects of land titles based on age and plot cultivated suggested that younger farmers and famers who cultivated no more than two acres have a higher productivity response.

In Chapter 3, I looked at the relationship between crop diversity in the field and nutritional diversity on the plate. We used ordinary least squares regression to estimate this set of equations for the full sample, using the CDI as the indicator for crop diversity and later using a median split for distance to the market. We also estimated the model for households living farther than 30 minutes or 60 minutes from the market. The summary statistics showed that, on average, dietary diversity for women was 3.4 out of 9 food groups, below the cut-off for adequacy of 5. Low dietary diversity is common among female populations in developing countries since their diets are primarily based on starchy staples, with few or no animal-sourced foods, fresh fruits, and vegetables. This poor diet may presumably be explained by socioeconomic status. The 7-day recall variable indicates that, on average, each household consumed 7.2 food groups out of 12. Regarding individual food items, they consumed 11.8 on average out of 29. Regression estimates reveal that a household with the maximum crop diversity observed in the sample (CDI=0.88) consumed on average 1.1 food groups and 1.2

different food items more in the past 7 days than a household cultivating only one crop (CDI =0). This does not translate to a significantly higher dietary diversity for women in the past 24 hours. The results thus indicate that crop diversity has a positive effect on household-level indicators of dietary diversity, but the effect is not very large and is not present for households that live close to the market.

In Chapter 4, I used an innovative approach to look into the issue of seed quality: we compared the productivity and technical efficiency (TE) of smallholders who used modern seeds with the productivity and TE of farmers who used traditional seeds. The analysis used a linearized Cobb-Douglas function with maximum likelihood to estimate separate production functions for traditional seed users and modern seed users. Results showed that the seed elasticity of production was much higher for modern seed users. On average, traditional and modern seed users produced at an efficiency of 64 and 63% of their respective frontiers. The standard deviation was 19% higher for modern seeds than for traditional seeds, suggesting the presence of heterogeneous seed quality. However, the findings provide limited evidence to support the perception that a substantial share of the modern maize seeds available in rural markets in Tanzania are either counterfeit or heavily deteriorated. The use of modern seeds resulted in higher productivity with average levels of TE similar to those of traditional seeds, and we found a unimodal distribution of TE with a larger density at high-efficiency levels for modern seeds.

In Chapter 5, I looked at the impact of participating in off-farm employment on rural households' food and nutritional security. We employed difference-in-difference and propensity score matching techniques to evaluate the impact of participation in off-farm employment on household food security, using three indicators with different recall periods. We find that more adults per household and a larger farm size stimulated involvement in off-farm activities, while farming experience and livestock ownership had a limiting effect. Participation in off-farm work significantly contributed to food security. However, the strength of the effects depends on the specific indicator selected.

The last chapter reviewed and discussed the key findings and provided a summary of the main conclusions and implications, as well as directions for future research. It offered more insights into how aspects of increasing productivity and TE can benefit rural households in terms of food availability and increasing income. In turn, this may improve these households' food and nutritional security by increasing their access to food from markets. In general, this thesis illustrates that while land titling is a good strategy for increasing productivity, the relation between crop diversity and dietary diversity depends on proximity to the market. The thesis shows that modern seeds used by farmers are of good quality, and that modern seed users therefore have higher productivity and TE. This study recommends the promotion of policies that target availability of modern seeds to improve productivity and TE and enhance food availability and income. While participation in off-farm employment activities has a significant effect in reducing food insecurity, its strength depends on the specific indicator selected using household food insecurity access scale (HFIAS). The impact is much more reflected in HFIAS followed by HDDS, while it was insignificant on the annual indicator for food insecurity.

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Biography

Fausta Marcellus Mapunda was born in Mbinga district, southern Tanzania. She works with the Sokoine University of Agriculture (SUA) in Tanzania as a lecturer, researcher, and consultant, a position she assumed in 2008. Before this, Fausta worked with the Ministry of Education and Vocational Training as an educational officer in Morogoro from 2000-2008. Fausta started her PhD journey in development economics section in the department of social science at Wageningen University in September 2012. With her career-long passion for academia, the move to commence a PhD was expected. Fausta obtained her master's degree in agricultural economics at SUA and graduated in 2007. In 2005, she graduated a Bachelor of Science in Agricultural Economics and Agribusiness at SUA in Tanzania. In 1998, she attained a diploma in education at Morogoro Teachers Training College in Morogoro, Tanzania. Fausta studied a high school, advanced certificate of secondary education at Ndanda High School in Masasi district in the Mtwara region. She gained an ordinary certificate of secondary education at Peramiho Girls secondary school from 1989 to 1992. Fausta received her primary education at Msamala primary school in the Songea district. Currently, Fausta lives in Morogoro municipality, in eastern Tanzania, and is based at the SUA in Tanzania. Currently, she is teaching courses in introduction to economics, development planning, and industrial development planning.

Fausta Marcellus Mapunda

Completed training and supervision plan
Wageningen School of Social Science (WASS)

Name of learning activity	**Department**	**Year**	**ECTS***
A) Project related competences			
PhD research proposal	WUR	2013	6
DEC 53306 Economic and policy of agricultural development	WUR	2012	6
AEP60306 Advanced Econometrics	WUR	2014	6
Research methodology from topic to proposal	WASS	2012	4
B) General research related competences			
Introduction course	WASS	2012	1
Institutional economics and economics organization theory	DEC	2012	6
DEC 51806 Microfinance and marketing in developing countries	WUR	2013	6
Information literacy including endnote introduction	WGS	2013	0.6
Experiments in developing countries, methods and applications	Groningen University	2015	2.0
‘’Estimating heterogeneous effects of land titling on rural households’ agricultural productivity: Evidence from Tanzania	WASS PhD day	2015	1.0
C) Career related competences/personal development			
Techniques for writing and presenting scientific paper	WGS	2013	1.2
Project and time management	WGS	2015	1.5
Total			**41.3**

*One credit according to ECTS is on average equivalent to 28 hours of study load