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Essays on Agricultural Development in Tanzania

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Abstract

This thesis is made of three self-contained essays on the agricultural sector of Tanzania, each of them focusing on an aspect of direct policy relevance. In the first essay, I study whether an inverse relationship exists between cultivated area and physical productivity (yield per acre) for a set of important annual crops. I define size as the area of a plot on which a crop is grown, thus introducing a more disaggregated level of analysis than the common plot or crop levels of analysis. I control for the existing hypotheses in the literature potentially explaining this inverse relationship and propose to control for two new hypotheses which are only testable at this level of analysis.

In the second essay, I look at output marketing for a set of important crops. I stress the links between the market failure theoretical narrative and empirical applications, and argue this has resulted in less attention being paid to the reasons why farmers may enter -or not- the market for a particular crop. I estimate participation and supply equations for a set of important crops and show that the rationale for entry differs across crops. This calls for a more flexible conception of 'the market'.

The first two essays use the Tanzanian National Panel Surveys to conduct econometric analysis. The third essay is based on primary data collected in 2016 in order to carry analysis of the Bambara nut, an underutilised crop. Because underutilised crops hardly feature in national datasets, primary data is needed to understand their socio-economic dynamics. Focusing on the Mtwara region of Tanzania, I study the importance of Bambara for local livelihoods using a mixed-methods study based on both quantitative and qualitative data. This study contributes to the growing interest on underutilised crops and their importance in designing more sustainable agricultural strategies.

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Chapter 1

Introduction

The sub-Saharan African region has witnessed a variety of development trajectories over the past decades. While some countries like Kenya have achieved a semi-industrialised economy and moved into the middle-income bracket, others like Tanzania have not yet achieved such structural change. However, despite this heterogeneity, predominance of the agricultural sector remains a common denominator across the continent. In Tanzania, the sector represented 31 % of GDP in 2016. In neighbouring Burundi, its share was even higher at 40%. The agricultural sector still employs a disproportionate share of the population and is characterised by low productivity, on which a large body of research has focused over the past years. In fact, there is evidence of a rising share of the national population being employed in farming in Tanzania (Haug and Hella, 2013). The 2008 World Bank report on 'Agriculture for Development' is one of the many examples of the concern expressed by international institutions and researchers about the state of agriculture, and how to ensure a successful transition towards industrialisation in developing countries. This thesis consists of three self-contained essays on the agricultural sector in Tanzania, each of them focusing on an aspect of direct policy relevance.

The first essay (chapter 2) takes up the classic development question of the inverse relationship between farm size and productivity in agriculture. For about a century, economists have debated the existence of an inverse relationship between cultivated area and productivity in agriculture, which has led to a vast theoretical and applied literature. In this essay, we introduce a crop/plot level of analysis and study its implications for the existence of such a relationship. The second essay (chapter 3) looks at the issue of market participation by rural households at the crop level, where we argue the process of par-

ticipation itself has not received enough attention in existing research. For both these chapters, we use the Tanzanian National Panel Surveys, which are part of the World Bank LSMS dataset. However, while LSMS data presents many advantages, we argue that the use of national surveys tends to blur regional specificities and neglects some crops which have regional importance but are marginal at the national level. Informed by this concern, the third essay (chapter 4) is based on primary data collected in the Southern Tanzanian region of Mtwara to research a marginal crop called the Bambara groundnut. Despite being of limited empirical importance at the national level, it is a widely grown crop in the region, and hence, deserves research attention to understand the dynamics associated to its farming.

In this introduction, we first give a brief overview of the Tanzanian agricultural sector, followed by a general description of the LSMS data used in the first two essays. We then present a more detailed introduction to each chapter of this thesis.

1.1 A brief overview of the agricultural sector in Tanzania

When thinking about agrarian change and agricultural policy in Tanzania, one often has in mind Nyerere's (in)famous Ujamaa policy, implemented in the aftermath of the Arusha Declaration in 1967. Although initially supported by international institutions such as the World Bank, these policies were seriously challenged from the mid-1970s onwards. Based on the ethics of the so-called 'peasant moral economy', Ujamaa policies aimed at grouping scattered rural households together in village settlements, thus facilitating the provision of agricultural services.[1] Now considered by many a failure, Ujamaa policies ended in the 1980s, when the country started a progressive phase of liberalisation in the well-known context of structural adjustment. From a development theory perspective, the shift in the views of leading international financial institutions was contemporary to the rising popularity of urban-bias theories of development and the end of developmentalism. The stagnation of the agricultural sector during Ujamaa became a hotly debated issue in academic research. The debate was framed around 'external causes' and 'internal causes'. External causes include weather conditions negatively affecting production, but also economic phenomena such as volatile or declining world commodity prices and the decline

[1] See Bryceson (2010) and Havnevik (2010) for a detailed discussion of the post-independence political transformation and its impact on the agricultural sector. For a recent take on the legacy of Nyerere in contemporary Tanzania, see Fouéré (2015).

in foreign aid in the early 1980s and throughout much of the 1990s (after peaking over 1989-92). Internal causes were those related to economic policies at the national level, notably the management (or mismanagement) of state parastatals, corruption or price distortions. It was the victory of supporters of the internal causes that eventually lead to structural adjustment in the agricultural sector, though its proponents never denied the importance of external causes (Skarstein, 2010).

It is generally agreed that the impact of structural adjustment and liberalisation on the agricultural sector is mixed. Performance of the agricultural sector before and after liberalisation has long been debated in the economics and political economy literatures. McKay, Morrissey and Vaillant (1999) stress the improved performance of the sector after liberalisation, with an increase of the share of the sector in GDP from 45% in 1980 to 60% a decade later, but argue that interventions to ensure farmers derive the benefits of liberalisation may be needed. Similarly, although acknowledging the increase in food crop production, Putterman (1995) stressed the fragility of the sector and pointed to a decreasing access to inputs. From a much more sceptical point of view, Skarstein (2010) argues that economic liberalisation aimed at increasing specialisation, but has resulted in the exact opposite: reversion to subsistence combined with a strong income diversification process, often via non-farm activities. The rise of private traders and availability of inputs -particularly chemical fertilisers- have also been contentious issues in the assessment of the effects of liberalisation. However, it is important to note that despite going through a phase of liberalisation, Tanzania has not converted to a full market-based economy either: national policies up to today have been based on a mix between private-led focus and a certain degree of state regulation (Haug and Hella, 2013). For example, export bans are commonly used by governments.

The current policies in the agricultural sector are embedded within the more encompassing National Development Vision 2025, a national economic strategy aiming at turning Tanzania into a semi-industrialised country. Within this national strategic framework, numerous national plans to stimulate the agricultural sector were launched over the past fifteen years, such as the Agricultural Sector Development Strategy in 2001, which led to the Agricultural Sector Development Program a year later. A more recent plan, *Kilimo Kwanza* (Agriculture First) was launched in 2009 by former president Kikwete. It aims at

putting the private sector at the heart of economic transformation within the agricultural sector (Leyaro, Boulay and Morrissey, 2014). *Kilimo Kwanza* is structured around ten very broad pillars, such as the mobilisation of Tanzanians, or the development of infrastructure. It is within this context that this thesis looks at three aspects of Tanzanian agriculture.

1.2 Using the Tanzanian National Panel Surveys

The Tanzanian National Panel Surveys are part of the series of datasets released by the World Bank for its Living Standards Measurement Study (LSMS) project. Four waves are available at the moment: 2008/09, 2010/2011, 2012/2013 and 2014/2015. The last wave was only released over the summer 2017 and hence is not included in the analysis of the first two essays of this thesis. The National Panel Surveys (NPS) build upon the Agricultural Census Sample Survey (ACSS) and the Household Budget Survey (HBS), for the years 2008 and 2007 respectively. For its rural data component, the NPS are based on villages previously covered in the ACSS. The first wave of the NPS data was compared with the previous reference agricultural survey, the 2002/2003 National Sample Census of Agriculture. By 2008/2009, average harvest for maize and paddy had increased by over 30%. The production of cassava, however, suffered a dramatic fall by almost 45% over the 2002/03-2008/09 period.

The datasets are divided into three broad categories: the household questionnaire, the agricultural questionnaire, and the community questionnaire, to which a fishery and livestock questionnaire was also added from the second wave onwards. The agricultural questionnaire is of particular relevance for researchers interested in agriculture, for it constitutes a clear improvement over previous surveys, which were usually less precise in the information provided, and not always representative of the country as a whole. Further, agricultural datasets tended not to provide a comprehensive socio-economic approach such as in the LSMS data. In the Tanzanian context for example, the National Sample Census of Agriculture were often used before the release of the National Panel Surveys, but only contained detailed information at the farming level (see Lokina *et al.* 2011 for an application). We use in this thesis the data for the long-rainy season (*masika*), which is the main agricultural season all over the country. Data for the short rainy-season (*vuli*) is also reported but sample sizes are much smaller, and the short-rainy season is unevenly

observed across the country. All information and analysis reported in this thesis is thus based on the main season.

The publication of LSMS data for several African countries has had a large influence on empirical research on the agricultural sector in these countries due to the amount of detailed information on household and farm characteristics, and the highly disaggregated level of production statistics. In fact, many of the studies cited in this thesis published in the past ten years or so use LSMS data.

The LSMS data is longitudinal in nature: the same households are followed over time. From an econometric point of view, this implies that panel analysis can be used when required to control for time-invariant household characteristics. The data is coded in such a way that households splitting across time can also be traced (following, for example, the creation of a new household by a son or daughter). Attrition is not considered a serious problem as the total rate of attrition calculated after the release of the third wave of data was 4.84%. One key feature of the agricultural module is the availability of production related statistics (harvest, sales etc.) at the crop and plot level. For example, if a crop is grown on two plots, two entries will be reported for the same crop, so that harvest is available for each plot on which the crop is grown, rather than at an aggregated level. A lot of information is also available at the plot level, such as elevation, or soil type. This high level of disaggregation also means that inputs usage is available at the plot level, a highly valuable feature for empirical analyses. However, usage is not available at the crop/plot level; thus the researcher needs to make an assumption on how to assign input usage if a crop focus is required by the analysis.

In this introduction we provide an overview of the agricultural sector using the entire dataset (unlike in the individual chapters, for which the sample sizes are smaller, depending on the research question considered). Despite being incredibly diverse, and more so than the surveys suggest as we argue in the last chapter of the thesis, the agricultural sector is characterised by a low productivity environment where semi-subsistence is widespread. The sector is largely reliant on rain, and the vast majority of plots do not have irrigation. Tools to water the land are also limited, as suggested in Table 1.1. The proportion of plots being irrigated by buckets or cans varies between 16 and 25% across waves, and that

of plots watered by flooding is very high. Similarly, the take up rate of chemical inputs

Table 1.1: Irrigation methods in the surveys

Method of irrigation (%)	NPS 2008/09	NPS 2010/11	NPS 2012/13
Flooding	0.66	0.69	0.59
Sprinkler	0.05	0.04	0.03
Drip irrigation	0.03	0.04	0
Bucket/watering can	0.25	0.16	0.23
Water hose	0.04	0.04	0.09
Other	-	0.03	0.07

Source: World Bank LSMS Final Report, National Panel Surveys Wave 3 (p.25)

is strikingly low, especially for inorganic fertiliser and pesticide, which saw a dramatic fall in their use rate following liberalisation and the progressive removal of the fertiliser subsidies in the 1990s (Skarstein, 2010). Table 1.2 reports the percentage of households using fertilisers, seeds and pesticides. Their use is largely stagnant over time, with no clear improvement in adoption rates between the first and last waves, except for improved seeds. However, the important increase in the use of improved seeds may be due to a methodological change in the way the variable is calculated. In the third wave, an additional seed category was included as improved seeds. Hence, the increase in the take up rate is at least partly explained by this change. Following liberalisation, the take up rate of chemical inputs suffered a dramatic fall due to rising prices and traders not supplying to remote rural areas. The government decided to introduce voucher schemes in 2009 to remedy this issue, which is reflected in the fourth line of the table. The voucher scheme was conceived as a 'smart-market subsidy' move to increase smallholders' productivity, particularly for maize and paddy (Malhorta, 2013). It is less easy to provide summary

Table 1.2: Fertiliser use in the surveys

Percentage of households using at least:	NPS 2008/09	NPS 2010/11	NPS 2012/13
Any fertiliser	30.1	32.6	35.4
Organic fertilisers	22.1	21.8	25.3
Non-organic fertilisers	12.9	16.8	15.3
Vouchers for non-organic fertilisers	-	49.5	30.1
Pesticides/insecticides	14.7	13.2	13.7
Improved seeds	21.4	18.0	43.2

Source: World Bank LSMS Final Report, National Panel Surveys Wave 3 (p.26)

information regarding the use of family and hired labour than for fertiliser. The surveys report highly disaggregated information on labour. For family labour, the questionnaires ask how many days of labour on each plot were worked by each household member. The

question is asked for separate agricultural tasks: land preparation and planting, weeding and harvesting. Further, the questions are not the same across years: from the second wave onwards, the surveys also ask for details regarding ridging and fertilising. Hence, to get a consistent measure of labour effort, one must decide which task to include in the measure, and whether to include the work of members outside the reference working-age boundaries (16 to 65). In the chapter on the inverse relationship, we need to compute measures of family labour intensity. Our measure is based on labour by adult male and female work on the following tasks: planting, weeding and harvesting. We compute a similar measure for hired labour. This is the same measure of labour as the one used in the study by Leyaro, Boulay and Morrissey (2014) focusing on the first wave of data. However, it is clear from the data structure that any measure of labour has to incorporate a degree of arbitrariness in its definition. Hence, it differs from the measure of other inputs such as fertilisers which tends to be more 'objective' in the sense that one does not have to construct the variables based on arbitrary criteria. To this must be added the limitation that the surveys do not capture reciprocal labour. Such work is not based on monetary compensation: one receives the help of other farmers on one's plot and works a similar amount of time on their plots later on. During the fieldwork in Mtwara for chapter 4, it became apparent that reciprocal labour is widespread in villages, particularly so with members from your family but outside your household. One simple way to assess how widespread hired labour is in the surveys it by computing the proportion of households hiring labour on at least one of their plots. In the first wave, 23% of households are hiring labour on at least one plot. In the second, 20% of households hire, and in the third wave the average rises again to 23%. The use of hired labour in the datasets is thus quite limited, with less than a quarter of rural households hiring formal labour on their plots. This shows, together with the low take-up rates of chemical fertilisers, that adoption of variable inputs across the country is very low.

In the first two essays of this thesis, we use the Tanzanian LSMS dataset to study the main crops in Tanzanian agriculture, such as maize, cassava, or food crops. In order to provide an overview of the agricultural diversity picked up by the surveys, we present information on the most important crops in the dataset for annual crops, as well as for cassava, a major perennial crop. Although all data collection comes with its mistakes, a word of caution about cassava is required. Although often treated as an annual crop, cassava classifies as a perennial crop, because it can be harvested more than 12 months after planting. The

Table 1.3: Key informations for the main crops in the full datasets

	NPS 2008/09	NPS 2010/11	NPS 2012/13
Maize			
Frequency, % (annual crop)	35	39.46	38.81
Plot harvest in Kg	493	484	501
Number of plots	1.82	1.96	1.92
Paddy rice			
Frequency, % (annual crop)	9.45	10.98	10.15
Plot harvest in Kg	522	623	735
Number of plots	1.46	1.36	1.31
Beans			
Frequency, % (annual crop)	10.68	10.91	10.98
Plot harvest in Kg	92	143	191
Number of plots	1.47	1.51	1.61
Groundnut			
Frequency, % (annual crop)	6.37	5.32	5.95
Plot harvest in Kg	256	173	204
Number of plots	1.24	1.18	1.20
Cassava			
Frequency, % (perennial crop)	39.14	32.18	31.55
Plot harvest in Kg	423	285	234
Number of plots	1.58	1.66	1.65

first two waves of data suffer from heavy miscoding for cassava. The coding mistakes for cassava are not systematic: it was sometimes coded as a perennial crop, sometimes as an annual crop, and sometimes coded in both datasets at the same time. The erratic coding of cassava as an annual crop means that the crop frequencies reported for annual crops can only be considered as approximate.[2] Similarly, the frequencies for perennial crops are not perfectly accurate: some perennial crops such as coffee are wrongly coded in the annual data. In Table 1.3, we report information for the four major annual crops: maize, rice, beans and groundnut, as well as for cassava. The frequency percentages reported refer to the proportion of crop level observations for a given crop. For example, 5.32% of crop observations in the second wave were coded as groundnut in the dataset for annual crops. We also report the average harvest for each crop at the plot level, as well as the average number of plots on which each crop is grown. Table 1.3 shows the dominance of maize,

[2]When communicating with a survey specialist from the Development Research group at the World Bank on the issue of cassava, I was told that 'In the first round of the survey many issues with implementation and design were revealed. Many of these issues can be seen in the final datasets. With every survey there are mishaps, some more than other. As you note, some of the crops were recorded in the wrong place. Rather than delete these, we maintain the datasets as is and allow researchers to deal with them as they see fit.' (personal correspondence, 27/01/2015)

rice, beans and groundnuts in terms of frequency of appearance in the annual datasets. In all waves, maize, rice and beans together represent around 60% of all entries at the crop level. The frequency of these crops is stable across waves. Cassava is also a major crop in the perennial category in terms of frequency. In terms of average plot harvest, maize has a stable average over time, around half a ton per wave. Maize, rice and cassava have large harvests as they constitute the backbone of diets throughout the country's rural areas. Because they are cereals or roots, the physical harvest tends to be large. Groundnut and beans, on the other hand, have smaller average harvests. This does not mean they are less important as such; rather, it reflects their agronomic difference with cereals or roots. Beans, nuts and pulses typically give smaller harvests. Their importance is reflected by the average number of plots per farm on which they are grown. Beans are planted on about one and a half plots on average, more than rice and similar to cassava. The large predominance of a few annual crops in terms of frequency hides the vast diversity in crops grown all over the country. Tables A.1 to A.3 in the Appendix report the frequency of all annual crops listed in the dataset. Many of these crops are marginal at the national level, but have regional importance, as we argue in chapter 4. For example, only 89, 54 and 71 observations for the Bambara nut are listed in wave one to three respectively. Other marginal crops, such as amaranth, are also under-represented in that sense.

Table A.4 in the appendix provides further information on the distribution of the main annual crops and cassava in the different agro-climatic zones of Tanzania. Maize and beans are mainly grown in the tropic-warm/sub-humid and tropic-cool/sub-humid zones. Groundnut is heavily grown in these zones too, but can also grow in tropic-warm/semi-arid climatic conditions, with between 13 and 18% of observations for that zone depending on the wave of data. Paddy rice is heavily grown in the tropic-warm/sub-humid zones, with about 80% of observations within this climatic zone. Cassava is also largely grown in this climatic region, although about a fifth of observations belong to the tropic-cool/sub-humid category. Note that none of these important crops is significantly grown in the tropic-warm/humid and tropic-cool/humid climatic zones.

The data also provides information on fruit trees and permanent crops, which can be of importance in the Tanzanian context. For example, bananas are an important crop in some regions of the country, though not all, and coffee is the major export crop in some

regions. However, we focus on annual crops and cassava only in the first two essays of this thesis, and do not study fruits and other permanent crops for several reasons. The first is that my fieldwork experience based on three yearly trips to Tanzania suggests that no specific farming endeavour is attached to fruit crops: farmers do not 'actively' cultivate fruit crops. Instead, whenever tree crops are planted on a plot, farmers may harvest some fruits for their own consumption or for sales, but there is no farming strategy to it as such. Hence, economic analysis on these crops is largely irrelevant in many cases (except if the focus is on large-scale commercial plantations, which is not the case in this thesis). The second reason is that, in the context of the first essay, computing measures of cultivated areas and physical productivity for tree crops is next to impossible. Hence, these crops cannot be included in the study of the inverse relationship (this is also why cassava is not included in that analysis). Admittedly, we are thus omitting an important part of the surveys, but this is largely driven by the nature of the research question. Nonetheless, we recognise that the diversity contained in the surveys is larger than implied by focusing on annual crops only.

Despite the disaggregated nature of the agricultural data and the effort at producing precise statistics across time, the data suffer from important limitations and several challenges are left unaddressed. The obvious miscoding for some crops and variables is a serious issue in the first and second waves of the data, particularly so for cassava, as explained above. Similarly, GPS measurements in wave one are very poor, which has a direct impact on the essay on the inverse relationship (only 25% of plots were randomly selected for GPS measurement in the first wave of data). More generally, some precision is lacking when it comes to working at the crop level. The absence of information about the form under which a crop was sold could be a potential issue in empirical studies, although there is no way to check the extent to which this is a problem. For example, cassava can be consumed/sold fresh or dried, or nut crops can be sold shelled or unshelled. Further, if unshelled they can be sold fresh, boiled or dried. There are also limitations to the use of the inputs variables when working at the crop level, because these are reported at the plot level only. Therefore, an approximation method needs to be used to estimate the amount of inputs dedicated to a crop on a plot, which will come with some degree of error. However, such limitations and challenges are common in all agricultural datasets, and the LSMS data do represent a clear improvement over the previous generation of surveys.

1.3 Thesis overview

Chapter 2 proposes to explore the classic question of the inverse relationship between size and productivity at a new level of analysis, which, to the best of our knowledge, has not been used in the literature. With the publication of more and more precise agricultural data for developing countries, this debate has gone through an empirical revival over the past fifteen years. In particular, the progress made in the quality of collected statistics has made it easier to correct for statistical biases and explore their effect on the existence of the relationship. Therefore, while several 'classic' studies on the inverse relationship focused on developing theoretical economic arguments that could explain the relationship, more recent studies have had a stronger empirical focus, giving more attention to statistical biases and emphasizing the risk of spurious results. It has become clear that in a context of widespread intercropping and different farming practices, the concepts of farm size and farm output are problematic.

Farm size aggregates all cultivated area without accounting for plot features and intercropping practices on some plots and not others, resulting in limited economic meaning. Similarly, the concept of farm output has restricted relevance both from an economic and an agronomic point of view. To the extent that different farms have different output mixes and different farming practices, an aggregate output figure is arguably problematic. More recent research has focused on analysis at the plot level. Although better and more disaggregated than farm size, such focus still suffers from the same pitfalls, unless it looks at a single crop in monocropping set ups. In this chapter, we take the level of analysis one step further to a crop/plot level - the area on a plot on which a crop is grown. We do not focus on a single crop, but cover four important crops in Tanzanian agriculture: maize, rice, beans and groundnuts. Unlike farm or plot size, which are largely time invariant, our measure of size is the portion of a plot cultivated with a given crop. Hence, it varies over time, and our estimation strategy is based on both OLS and panel specifications. This allows us to corroborate whether unobserved plot heterogeneity is driving a potentially spurious inverse relationship or not. From a broader perspective, this essay relates to the debate on productivity in African agriculture, and the transition from an agriculture-based economy to an industry-based one. It also relates to the contentious issue of land redistribution policies, which has sparked a large debate among academics and policy makers working on development issues.

While chapter 2 focuses on agricultural production and physical productivity, chapter 3 is concerned with output marketing, another topic which has received a lot of attention in the literature on rural development. Most of the empirical literature on this topic is rooted in theoretical developments based around the idea of market failures: farmers do not enter certain markets because market failures prevent them from doing so. We argue that the underlying theoretical commitment to this narrative has pushed empirical studies to over-concentrate on supply on the market corrected for selection. If farmers do not market their crops due to market failures, this implies that there is no real need to look deeply into the reasons why people may or may not enter agricultural markets. When farmers market their crop, this is because markets are not failing; and if they do not market their crop, it is because market failures are too strong to allow for transactions to take place. As such, focusing on market entry loses theoretical appeal, while focusing on quantity supplied/sold seems more relevant. Because of this theoretical a priori, empirical applications have tended to study output marketing using Heckman selection models, where supply equations need to be corrected for selection into the market. In practice, it is not clear whether this is the right approach, as most papers do not find a significant selection mechanism into output marketing. Arguably, these studies have thus neglected (relatively speaking) the selection process by not enquiring in detail about the rationale for marketing a proportion of output. We propose to study the process of output marketing for maize, cassava, food crops and export crops by paying close attention to both the selection mechanism (participation equation) and the quantity marketed (supply equation), i.e., we do not simply view estimation of participation equations as a necessary statistical correction for the estimation of unbiased supply equations. Further, we argue that the literature on agrarian political economy should also be considered when studying output marketing as it can help us understand the process of participation in different markets.

In both chapters 2 and 3 we use the National Panel Surveys, which provide rich detail on agricultural practices at a high level of disaggregation. However, the data tend to give more importance to crops grown nationally than to more regional crops, despite growing evidence that these regional crops are important contributors to livelihoods. Chapter 4 focuses on one such crop, the Bambara nut, which is heavily grown in two regions of the

country: Mtwara and Dodoma. Analysis is based on primary data, both quantitative and qualitative, collected in the Mtwara region in 2016 with support from the Naliendele Agricultural Research Institute. Because socio-economic research on marginal crops is extremely scarce, the nature of the analysis is largely exploratory: our main interest is to learn whether growers and non-growers are different, why do growers grow, and what are the constraints to production and marketing. Nevertheless, the research is guided by insights from the previous chapters, particularly chapter 3. Part of the exploratory approach is to understand the status of Bambara as opposed to other crops; and hence, how the way it is marketed differs (or not) from those other crops.

This chapter can be seen as being part of the growing effort at mainstreaming marginal crops in academic and policy-oriented research. Indeed, there is a nascent literature on these crops, although it is still largely confined at the margins of current research streams. The Crops for the Future Research Centre at the University of Nottingham Malaysia campus has been at the forefront of biological research on underutilised crops, and has also provided some socio-economic evidence on their importance. This topic is also receiving a heavier attention in the policy research realm. The vey recent publication by Bioversity International of a book entitled 'Mainstreaming Agrobiodiversity in Sustainable Food Systems' is an example of this trend.

The aim of this thesis is to explore important issues related to the agricultural sector in Tanzania from an empirical perspective. We do so in two ways. First, we study in chapters 2 and 3 classic topics which have received a lot of attention in research over the past decades. We contribute to these literatures by bringing a new level of analysis in chapter 2, and by reflecting on the links between theoretical concepts (market failures) and empirical applications in chapter 3. Second, we explore the issue of marginal crops in chapter 4 by using primary data collected during fieldwork in order to assess the importance of one such crop. We show that over-reliance on national datasets makes it difficult to grasp the 'full picture' because it tends to push aside crops which are not grown enough at the national level to allow for quantitative analysis.

Chapter 2

A Study of the Inverse Relationship at the Crop/plot Level

2.1 Introduction

Since the seminal work on Russian peasantries in the early 20th century by agricultural economist and statistician Chayanov, economists have debated the existence of an inverse relationship between size and productivity in agriculture. This debate has had an important influence on land redistribution policies in several countries across Africa, such as Ethiopia or Zimbabwe. Despite being contested for about a hundred years, no consensus has been reached regarding this matter, and the inverse relationship still constitutes an important research area both at the theoretical and empirical levels, as well as at the policy level. At the theoretical level, it is at odds with the textbook which argues the inverse relationship should trigger a reallocation of land *across* households from the least productive to the most productive ones in the absence of market failures. Factor reallocation should also occur *within* households so as to equate productivity across plots farmed (Barrett, Bellemare and Hou, 2010). At the empirical level, the nature of agricultural data makes analysis subject to many biases, many of which remain to be acknowledged. Finally, at the policy level, the theoretical case for land redistribution policies as a means for eradicating poverty has been heavily challenged and called into question.

Using Tanzanian agriculture as a case study, this paper argues that a fruitful way to

look at this old question is to consider a different level of analysis than the usual plot or farm size levels. Indeed, we argue that the concept of size is problematic when following such analysis. This is especially the case in sub-Saharan African countries where intercropping is heavily practiced, which implies there can be an important difference between a plot size and the area on that plot on which a crop is grown. This further enhances the complexities linked to crop-composition effects (Kimhi, 2006).

This study proposes to take the analysis to a new level, the crop/plot level, to help bypass some of the issues arising when studying the existence of the inverse relationship, especially regarding the problem of size, as argued above. By looking at the determinants of yields for a given crop on a particular plot, our focus makes the estimates of cultivated area more precise than is usually the case, and also allows us to exploit the specificities of each crop on each plot (for instance, whether the crop is intercropped). This paper thus contributes to redifining the concept of 'size' in the context of Tanzanian agriculture, which is a problematic issue in the applied agricultural literature.

With this approach, we contribute to the literature in two important ways. First, we test whether the existing theoretical hypotheses in the literature, following the typology established in Barrett, Bellamare and Hou (2010), can explain the relationship at our new level of analysis. These hypotheses posit that the inverse relationship may be due to household characteristics, plot characteristics or statistical fallacy (or any combination of them). Second, we propose two new hypotheses which, to the best of our knowledge, have not been formally tested in the literature: at a crop/plot level, the inverse relationship could be driven by omitting to account for whether the crop is intercropped or monocropped, or by not accounting for the fact that some crops are primary crops on a plot and hence may reflect a different type of farming. Results show that the inverse relationship is strikingly robust to the crop/plot level of analysis for the hypotheses established in the literature. Further, the inverse relationship is also robust to the new set of hypotheses we test.

Section 2 establishes a typology of the different theories proposed to explain the inverse relationship, and recent developments in the empirical literature. Section 3 presents the data and key summary statistics. Section 4 sets out the methodology to control for the existing hypotheses in the literature and reports empirical results. Section 5 is dedicated

to testing new hypotheses that could explain the inverse relationship, together with associated empirical results. Section 6 concludes.

2.2 A Brief History and Typology of the Inverse Relationship

Chayanov is often credited with being the first to notice the possibility of an inverse relationship (henceforth IR) in Russian peasantry in the early 20^{th} century (Assunção and Braido (2007), Barrett, Bellemare and Hou (2010)).[1] In the early 1960s, Sen also reported on an observed inverse relationship in Indian agriculture: 'By and large, productivity per acre decreases with the size of holding. This trend with gross output per acre is observed, more or less strongly, in practically all the regions studied' (1962:243), which he would then theorize into the idea that different modes of production may be underlying this relationship. This is the origin of one important orthodox explanation for the inverse relationship, namely that smaller farms relying on family labour escape the capitalist logic, under which less labour would be used, and use more unit of labour per acre of land.

The literature on the inverse relationship is so vast that it cannot be entirely covered here, for it would deserve a study of its own. Instead, we propose to establish a typology of existing theories, and classify them into one of four categories. The first category is made of studies based on orthodox economic theory. It encompasses both a large theoretical and empirical literature. While Sen can be considered a pioneer in this strand, the most prominent contemporary economist in this tradition is Barrett, who wrote extensively on the inverse relationship (see for example Barrett (1996) and Barrett, Bellemare and Hou (2010)). This tradition tends to emphasize theoretical arguments based on imperfect markets and a higher efficiency of family labour, as opposed to hired labour which is considered harder to monitor and supervise. On the empirical side, it tends to emphasize the possibility of large omitted variable biases in econometric applications, as well as issues related to the quality of data available, which could drive an artificial relationship. Recently, several studies have stressed the need to move to more disaggregated levels to assess whether the relationship can still be observed. This literature can be seen as going hand in hand with the publication of more and more detailed national agricultural

[1] However, the idea of an IR can be found in earlier work, notably that of Marx and early marxists like Klautsky, who refer to the possibility of an IR, albeit arising out of different reasons that the ones usually

surveys (especially by the World Bank), and a growing awareness of problematic aspects of agricultural data, especially when it comes to measurement issues (Gourlay, Kilic and Lobell, 2017).

The second category is sometimes referred to as 'neo-classical populism' (particularly criticized by the third tradition). In this category, the seminal contribution is undoubtedly Griffin, Khan and Ickowitz (2002), who argue that small-holders tend to economise more on capital and farm the land more intensively (more units of inputs per unit of land). Large scale farmers, on the other hand, have higher capital-labour ratios and farm the land more extensively (less units of inputs per unit of land but over more land). This is considered to be the key mechanism by which an inverse relationship arises. While the term 'neo-classical' is used to explain that this tradition relies on the orthodox framework of differential factor prices and imperfect markets (developed in the first category), the term 'populist' comes from the fact that it largely emphasizes the usual policy implication in favour of land redistribution. In fact, it supports a radical program of land redistribution from large to small holders as a means to eradicate widespread rural poverty.

The third category is made of studies based on heterodox economic theories and the political economy of development. This approach is critical towards the two previous approaches on the ground that orthodox theory does not offer a framework dynamic enough to explain peasant transformations and modes of farming. This tradition is based on a criticism of the assumptions underlying theoretical frameworks in other categories as well as those underpinning support for land redistribution policies. For example, Sender and Johnston (2004) argue that the theoretical narrative on imperfect markets is an example of circular reasoning: while inequalities in size distributions are conceptualised as the result of market failures, the very same argument is used to explain any absence of empirical evidence in favour of greater efficiency in smaller farms. Taking the example of land redistribution policies in Zimbabwe and South Africa, they question the policy implications drawn in previous research, namely that land redistribution in favour of smallholders would trigger reductions in poverty. In both countries, redistribution was highly problematic: in

posited in the literature: 'As Marx had suggested, peasants on small-sized farms which were so small in scale would be pushed by subsistence to work harder in order to survive while remaining mired in poverty' (Akram-Lodhi and Kay, 2010).

[2]This does not constitute a rejection of the existence of an inverse relationship as such, but it is a good example of the debate on the effectiveness of development policies based on the idea that an inverse relationship prevails in agriculture.

South Africa, less than 4% of poor households actually benefited from the program, while in Zimbabwe, women were largely excluded from any benefits following redistribution.[2] In the same tradition, Dyer (2004) explains that existing studies tend to conflate the macro and micro dimension of the topic. While it is true that an inverse relationship at the macro level exists (due to historical population shifts and patterns of settlements in best endowed regions), the same cannot be said for the micro level, for which there is in fact very little evidence (at the village or district level for instance).

Finally, a fourth category can be identified, which relies more on rural sociology and anthropology than economics. A leading contemporary scholar in this tradition is van der Ploeg. This agrarian tradition is critical of the economic traditions because it argues they are inherently static and fail to account for the continuously shifting nature of peasant farming, as well as the fact that a farming strategy has to be understood in its totality for it to make sense. It argues that the inverse relationship cannot hold in the long run, for when diminishing returns are observed, farming practices change, shifting the production function on a new path, thereby offsetting diminishing returns. Its strong anthropological focus also makes this literature critical of neo-classical populism, because it argues that agrarian reform can never simply boil down to a land redistribution reform (van der Ploeg, 2013). Finally, this tradition argues that economic analysis often assumes that both peasants and capitalist farmers share the aim of profit maximisation. While it is true that capitalist farming seeks to maximise profit (total production minus inputs *and* wages), peasant farming would instead maximise net gross output (total production minus inputs).[3]

All of these traditions reveal interesting insights, from the necessity to address statistical concerns in orthodox theory to that of understanding farming endeavours in agrarian studies. Finally, it is important to note that these categories are not completely isolated from each other. Rather, each of them tends to insist more on particular aspects of the debate, and the extent to which two categories share some features varies with the existing state of research. For example, Sen (1962), while operating within the orthodox tradition, seemed to share in the 1960s some common grounds with contemporary agrarian studies.

[3]This tradition of thought is very Chayanovian in its conception of a farming household, where 'household equilibrium' depends on a set of internal balances such as the one between effort and drudgery.

Within the orthodox tradition, the possibility of an inverse relationship is in principle at odds with the standard textbook approach. Neoclassical theory suggests that if smaller farms (or plots) are more productive, then production factors would adjust towards the most productive land/farms. Several categories of explanations for explaining the inverse relationship have been given in this literature. Barrett, Bellamare and Hou (2010) classify them into the following categories [4]:

• **Household characteristics**: The idea behind this hypothesis is that imperfect factor markets are triggering the IR. For example, small-scale farmers may be more productive than their large-scale counterparts if surplus labour is abundant and family labour is cheaper than hired labour, as argued by Sen (1966). Another reason could be the oversupply of labour on smaller farms in a case of imperfect or missing land and insurance markets. Barrett (1996) explains that in such situation, small farmers, who tend to be net buyers of crops, would protect themselves from price fluctuations by supplying extra labour. Whichever particular form this imperfect factor market story takes, the important aspect for the IR lies in the fact that 'there may exist unobservable inter-household variation in the shadow prices of factors of production that lead to different input intensity levels that are correlated with farm size, leading to the inverse farm size–productivity relation.' (Barrett, Bellamare and Hou, 2010:89) This will be referred to as **Proposition 1 (P1)** in our study.

• **Plot-level characteristics**: This explanation is based on the fact that many features of soil quality, such as potassium content, are unobservable to researchers. If such features are positively correlated with production (because soil nutrients are a determinant of output) but negatively correlated with cultivated area (for example if the best plots are partitioned), then omitting these unobservable factors may generate a spurious inverse relationship between productivity and size. This will be referred to as **Proposition 2 (P2)** in our study.

• **Statistical fallacy**: The idea of statistical fallacy relies on the fact that if size is measured with error and this error is negatively correlated with size (i.e., if the size of

[4] In the original paper, they call the first hypothesis the 'imperfect markets hypothesis', and the second one the 'omitted variable bias' hypothesis. However, we find that these expressions can be quite confusing. We therefore rename them as the 'Household characteristics' hypothesis and the 'Plot-level characteristics' hypothesis respectively. The name of the third hypothesis is clear enough and does not require change.

smaller farms is systematically over-estimated), then coefficients on land can be artificially biased downwards, and any observed inverse relationship is simply driven by 'bad data'. To the extent that non-biased measures of land become available to researchers, one may be able to directly test for the possibility of this statistical fallacy by simply comparing econometric specifications using farmers' supposedly erroneous estimates with alternative specifications using objective measures instead.[5] This will be referred to as **Proposition 3 (P3)** in our study.

Barrett, Bellamare and Hou (2010) use data on Madagascar collected in 2002, with the special feature that it includes precise soil measurements at the *plot level* like nitrogen and potassium content. Their results suggest that proposition 1 can only explain up to one third of the observed relationship, while no support for proposition 2 is found. Assunção and Braido (2007) use Indian data from the ICRISAT project and show that explanations based on peasants' 'mode of production' or on excessive supervision costs in large farms (i.e., explanations following the imperfect market proposition) are not supported by their analysis either.

The statistical fallacy proposition sheds light on the possibility that the observed inverse relationship is simply an artefact of the data due to behavioural response biases. This is a serious point to consider, for if it is valid, it casts doubt on decades of research on the inverse relationship. Traditionally, survey data report plot or farm areas as reported by the farmer, which is the most straightforward and economical way to report areas. However, GPS measurement is becoming cheaper as a technology and many surveys now report both farmers' self-reported areas and GPS measurements. Our data does report both measures, which allows for directly testing for this possibility.[6] Carletto *et al.* (2015) compare measures of areas for several datasets for which both measures are available, including the dataset used for this study. They find large discrepancies in measurements and show that area for small plots is often over-reported while that for large ones is usually under-reported. These findings emphasize the need to enquire whether an inverse relationship can be observed using GPS measurements in order to test whether any observed relationship is a statistical artefact coming from report bias or not. Very recent research

[5] Although it is arguably hard to obtain perfectly accurate measures of land. For example, GPS measures are seen as superior in quality to reported estimates but can also be biased, as explained later in the chapter.

[6] Although in the first wave of data, only 25% of plots were randomly assigned for GPS measurement.

suggests that measurement error in production may also be problematic. Gourlay, Kilic and Lobell (2017) is the first study we are aware of looking at possible biases in farmers' self-reported output measures for maize in Uganda. These can be due, for example, to a natural tendency of rounding off, or to recall bias which distort the measurement of production. Their results show that farmers' over-estimation of output may be the driving force behind the existence of the inverse relationship, the over-estimation being particularly strong for small plots in their Ugandan dataset.

Recently, empirical research has also taken into account the important difference between plot size and farm size when discussing a possible inverse relationship (Sheahan and Barrett, 2016). Traditionally, studies have focused on farm size, but as more precise agricultural data becomes available, it is clear that farm size is a problematic measure. Furthermore, the choice of crop on a particular plot may be endogenous: farmers may devote particular crops to particular plots. In that sense, looking at the possibility of an inverse relationship at the plot level looks more appropriate. Kimhi (2006) stresses the possibility of having *crop composition effects*: small-scale farmers may produce different crops than their large-scale counterparts, which may drive an artificial inverse relationship if not taken into account. However, even the plot level is not satisfying in a context of widespread intercropping, as the plot aggregate output only has limited economic and agronomic meaning when several crops are grown together on a single piece of land. In this study, we overcome these difficulties by looking at whether an inverse relationship holds at the crop/plot level for a set of important crops in Tanzanian agriculture: maize, rice, beans and groundnut.

2.3 Data and Summary Statistics

The data used in this study is the World Bank LSMS data for Tanzania, as explained in detail in chapter 1. We use the first three waves, covering the years 2008/09, 2010/11 and 2013/14. Variables used for the analysis come from the household and agricultural modules. Table 2.1 presents summary statistics for the main variables in the analysis by pooling the three waves of data available. Most farms and plots are observed two or three times. In total we have 6669 observations in our sample.

Summary variables in the **area variables** category report average plot size and average cultivated area for a crop on a plot using both self-reported (SR) and GPS measurements.

Table 2.1: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.
Area variables				
Plot size SR (acres)	2.79	5.82	0.05	130
Plot size GPS (acres)	3.15	6.39	0.01	155.83
Discrepancy (GPS-SR)	0.36	3.76	-86.19	59.25
Cultivated area on plot SR (acres)	1.62	2.14	0.01	50
Cultivated area on plot GPS (acres)	1.8	2.77	0.01	68.2
Input variables				
Family labour (days/plot)	78.61	78.45	0	1170
Hired labour (days/plot)	6.17	15.9	0	161
Organic fertiliser (kg/plot)	77.54	278.84	0	2000
Inorganic fertiliser (kg/plot)	13.74	51.09	0	950
Plot characteristics				
Elevation (meters)	1055.58	512.28	3	2184
Irrigation facility on plot (0/1)	0.02	1=112	0	1
Soil quality	2.41	0.61	1	3
Farm and household variables				
Farm size (acres)	5.99	11.21	0.05	274
Number of crops on farm	5.4	3.14	1	20
Female-head (0/1)	0.23	1=1518	0	1
Age of head	50.09	15.93	19	108

Note: Full details are available in Table B.1 in the Appendix

The sample is restricted to plots being GPS measured so that comparisons between measures can be directly made. We compute a measure of discrepancy defined as the difference between the GPS measurement and the self-reported measurement.[7] On average, plots are bigger when measured by GPS, with a higher standard deviation. The average discrepancy between GPS and SR measure is quite large, at 0.36 acre, suggesting that controlling for land measurement may impact the study of the IR.[8] Note however, that the discrepancy measure can be very large both in underestimating and overestimating plot size as revealed by the minimum and maximum values. Although we do observe a general tendency for larger plots to be underestimated, these statistics show they can also sometimes be largely overestimated. Average cultivated area for a crop on a plot is much smaller than average plot area, reflecting widespread intercropping and mixed-cropping strategies: on average, a crop in our sample is planted on 58% of the plot surface when using self-reported measures. These statistics confirm that looking at plot level aggregates in the context of Tanzania is misguided, hence justifying our more disaggregated level of analysis.

In terms of **inputs**, family labour is very prevalent, with an average use of about 79 days per plot over the previous long season. Hired labour is much lower with just above 6 days, although this takes into account all farmers (i.e., it includes non-hirers). Restricting to hirers only, average hired labour increases to 21 days per plot. Similarly, we observe a large difference between use of organic and inorganic fertiliser. Most farmers cannot afford inorganic fertiliser, either because of its prohibitive price or because of access constraints (Minot, 2009). By restricting the sample to users only, average use of inorganic fertiliser increases to 81 kg per plot.

Regarding **plot characteristics**, the average elevation is rather uninformative given the vast geographical heterogeneity in Tanzania. This is reflected by the large standard deviation. Farming can take place at high altitudes, especially in the northern regions of the country, where climatic and soil conditions are very different from central or southern regions. Virtually all plots in our sample are heavily rainfall dependent: only 2% of them

[7] We thus make the assumption here that the GPS measure is the 'true' measure of area. This is of course problematic, but as explained later in the section, GPS measures are seen as superior in quality to self-reported ones. We follow Carletto *et al.* (2013) in the computation of the discrepancy measure, who find a much lower average discrepancy for Uganda at 0.11 acres.

[8] Figure B.1 in the Appendix plots discrepancy against plot area. Consistent with De Groote and Traoré (2005), the discrepancy tends to be negative for very small plots and positive for larger ones, suggesting small-scale farmers overestimate their plot size, while large farmers underestimate it.

are irrigated. The soil quality variable is a categorical variable taking value 1 if the farmer judges the soil to be bad, 2 if average and 3 if good. Most plots are thus deemed to have relatively good soil according to farmers.[9] Finally, in terms of **farm/household** features, the average farm is 6 acres, with about 5 crops grown on the farm. Almost a quarter of households are female headed in our sample.

Table 2.2 refers to another important dimension of our study: the extent of intercropping (crops planted together on the same part of a plot) and the degree of priority of a crop (whether the crop is reported as being the priority crop on a plot by farmers). Apart from rice, all other crops are largely intercropped in our sample. On the other hand, while both maize and beans are overwhelmingly treated as priority crops, beans and groundnut are only considered to be the main crop in 20 and 24% of cases respectively. These important differences may have an impact on the IR if intercropping or the status of a crop correlates with size. We take up this issue in section 2.5.

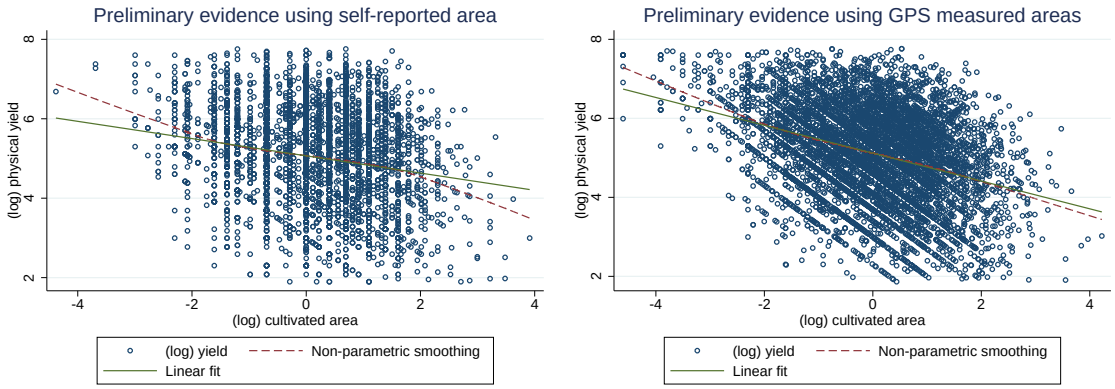
Table 2.2: Intercropping and priority crops

	Mean	**Std. Dev.**	**N**
Maize			
Intercropped ? (1=yes, 0=no)	66	1=2240	3407
Priority crop ? (1=yes, 0=no)	84	1=2845	3407
Rice			
Intercropped? (1=yes, 0=no)	22	1=136	630
Priority crop ? (1=yes, 0=no)	85	1=538	630
Beans			
Intercropped ? (1=yes, 0=no)	84	1=785	936
Priority crop ? (1=yes, 0=no)	20	1=186	936
Groundnut			
Intercropped ? (1=yes, 0=no)	76	1=351	460
Priority crop ? (1=yes, 0=no)	24	1=112	460

One way to motivate a study on a possible inverse relationship is to estimate a non-parametric regression of the log of yield on the log of area cultivated (Barrett, Bellemare and Hou (2010), Assunção and Braido (2007)). Figure 2.1 plots both a parametric and non-parametric regression of the log of yield on the log of cultivated area for all data (time and crops pooled), using both farmers' self-reported areas, and GPS measured areas. Results a priori confirm the existence of an inverse relationship and motivates our research question. Comparison of the linear and non-linear fit also suggests that parametric regres-

[9] Although such a measure is admittedly imperfect and most likely comes with a bias.

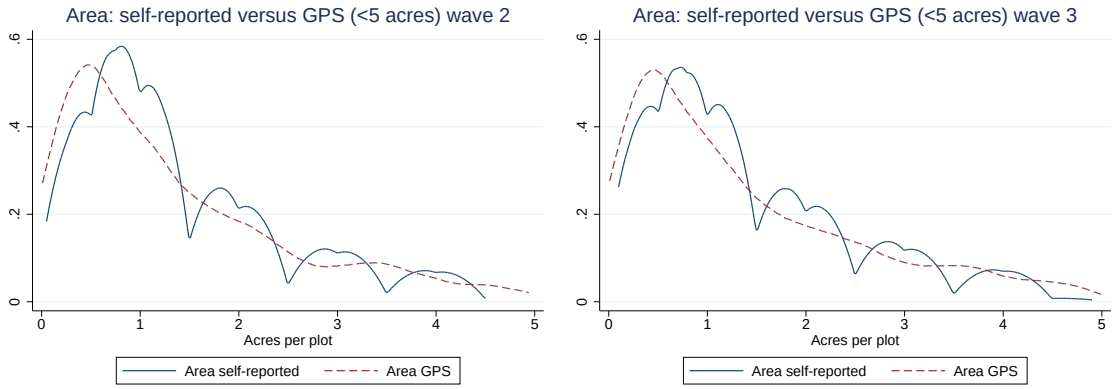
sion analysis is well suited for our purpose.



(a) Self-reported measures (b) GPS measures

Figure 2.1: Preliminary evidence using both self-reported and GPS measures

Although Figure 2.1 indicates that an inverse relationship a priori holds for both SR and GPS data, this does not imply that self-reported areas are not biased, as shown in Figure 2.2.



(a) Wave 2 (b) Wave 3

Figure 2.2: Kernel densities of cultivated area for SR and GPS measures

Figure 2.2 reports the kernel densities of self-reported areas and GPS measured areas for the second and third waves of the data (the proportion of GPS measured plots in wave 1 is too small to be reported), and shows that a bias is at work in the distribution of self-reported areas. The rationale for the statistical fallacy idea (proposition 3) is that

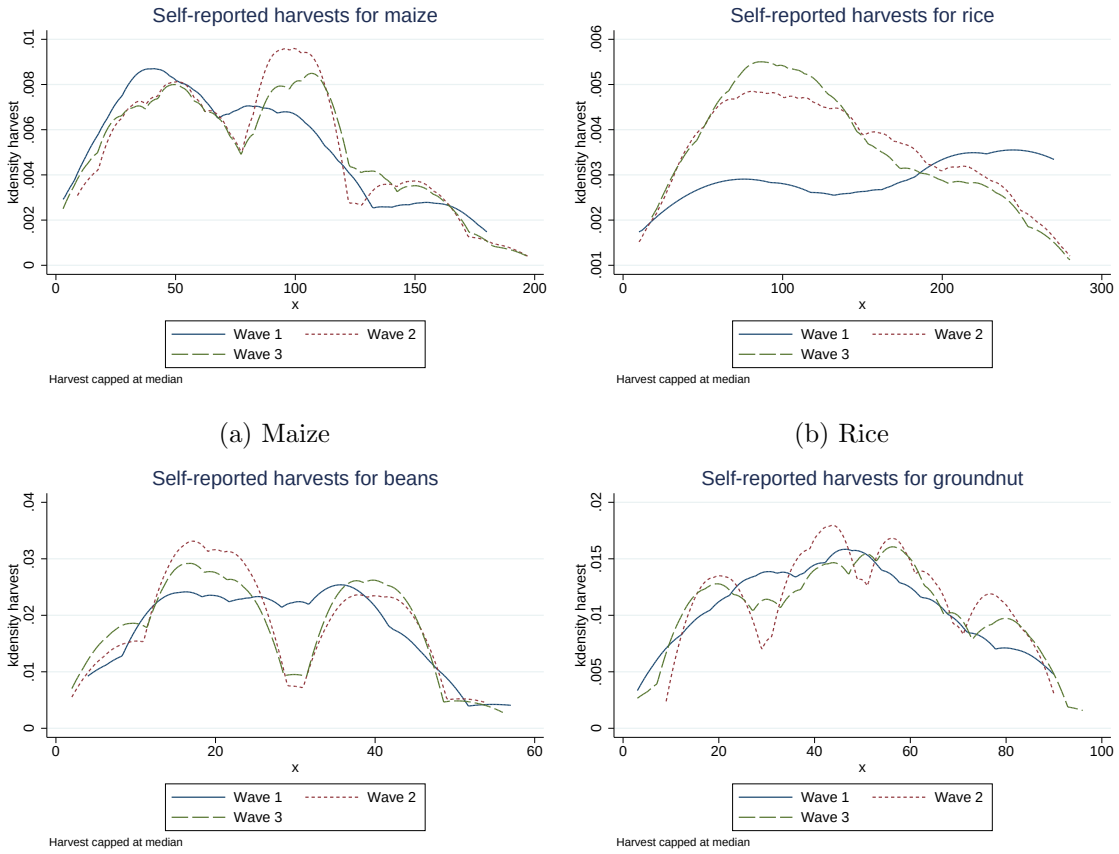
[10]'For the IR to be partially or fully explained by errors in land measurements, smaller farmers would have to systematically underreport land area with respect to larger farmers, thus resulting in artificially inflated yields in the bottom part of the distribution.' (Carletto *et al.*, 2013:255)

measurement error may wrongly induce an inverse relationship *if* the bias takes the form of an underestimation of the size of small plots (i.e., if the error is negatively correlated with size).[10] Figures 2.2a and 2.2b reveal there is indeed a bias, but of a different kind. Rather than a systematic under reporting of small plots (which is only observed on *very* small plots, up to just above 0.5 acre), it seems that independent of plot size, the bias materialises in the form of bunching around integer values. After each integer value, the densities dramatically drop, resulting in a wave shaped distribution of self-reported areas, with peaks at integer values. On the other hand, the GPS distributions are, as expected, much smoother (Holden and Fisher (2013) observe a very similar pattern in their study of the IR in Malawi). However, while the bias is different from that described in proposition 3, the latter can still be empirically valid. Because many plots are very small (less than 1 acre), it may still be the case that small plots are under-reported on average. This is a point also made by Carletto *et al.* (2013) using Ugandan data: farmers are largely rounding up their estimates, which is directly related to the statistical fallacy idea since rounding off proportionally affects smaller plots more than larger ones.

Regarding GPS measures, a word of caution is useful. These measures are not devoid of bias either and should not be viewed as reflecting perfectly accurate measurements (Carletto *et al.*, 2015). Possible biases with GPS measurements include: bad weather conditions, inadequate walking speed, cutting corners and steepness of the land. Further, evidence from Monte Carlo simulations shows that GPS measurement accuracy increases with plot size (Bogaert *et al.*, 2005). Hence, when looking at small-scale agriculture as is the case in Tanzania, there is also a risk of measurement error with GPS data. However, it is generally accepted that when comparing self-reported and GPS data, the latter should be considered superior, with biases of smaller magnitude and less random that in self-reported data.

Finally, one potential concern is that while we possess more 'objective' measurement than self-reported areas with GPS measurements, we only have self-reported harvests. Recent frontier research has started exploring possible biases in *production* figures (i.e., in reported harvests and hence computed yields), and argues this may be of importance for the existence of an IR. Gourlay, Kilic and Lobell (2017) collected objective data in Uganda for production measures (using remotely-sensed estimates and precise cross cut-

tings) alongside self-reported measures. Possible measurement errors can arise because of a tendency of rounding off, but also because of recall problems or intentional biases (for example, a farmer may over-report his production if it is believed this could trigger participation in a public program). They find that self-reported yields tend to be higher, on average, than those calculated from more objective measures. The type of data they use is highly novel and is not available for existing LSMS datasets, including the one we use. Hence, we cannot replicate here their method. However, by plotting the densities of harvest for each crop, we can check whether any systematic bias in reported output seems to take place (for example, whether bunching around 'key' amounts, such as 50 or 100 Kg occur). Figure 2.3 plots densities of self-reported harvests capped at the median.[11]



(a) Maize

(b) Rice

(c) Beans

(d) Groundnut

Figure 2.3: Kernel densities of self-reported harvest

Figure 2.3a shows that for maize, the main crop in our analysis, no clear bias is discernible, except perhaps for possible bunching around 100 kilograms in wave two. For rice there

[11]The reason for capping at the median is twofold: the first is that it makes it easy to identify bunching over a smaller distribution, and the second is that we are mostly interested in small-scale farmers given that

is no clear-cut evidence of widespread rounding off apart from a possible effect at 100kg in the third wave. For beans and groundnut, the concern for a possible report bias in harvest seems more justified in waves two and three. However, this is not a systematic under or overstimation bias, and hence is unlikely to affect the inverse relationship. In fact, the bunching around multiples of 20 may reflect relatively accurate measurements. Farmers typically evaluate their beans and nuts harvests using 20 litre plastic bags as units of measurement, which is often translated into 20 kilograms when reporting harvest. Hence, Figure 2.3 shows there is no a priori reason to suspect that a systematic under or over-estimation of harvests may affect our estimation of the IR.

2.4 Estimation Strategy & Results: Testing for Conventional Propositions

2.4.1 Estimation strategy

Our estimation strategy first consists in testing: the household characteristics proposition (*P1*), the plot-level characteristics proposition (*P2*), and the statistical fallacy idea (*P3*). To do so, we exploit both the rich agricultural details from the questionnaires and the structure of the data (cross section and panel). As is common in the empirical literature, we estimate production functions from the most naive to the least naive specification, and we study whether the relationship still holds as one moves from more to less naive versions. The dependent variable is output per unit of land (kg/acre), so we will refer to our specifications as *yield functions* rather than production functions to avoid confusion. Table 2.3 summarises our estimation strategy, which builds and expands upon Barrett, Bellamare and Hou (2010).

Our measure of size is defined as the *portion of a plot on which a crop is grown.* After providing an estimate of the size of each plot, farmers are asked on what approximate proportion of the plot do they grow each crop (25%, 50%, 75% or 100%). Hence, we are able to approximate for each crop the area on which it is grown. We construct our first measure of area by calculating these proportions with respect to self-reported areas, and our second measure by doing so with respect to GPS measurements instead.

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we are trying to evaluate whether yields are higher on smaller cultivated areas (there is growing consensus in the literature that self-reported bias are higher among small-scale farmers than their larger counterparts).

Further, we also possess information regarding whether a crop is intercropped. Our measure of area represents the total area on a plot on which a crop is grown, whether it is intercropped or not. In addition, we include in models controlling for proposition 2 a dummy taking the value of one if the crop is intercropped. As an illustration, imagine the following situation: a farmer has a plot of 1 acre. The farmer reports that on roughly half the plot, maize and beans are intercropped together. The other half has pure-stand groundnut. According to our definition of size, we have the following: *(i)* maize planted of 0.5 acre with the intercropping dummy taking the value of 1, *(ii)* beans planted of 0.5 acre with the intercropping dummy taking the value of 1, and *(iii)* groundnut planted of 0.5 acre with the intercropping dummy taking the value of 0.

Table 2.3: Estimation strategy: specifications

Hypothesis	Implications	Specification	Model
-	Benchmark model (OLS)	$log(yield_{cpi}) = \alpha_1 + \beta_1 log(area_{cpi}) + \boldsymbol{\gamma_1'} \boldsymbol{x_{cpi}} + \epsilon_{cpi}$	(1)
1	Control for household heterogeneity (OLS)	$log(yield_{cpi}) = \alpha_2 + \beta_2 log(area_{cpi}) + \boldsymbol{\gamma_2'} \boldsymbol{x_{cpi}} + \boldsymbol{\theta_2'} \boldsymbol{HH_i} + \eta_{cpi}$	(2)
2	Control for plot characteristics (OLS)	$log(yield_{cpi}) = \alpha_3 + \beta_3 log(area_{cpi}) + \boldsymbol{\gamma_3'} \boldsymbol{x_{cpi}} + \boldsymbol{\tau_3'} \boldsymbol{plot_{pi}} + \rho_{cpi}$	(3)
1+2	Control for both (OLS)	$log(yield_{cpi}) = \alpha_4 + \beta_4 log(area_{cpi}) + \boldsymbol{\gamma_4'} \boldsymbol{x_{cpi}} + \boldsymbol{\theta_4'} \boldsymbol{HH_i} + \boldsymbol{\tau_4'} \boldsymbol{plot_{pi}} + \nu_{cpi}$	(4)
1+2+3	Control for both using GPS measures (OLS)	$log(yield^{gps}_{cpi}) = \alpha_5 + \beta_5 log(area^{gps}_{cpi}) + \boldsymbol{\gamma_5'} \boldsymbol{x^{gps}_{cpi}} + \boldsymbol{\theta_5'} \boldsymbol{HH_i} + \boldsymbol{\tau_5'} \boldsymbol{plot_{pi}} + \kappa_{cpi}$	(5)
1'+2'	Panel FE deals with unobserved HH and plot heterogeneity	$log(yield_{cpi}) = \alpha_6 + \beta_6 log(area_{cpi}) + \boldsymbol{\gamma_6'} \boldsymbol{x_{cpi}} + \boldsymbol{\theta_6'} \boldsymbol{HH_i} + \boldsymbol{\tau_6'} \boldsymbol{plot_{pi}} + \zeta_{cpi}$	(6)
1'+2'+3	Panel FE with land size corrected with GPS measures	$log(yield^{gps}_{cpi}) = \alpha_7 + \beta_7 log(area^{gps}_{cpi}) + \boldsymbol{\gamma_7'} \boldsymbol{x^{gps}_{cpi}} + \boldsymbol{\theta_7'} \boldsymbol{HH_i} + \boldsymbol{\tau_7'} \boldsymbol{plot_{pi}} + \varepsilon_{cpi}$	(7)

Notes:
- The vector $\boldsymbol{x_{cpi}}$ includes controls for input usage at the plot/crop level: organic fertiliser and family labour (fixed) and inorganic fertiliser and hired labour (variable). Rainfall is also included as a fixed input.
- In specifications using GPS measurement, land, yield and input usage have all been rescaled according to GPS measures instead of farmers' self-reported areas
- In model 6 and 7, propositions 1 and 2 are renamed 1' and 2' to differentiate the panel models from their OLS counterparts
- OLS specifications include regional and year fixed effects. Panel specifications include year dummies

We first start with OLS specifications. Model 1 is a benchmark model, where we simply regress the log of yield on the log of area cultivated, regional and year fixed effects and a set of controls including inputs usage. Fixed inputs include days of family labour, organic fertiliser and rainfall, and variable inputs include days of hired labour and inorganic fertiliser. The data provides information for labour and fertiliser use at the plot level, so that we have normalised relevant quantities by acre (days of work in the case of labour, and kilograms in the case of fertiliser). For example, if 40 days of household labour were spent on a plot of two acres, family labour per acre of land on that particular plot will be 20 days. However, the proportion of farmers not using inputs can be large (particularly for inorganic fertiliser), thus generating missing observations when taking logs. While imputing an arbitrarily chosen positive small number to the zeros is often used as a solution, we implement instead the inverse hyperbolic sine transformation (IHS), which is considered less arbitrary. Implementing the IHS has several benefits, such as adjusting for skewness in the data, retaining zero and negative observations, and not disproportionately misrepresenting zeros (Friedline *et al.*, 2015). For a given value x, the IHS transformation is given by:

$$ihs(x) = ln(\sqrt{x^2 + 1} + x)$$

While the IHS is usually used for dependent variables, it can also be applied to independent variables (Friedline *et al.*, 2015, Layton, 2001).[12] Once the IHS transformation is implemented, we are able to retain all observations for which no input use was reported.

Model 2 tests proposition 1. The conventional way to test for this in the literature is to include household fixed effects in order to control for within-household unobserved heterogeneity (Heltberg (1998), Barrett, Bellemare and Hou (2010), Assunção and Braido (2007)). Inclusion of fixed effects is made possible by the levels of analysis usually followed in the literature: farm or plot level. In sub-Saharan Africa, farmers typically have several plots and several crops on the farm, so that any estimation strategy using a crop level or a plot level analysis will feature several observations *per household*. However, we study the IR at a more disaggregated level: the crop/plot level, where the level of observation is a crop on a given plot. As such, our samples do not have enough within variation to justify the use of household fixed effects. The proportion of households growing a given

[12]For examples of studies in the field of agricultural economics using the IHS, see Mihalopoulos and Demoussis (2001), or Yen and Jones (1997). For a thorough study of the merits and uses of the IHS, see Pence (2006).

crop on one plot only is very large in our sample, particularly so for rice and groundnut. For example, the percentage of rice growers growing rice on only one plot is 89% in wave three, that of groundnut growers growing groundnut on only one plot is 92% in both waves two and three. Hence, using household fixed effects would dramatically reduce the number of degrees of freedom in our analysis and undermine the interpretation of results.[13]

Therefore, we test for the household characteristics proposition by controlling for household level observable characteristics instead. These include a dummy to control for female headed households, its interaction with the area variable (to capture the possibility of different IRs for male and female-headed households), a dummy for whether anyone in the household is a member of a saving group, the education level and log of age of the head of household, a dummy capturing whether the household owns a means of transport, and the log of farm size. We also control for the total number of crops grown on the farm and that grown on a plot, as well as a dummy taking the value of one if a household plants any crop on more than one plot and zero otherwise. We also include village-level variables which may also affect household-specific market failures.[14] These are dummy variables capturing whether there is a cooperative in the village, and whether improved seeds are available in the village.

Model 3 controls for plot-level characteristics (*P2*) by including a vector of observable plot features. The data are quite rich in this respect and provide information regarding several aspects of each plot. The underlying assumption here is thus that we have sufficient information on plot characteristics to remove this possible bias. The vector includes: soil quality (categorical variable reported by farmer), steepness of the land, log of elevation, whether the plot has an irrigation facility, whether it has an erosion facility, and dummies for soil type (loam, clay, sandy or other). We also include dummies capturing whether the crop is intercropped and whether it is the main crop on the plot. Although these are not physical features of plots as such, they may influence soil productivity and quality. For example, pulses can replenish the soils in nitrogen content. Model 4 combines the previous two propositions together (*P1 and P2*).

[13] However, we are able to control for time invariant household/plot characteristics when moving to panel estimation, as explained below.

[14] In levels of analysis that allow for household fixed effects, their inclusion also controls, by definition, for village factors that affect the degree of market failures.

Model 5, our last specification using OLS estimation, is similar to model 4 but it additionally controls for the statistical fallacy possibility (*P1, P2 and P3*). As such, it is analogous to model 4 except that yields, area cultivated and input usage have all been rescaled according to GPS measurements instead of farmers' self-reported measurements.

We then move to panel fixed effect estimation. The rationale is that although we are controlling for a set of observed plot characteristics, there may still be large unobserved heterogeneity. This is an important step in the development of the literature on the IR. Studies relying on a plot level focus usually have to rely on OLS, because their level of analysis makes the use of panel techniques complicated as plot size is largely time invariant. Among studies using panel techniques are Lamb (2003) who uses ICRISAT data, and Kagin *et al.* (2016) who use Mexican data to study the relationship between land cultivated and productivity and efficiency. However, their focus is at the farm level only, and hence is subject to issues of crop composition effects and general lack of precision regarding what is actually measured, as argued in Section 2. A recurrent criticism of existing studies is that any 'observed' IR may be driven by unobserved plot heterogeneity. Obvious missing variables are soil composition variables which truly measure land quality (such as nitrogen and potassium contents). Bringing a new focus at the crop/plot level of analysis allows us to bypass this issue, by looking into the determinants of productivity for a given crop on a given plot. Hence, even if plot size is time invariant, the crop mix on a plot is *not*. As a simple example, consider the following hypothetical situation: a plot of one acre is used to grow maize (monocropped). One year later, the same plot is covered with monocropped maize on half the plot only (0.5 acre) while the other half has beans and sorghum intercropped. Even though plot size is time invariant, the area planted with maize on that plot is not.[15] Because crop mixes are not time invariant, we have an unbalanced panel (not all farmers grow the same crops on the same plots across time).

The data thus allows us to study whether we can still observe an inverse relationship in panel analysis, and doing so means we can also confirm or refute the claim that any negative relationship found through OLS estimation is driven by unobserved heterogeneity at the plot level. Because the study looks at productivity determinants at the crop/plot

[15] In some instances, even plot size can change. This can be because patches of land can be cleared and added to an existing plot, or because the structure of plots changes after a household splits (giving out some of the land to a son or daughter leaving the household for example). The cultivated area of a plot can also be altered over time.

level, the panel *id* level declared is a combination of household and plot. The unique panel identifier thus refers to a particular plot within a given household. These *id*s account for splitting households across time. Hence, when using panel specifications we are controlling for all household/crop/plot time invariant features. One such unobservable is crop specific farming knowledge, which is an important determinant of productivity.

We estimate two panel models, which are the equivalent to the two most complete OLS specifications: model 6 controls for propositions 1 and 2, and model 7 further controls for proposition 3.

2.4.2 Empirical results: testing propositions 1 to 3

Tables 2.4 to 2.7 below present key results for maize, rice, beans and groundnut. In all specifications, both the dependent variable and continuous variables are in logs so that coefficients can be interpreted as elasticities, with inputs transformed using the inverse hyperbolic sine transformation. Output tables in the main text have been simplified as much as possible with full output presented in the appendix. For the sake of simplicity, we do not report in the main text outputs for the model testing only for proposition 1 or only for proposition 2. We only present here the more complete models that control for several propositions at the same time. The full output tables for all crops are reported in Tables B.2 to B.5 in the Appendix.

In each table, the first column reports results for the benchmark model ('naive specification') which only includes area cultivated and inputs as independent variables. The second column reports results for the model controlling for the household characteristics and plot-level characteristics propositions (*P1 and P2*). The third column further controls for the possibility of statistical fallacy (*P1, P2 and P3*). The last two columns are the panel equivalents to columns 2 and 3. Column 4 controls for propositions 1 and 2, and column 5 further controls for proposition 3. The 'Estimation' line at the bottom of each table gives a reminder of whether OLS or panel fixed effects model is used, while the 'Area' line specifies whether self-reported (SR) or GPS measures are used.

Table 2.4: Yield functions for maize (main coefficients only)

	(1)	(2)	(3)	(4)	(5)
	Benchmark	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.221***	-0.259***	-0.358***	-0.637***	-0.654***
	(0.021)	(0.026)	(0.020)	(0.050)	(0.050)
Area*female		-0.144***	-0.109***	-0.074	-0.079
		(0.040)	(0.030)	(0.084)	(0.081)
Hired labour	0.123***	0.124***	0.115***	0.027	0.031
	(0.016)	(0.015)	(0.015)	(0.022)	(0.021)
Inorganic fert	0.140***	0.127***	0.116***	0.049**	0.050**
	(0.012)	(0.011)	(0.010)	(0.020)	(0.020)
Soil quality		0.133***	0.137***	0.072*	0.079**
		(0.026)	(0.024)	(0.038)	(0.038)
Female head		-0.064	-0.058	0.200	0.239
		(0.049)	(0.049)	(0.320)	(0.310)
Intercrop		-0.084**	-0.088**	-0.103*	-0.087*
		(0.036)	(0.034)	(0.053)	(0.052)
Maincrop		0.303***	0.328***	0.208**	0.234**
		(0.047)	(0.045)	(0.093)	(0.095)
N	3407	3407	3407	3407	3407
R^2	0.25	0.31	0.40	0.28	0.32
Regions	Yes	Yes	Yes	-	-
Year	Yes	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	SR	GPS	SR	GPS

Standard errors clustered at HH level for models 1-5, and at HH/plot level for models 6-7

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: This table and all subsequent output tables reported in the main text only present the main coefficients of interest. Variables entering the analysis but not reported in the main text include **fixed inputs** (family labour, organic fertiliser and rainfall), as well as controls for the **household characteristics** proposition (education level and age of head of household, membership of a saving group, ownership of a means of transport farm size, presence of village cooperative, availability of improved seeds, number of crops grown on the farm and number of plots with a given crop) and controls for the **plot-level characteristics** proposition (soil type, steepness and elevation of the land, irrigation and erosion facility, number of trees per plot).

Table 2.5: Yield functions for rice (main coefficients only)

	(1)	(2)	(3)	(4)	(5)
	Benchmark	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.242***	-0.374***	-0.431***	-0.813***	-0.775***
	(0.050)	(0.064)	(0.053)	(0.147)	(0.098)
Area*female		-0.038	-0.056	-0.293	-0.206
		(0.090)	(0.072)	(0.220)	(0.204)
Hired labour	0.184***	0.163***	0.155***	0.116**	0.127**
	(0.022)	(0.021)	(0.019)	(0.052)	(0.057)
Inorganic fert	0.111***	0.096***	0.084***	-0.016	-0.034
	(0.033)	(0.028)	(0.026)	(0.056)	(0.058)
Soil quality		0.102*	0.115**	-0.054	-0.070
		(0.055)	(0.053)	(0.123)	(0.119)
Female head		0.089	0.038	1.307***	1.458***
		(0.094)	(0.093)	(0.452)	(0.403)
Intercrop		-0.419***	-0.479***	-0.218	-0.214
		(0.105)	(0.108)	(0.184)	(0.177)
Maincrop		0.092	0.108	0.219	0.175
		(0.097)	(0.095)	(0.221)	(0.218)
N	630	630	630	630	630
R^2	0.41	0.48	0.57	0.54	0.54
Regions	Yes	Yes	Yes	-	-
Year	Yes	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	SR	GPS	SR	GPS

Standard errors clustered at HH level for models 1-5, and at HH/plot level for models 6-7

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: the full output includes the same controls as those listed under table 2.4

Table 2.6: Yield functions for beans (main coefficients only)

	(1)	(2)	(3)	(4)	(5)
	Benchmark	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.357***	-0.464***	-0.515***	-0.569***	-0.610***
	(0.041)	(0.051)	(0.040)	(0.092)	(0.090)
Area*female		-0.176**	-0.105	-0.048	-0.320
		(0.082)	(0.065)	(0.127)	(0.209)
Hired labour	0.074***	0.086***	0.064***	0.093**	0.077**
	(0.026)	(0.023)	(0.024)	(0.037)	(0.036)
Inorganic fert	0.005	0.011	0.014	-0.010	0.003
	(0.021)	(0.021)	(0.021)	(0.035)	(0.033)
Soil quality		0.089*	0.097**	0.067	0.057
		(0.049)	(0.048)	(0.082)	(0.080)
Female head		-0.089	-0.064	-0.038	-0.185
		(0.092)	(0.089)	(0.319)	(0.333)
Intercrop		-0.241**	-0.248***	0.026	-0.040
		(0.101)	(0.095)	(0.152)	(0.148)
Maincrop		0.391***	0.417***	0.234*	0.239
		(0.092)	(0.088)	(0.135)	(0.146)
N	936	936	936	936	936
R^2	0.24	0.33	0.44	0.50	0.50
Regions	Yes	Yes	Yes	-	-
Year	Yes	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	SR	GPS	SR	GPS

Standard errors clustered at HH level for models 1-5, and at HH/plot level for models 6-7

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: the full output includes the same controls as those listed under table 2.4

Table 2.7: Yield functions for groundnut (main coefficients only)

	(1)	(2)	(3)	(4)	(5)
	Benchmark	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.358***	-0.431***	-0.473***	-0.988***	-0.925***
	(0.058)	(0.078)	(0.062)	(0.190)	(0.191)
Area*female		-0.043	-0.073	0.008	-0.220
		(0.091)	(0.078)	(0.302)	(0.207)
Hired labour	0.072*	0.067*	0.056	0.126	0.126
	(0.038)	(0.040)	(0.039)	(0.095)	(0.087)
Inorganic fert	0.006	0.009	0.004	-0.016	-0.045
	(0.037)	(0.038)	(0.039)	(0.093)	(0.085)
Soil quality		-0.111	-0.093	0.240	0.227
		(0.073)	(0.074)	(0.175)	(0.177)
Female head		-0.116	-0.056	-3.923***	-4.261***
		(0.113)	(0.111)	(0.801)	(0.689)
Intercrop		-0.036	0.018	0.204	0.192
		(0.110)	(0.107)	(0.303)	(0.296)
Maincrop		0.359***	0.363***	0.412	0.369
		(0.125)	(0.124)	(0.301)	(0.259)
N	460	460	460	460	460
R^2	0.25	0.33	0.40	0.66	0.66
Regions	Yes	Yes	Yes	-	-
Year	Yes	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	SR	GPS	SR	GPS

Standard errors clustered at HH level for models 1-5, and at HH/plot level for models 6-7

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: the full output includes the same controls as those listed under table 2.4

The discussion of results is mainly focused on maize, which is the most important crop in our sample, and one of the most essential crops in Tanzania. We comment on results for rice, beans and groundnut whenever they clearly differ from those for maize.

Results for maize are presented in Table 2.4. The IR is robust to all specifications. In the benchmark model, a one percent increase in area cultivated is associated with a decrease in yield of 0.22% on average. Controlling for the imperfect market and omitted variable bias propositions (column 2) does not remove the IR. In fact, it slightly increases

its magnitude: a one percent increase in area cultivated is now triggering a decrease in yields of around 0.26% on average. Controlling for the possibility of a statistical fallacy due to self-reported data unambiguously points towards an increase in the magnitude of the IR: a one percent increase in area cultivated is associated with a 0.36% decrease in yields. This result clearly goes against the proposition that the IR could be artificially driven by self-reported data. This is consistent with results in Carletto *et al.* (2015) who also find an increase in the strength of the relationship when moving from self-reported to GPS measured data.[16]

When moving to panel models, the IR effect roughly doubles: a one percent increase in area cultivated is associated with a 0.64% decrease in yields in the model with self-reported areas or 0.66% decrease in that with GPS measures. Controlling for unobserved time-invariant household/plot heterogeneity therefore triggers an increase in the magnitude of the IR, which goes against the criticism often made that negative area coefficients in OLS regressions are simply driven by this heterogeneity.

Also note that the IR is stronger for female-headed households in the OLS models: the interaction terms between area cultivated and a dummy taking value 1 if the household is female-headed are strongly negative and significant in columns two and three. However, the interaction loses significance in the panel models, which may be due to too little within variation in the dummy for female-headed households.

As expected, variable inputs have a strong positive effect on yields. Although the effect of inorganic fertiliser on yields weakens when moving from OLS to panel estimation, statistical significance is preserved. The dummy variable capturing whether the crop is intercropped is consistently negative across specifications, although it becomes weakly significant in the panel models. This implies that intercropping practices have a consistently negative effects on physical yields for maize independently of the area cultivated. This can be expected, to the extent that less maize can be harvested from one acre of land where it shares space with other crops than from one acre when it is planted as pure-stand. Intercropping in Tanzania usually implies a situation where the practice leaves parts of a plot

[16]It is also consistent with preliminary evidence reported on Figures 2.1a and 2.1b in the summary statistics section. The fitted line for the GPS data cloud is steeper than the fitted line for the self-reported data.

'empty'. In that sense, it clearly differs from the conception of intercropping in the plant sciences which emphasizes optimal agronomic practices to improve yields by exploiting biological complementarities between crops.[17] Note that at this stage of the analysis, this dummy only tells us that the physical productivity of maize tends to be lesser on plots on which it is intercropped. In the next part of the analysis, we explore whether it could also impact the existence of the IR: if intercropping negatively correlated with size, this could artificially drive the relationship.

The dummy variable capturing whether the crop is the main crop on the plot is significant in all models at least at the 5% level. The effect is stable across specifications, at around 0.3 for OLS models, and 0.2 for panel ones. Hence, the physical productivity of maize is higher when the crop is treated as a priority crop by the farmer (this may involve higher effort, or better quality seeds for example).

To summarise, we find no evidence that controlling for propositions one to three is able to remove the IR: area coefficients are consistently negative and significant. In fact, using more precise GPS measurements as well as panel estimation increase the magnitude of the relationship.

Results for rice, beans and groundnut also show a consistently negative and significant area coefficient in all specifications. Hence, the IR is robust for all crops in all models. We also observe for these crops an increase in the strength of the relationship when moving from self-reported to GPS measured area, as well as a strong increase when moving from OLS to panel estimation. This is particularly the case for groundnut, for which the magnitude of the IR in panel models is approaching unity.

There are, however, some important differences with respect to other variables. One is the interaction term between cultivated area and the female dummy. It is not significant in any models for rice and groundnut, suggesting that the IR is not significantly different in female headed households.[18] For beans, the interaction term is significant in the first

[17] For example, maize crucially requires nitrogen but is unable to fix it in the soil. In that sense, a carefully designed strategy of intercropping with a crop that can fix nitrogen in the soil (such as a pulse) could theoretically be yield-enhancing.

[18] This does not imply that female headed households are less productive in general, but only that the magnitude of the IR is not stronger than for male headed ones.

OLS specification, but it is not robust to GPS measurements or panel estimation. As expected, the effects of variable inputs on yields also differ across crops. For example, we find no effect of inorganic fertiliser on yields for beans and groundnut, perhaps because pulses and nuts fix nitrogen in the soil, and hence do not require as much fertiliser as crops that cannot fix it, such as maize. The effects on yields of intercropping or being a priority crop also differ across crops. For rice, the intercropping dummy is strongly negative and significant in the OLS models, with a much larger effect than for maize. On the other hand, being a priority crop has no effect on yields. The opposite happens for groundnut: the intercrop dummy is not significant in any model, but the main crop one is strongly significant in the OLS specifications. This crop is often considered a cash crop in the Tanzanian context. As such, treating it as a main crop rather than a residual one may characterise a commercial endeavour. Farmers may concentrate a greater (unobservable) effort on groundnut when treating it as a priority crop.

Summary of Results

Our results show unambiguous support for the existence of an IR between cultivated area and physical productivity measured in yields. For each crop we run a baseline benchmark regression, progressively augmented to control for existing hypotheses in the literature. Beyond crop-specific differences (notably in terms of the magnitude of the relationship, or the effect of variable inputs on productivity), three key findings characterise results:

> ***Finding 1****: The use of GPS data does not remove the IR. Hence, the claim that biases in farmers' self-reported areas may be driving the relationship (proposition 3) is not verified. In fact, the IR is even stronger when using GPS data, which is consistent with recent empirical evidence comparing self-reported and GPS data.*

> ***Finding 2****: The IR does not vanish when using panel fixed-effects models, suggesting that the criticism of OLS regressions based on the claim that the IR may be driven by unobserved plot heterogeneity is misguided. Once controlling for unobserved household/plot heterogeneity, we find a dramatic increase in the magnitude of the IR. This holds for all crops in our analysis.*

> ***Finding 3****: Results show that whether a crop is intercropped and/or is the primary crop on a plot can have a strong effect on physical productivity. This result partly*

comes from our level of analysis at the crop/plot level, and hence, has been largely ignored in the existing literature on the IR.

Having tested for the conventional explanations for the IR, we now build on previous specifications to control for two new hypotheses following *Finding 3*. The effect of the intercropping and main crop dummies on yields suggests they may reflect different farming endeavours. As such, they could influence the presence of the IR if their prevalence correlates negatively with size. We thus take the analysis further in the next section by controlling for their possible effect on the IR.

2.5 Controlling for Two New Hypotheses

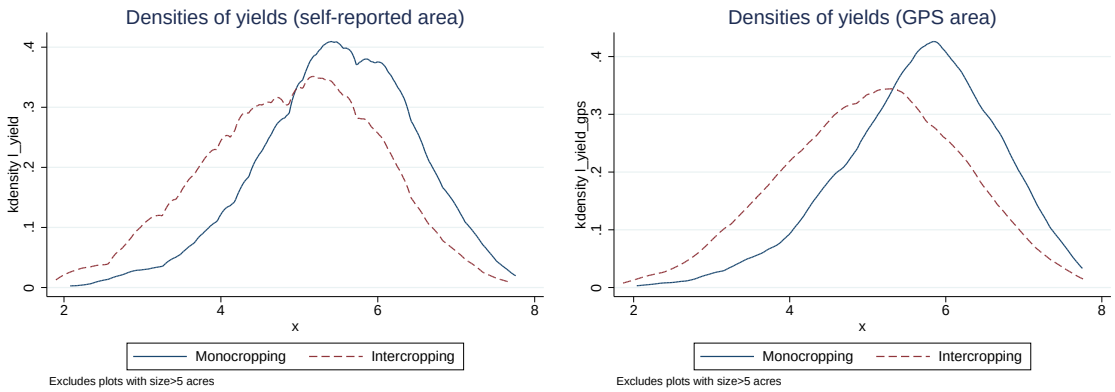
2.5.1 The 'intercropping' and 'main crop' propositions

Our results so far imply that whatever specification is followed, we observe a negative relationship between cultivated area and physical productivity. We have tested for the three propositions identified in the literature, and found that while they may influence the magnitude of the coefficient on cultivated land, the relationship still holds.

However, results from section 4 reveal two interesting features. The first of these is that the dummy variable for whether a crop is intercropped is strongly negative and significant in OLS models for maize, rice and beans, suggesting a higher productivity on plots (or parts of plots) which are monocropped. The effect is also weakly significant in the panel models for maize. This may be a preliminary indicator that intercropping may characterise a low productivity environment, and as such may directly influence the existence -or at least magnitude- of the inverse relationship. The second is that whether a crop is the main crop grown on a plot or not has an important impact on the yields of maize, beans and groundnut. This may characterise a particular farming endeavour which can also affect the relationship between size and productivity. We explain in more details the rationale for these propositions in the next subsections.

The intercropping proposition (*P4*)

Figure 2.4 plots graphs of the kernel densities of yields for crops which are intercropped (dashed line) and monocropped (plain line) for both measures of area.



(a) Self-reported measures (b) GPS measures

Figure 2.4: Kernel densities of yields for intercropped and monocropped crops

At low levels of yields, there is a higher density of intercropped crops and vice versa. The mean is higher for monocropping with also a lower variance. This holds for both self-reported and GPS measures. Figures 2.4a and 2.4b are thus consistent with results in tables 2.4, 2.6 and 2.7 which report strongly negative and significant coefficients for the intercropping dummy. Results indicate that yields decline both when area cultivated increases and when a crop is intercropped. If intercropping negatively correlates with area cultivated (i.e., if it is more prevalent on smaller plots), then the IR could be driven by a missing interaction between area and intercropping. We thus propose to formally control for this, which has not been done in the literature to the best of our knowledge.

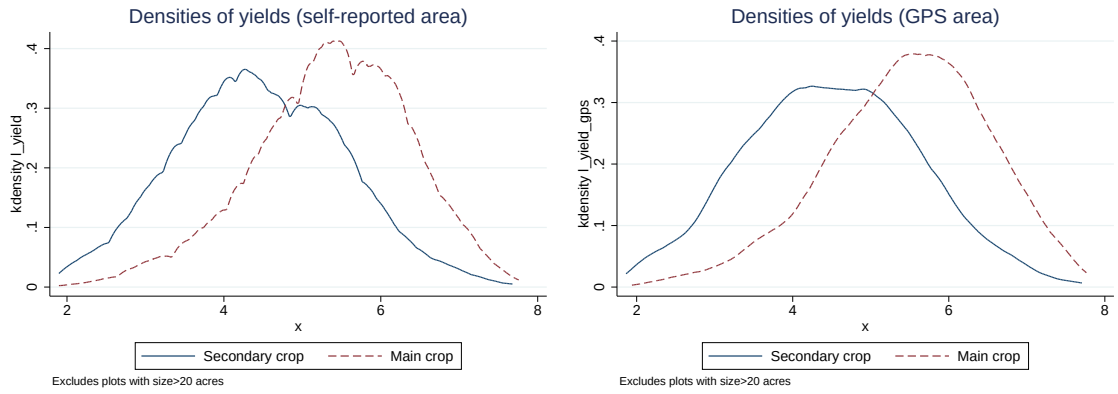
Proposition 4: The inverse relationship may be driven by a missing interaction between area and a dummy for intercropping. More formally, the OLS regression controlling for propositions 1 to 3 (model 5) becomes:

$$log(yield_{cpi}^{gps}) = \alpha_5 + \beta_5 log(area_{cpi}^{gps}) + \underbrace{\delta_5 log(area_{cpi}^{gps}) * intercrop}_{\text{new interaction}} + \boldsymbol{\gamma_5' x_{cpi}^{gps}} + \boldsymbol{\theta_5' HH_i} + \boldsymbol{\tau_5' plot_{pi}} + \varrho_{cpi} \tag{2.1}$$

If this is our true model, then omitting to include this interaction term will make the OLS estimator biased downwards. If this interaction term explains the IR, we should fail to reject the null hypothesis $H_0 : \beta_5 = 0$. Accounting for intercropping is important for several reasons. One of them is that the rationale for intercropping may be different from what is usually thought. While it may be considered as a fertility enhancing strategy, the vast majority of farmers in Tanzania use intercroping as a risk mitigation strategy instead, where one crop can be used as a substitute for another in case of failure. This sort of risk reduction mechanism reflects a low productivity environment, as suggested by Figure 2.4. For farmers answering the questionnaire, intercropping may simply refer to a situation where several crops are grown on a plot, without necessarily implying that crops are densely planted together on a given area, as is usually conceived. This implies that there may be 'empty space' in intercropped areas which can mechanically generate an inverse relationship if such empty space is related to plot size. The pictures on Figure B.2 in the Appendix may help conceptualise this issue.

The main crop proposition (*P5*)

The second proposition we wish to test is whether an IR still holds for crops which are the main crop on a plot. For each plot, farmers are asked to provide the relevant crop mix, and state which crop from that mix is the most important one.[19] The dummy variable for being main crop is highly significant and positive in OLS models for beans and groundnut and in both OLS and panel models for maize. Hence, a crop has on average a higher physical productivity if it is treated as a priority crop by the farmer.



(a) Self-reported measures (b) GPS measures

Figure 2.5: Kernel densities of yields for primary and secondary crops

Maize and rice are typically the main crop on plots on which they are grown (84% for maize, 85% for rice), while for beans and groundnut the proportion is much smaller (20% for beans, 24% for groundnut). To the extent that farmers treat main crops and secondary crops differently, their productivity determinants can differ (for example, the input mix, effort applied or farming knowledge can be different). Figure 2.5 shows the densities of yield for primary and secondary crops. Both with self-reported and GPS data, secondary crops prevail in the lower tail of the distribution while primary crops prevail in the upper tail. As such, the existence and magnitude of the inverse relationship may be affected by this ranking of crops made by farmers if crop status correlates with cultivated area. We thus propose to control for this.

Proposition 5: The existence of an inverse relationship can be driven by omitting to account for whether a crop is the main crop on a plot or a secondary crop only. More

[19] A priority crop can be either a cash crop that is a key determinant of income, or a important subsistence crop for example.

formally, the OLS regression controlling for propositions 1 to 3 (model 5) becomes:

$$log(yield_{cpi}^{gps}) = \alpha_5 + \beta_5 log(area_{cpi}^{gps}) + \underbrace{\delta_5 log(area_{cpi}^{gps}) * maincrop}_{\text{new interaction}} + \boldsymbol{\gamma_5' x_{cpi}^{gps}} + \boldsymbol{\theta_5' HH_i} + \boldsymbol{\tau_5' plot_{pi}} + \xi_{cpi} \tag{2.2}$$

If the IR is driven by conflating secondary and primary crops, then including the interaction term should remove the relationship for main crops.

2.5.2 Results: testing propositions 4 and 5

We test propositions 4 and 5 by building on specifications 4 and 5 using OLS, and 6 and 7 using panel fixed effects, which are the most complete specifications.[20] We only present key results for maize in the main text. Full output results for all crops are reported in the Appendix. As in the previous section, we briefly comment results on rice, beans or groundnut only if they clearly differ from those for maize. Table 2.8 presents key results of models testing for proposition 4, including an interaction term between area cultivated and whether the crop is intercroped. Table 2.9 presents results of models testing for proposition 5, including an interaction term between area cultivated an whether the crop is the main crop on the plot. Table 2.10 reports results for models controlling for both propositions 4 and 5.

[20] Hence, we omit in this part of the analysis the most naive specifications: the benchmark model, the model only controlling for the imperfect market proposition (P1), and that only controlling for the omitted variable possibility (P2).

Controlling for the intercropping proposition

Table 2.8: Testing P4 for maize (land coefficients only)

	(1)	(2)	(3)	(4)
	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.180***	-0.302***	-0.571***	-0.622***
	(0.036)	(0.025)	(0.059)	(0.056)
Intercrop	-0.082**	-0.094***	-0.103*	-0.091*
	(0.036)	(0.034)	(0.054)	(0.052)
Area*Intercrop	-0.118***	-0.088***	-0.100**	-0.049
	(0.035)	(0.025)	(0.050)	(0.042)
N	3407	3407	3407	3407
R^2	0.31	0.40	0.29	0.32
Estimation	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	GPS	SR	GPS

Clustered standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Results in Tables 2.8 show that controlling for proposition 4 does not remove the IR for maize, although it weakens its magnitude. For example, in the OLS specification that jointly controls for propositions one and two, the IR is weakened by about 31% (the area coefficient is reduced in magnitude from -0.259 to -0.180). As expected, the interaction term is negative across all models (although it loses significance in the last panel specification). The stand alone dummy is still negative and significant. This suggests that productivity is generally lower when maize is intercropped *and* that the IR more pronounced. We still observe an increase in the magnitude of the IR when moving from self-reported measures to GPS ones, and from OLS to panel estimation.

The IR is also robust to the inclusion of the interaction term for rice, beans and groundnut. Results for rice are similar to maize in the sense that adding the interaction term reduces the mitigates the IR but does not remove it. For beans, although the interaction term is only significant in one model, its inclusion in the regressions weakens the coefficient on area in all specifications. In the case of groundnut, none of the intercation coefficients is significant, which is expected, since we did not find the dummy for intercropping to be significant in the original set of results.

To summarise, while accounting for the intercropping proposition is able to remove a sizeable part of the observed negative relationship in the case of maize and rice, we still observe negative and significant coefficients on area cultivated.

Controlling for the main crop proposition

We now consider the effect of including an interaction term between the area variable and the main crop dummy (proposition 5).

Table 2.9: Testing P5 for maize (land coefficients only)

	(1)	(2)	(3)	(4)
	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.421***	-0.479***	-0.851***	-0.868***
	(0.042)	(0.037)	(0.089)	(0.081)
Maincrop	0.297***	0.328***	0.227**	0.245***
	(0.047)	(0.045)	(0.092)	(0.093)
Area*Maincrop	0.196***	0.141***	0.253***	0.244***
	(0.041)	(0.037)	(0.087)	(0.077)
N	3407	3407	3407	3407
R^2	0.32	0.40	0.29	0.33
Estimation	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	GPS	SR	GPS

Clustered standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

For proposition 5, we expect the interaction term to be *positive* in sign, as opposed to proposition 4: yields of priority crops tend to be higher than those of secondary crops, on average. Hence, the interaction between area cultivated and the dummy for whether the crop is a main crop should pick up this positive effect of being a 'priority crop' (possibly reflected in higher effort level). The baseline coefficients on area should increase in absolute value (i.e., become more negative), reflecting a stronger relationship for secondary crops. To compute the IR for main crops, one must now add the baseline term and the interaction term.

Results confirm that the baseline coefficients are stronger in magnitude, while the interaction term is positive whenever significant. All interaction terms are significant for maize at the one percent level. For the most complete OLS model for maize (jointly controlling for propositions one to three), the magnitude of the IR for a main crop is: -

0.479+0.141=-0.338, which is close to the original coefficient of -0.358 in Table 2.4. The IR is much stronger for maize when it is treated as a secondary crop: a one percent increase in area cultivated is associated with a 0.48% decrease in yields. Similarly, while the IR in panel models is of similar magnitude for a main crop as in Table 2.4, it largely increases for secondary crops: a one percent increase in area cultivated results in a decrease in yields of about 0.86% in both panel specifications.

For rice, the interaction term is only significant in the OLS models. For beans, interaction terms are significant in both OLS models which suggests that the inverse relationship is largely overestimated for main crops when not accounting for their priority status. Finally, none of the interaction terms is significant for groundnut, for which the baseline area coefficients remain very close to those in Table 2.7. Given that the maincrop dummy is positive and significant in Table 2.7 in the OLS models, this implies that groundnut has a higher productivity when treated as a main crop, but that the IR itself is unaffected by whether it is a primary or secondary crop.

To sum up, results for maize suggest that the inverse relationship is underestimated whenever it is grown as a secondary crop, and overestimated whenever it is treated as priority crop. However, accounting for the priority of some crops over others does not remove the IR.

Jointly controlling for the intercropping and main crop propositions

Finally, we control for both interaction terms in the regressions: we allow the inverse relationship to be affected both by intercropping and the priority status of a crop.

Table 2.10: Testing P4 and P5 for maize (land coefficients only)

	(1)	(2)	(3)	(4)
	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.343***	-0.419***	-0.785***	-0.842***
	(0.053)	(0.043)	(0.103)	(0.091)
Intercrop	-0.080**	-0.093***	-0.100*	-0.081
	(0.035)	(0.034)	(0.053)	(0.052)
Area*Intercrop	-0.091***	-0.069***	-0.075	-0.031
	(0.035)	(0.026)	(0.051)	(0.043)
Maincrop	0.294***	0.325***	0.227**	0.243***
	(0.047)	(0.045)	(0.092)	(0.093)
Area*Maincrop	0.175***	0.121***	0.234***	0.237***
	(0.041)	(0.037)	(0.090)	(0.078)
N	3407	3407	3407	3407
R^2	0.32	0.40	0.29	0.33
Estimation	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	GPS	SR	GPS

Clustered standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Again, results unambiguously point towards the persistence of the IR: area coefficients are negative and highly significant in all models for all crops. However, the magnitude of the IR is substantially reduced when maize is both monocropped and treated as a priority crop. In the OLS model testing for propositions one and two, the original coefficient in Table 2.4 is -0.259. When accounting for both interaction terms, the relevant IR coefficient is now: -0.343+0.175=-0.168. Hence, we are explaining about 35% of the IR for monocropped maize when it is a priority crop. Similarly, we explain about 17% of the relationship in the OLS model using GPS measurements.

To summarise our results, we find that neither of the two new hypotheses we control for is able to remove the strong IR observed for all crops. Similar to our baseline re-

sults presented in section 4, we also find evidence of a greater magnitude of the IR when using GPS measured variables rather than self-reported, and that the magnitude of the relationship largely increases when moving from OLS to panel estimation.

2.6 Discussion and Conclusions

The aim of this study is threefold. First, we propose to introduce a new level of analysis in the literature on the IR. By focusing on a crop/plot level, we are able to enquire in greater detail about the issue of cultivated area, which represents an improvement over the plot level focus. Indeed, the latter omits from crop composition effects whenever more than one crop is grown and fails to account for the effect of intercropping on cultivated size and on yields. Hence, from a methodological perspective, this study tries to open the 'black-box' of size and show why and how this matters for the debate on the IR. Second, we control for the existing theoretical hypotheses that could explain the IR in this novel setup. Third, we control for two new hypotheses that could explain the IR. These can be tested only via a crop/plot focus, and hence have not formally been assessed yet in the literature (to the best of our knowledge).

Results show unambiguous support for the existence of an IR. We find that the existing propositions are not able to remove the observed IR. We further show the existence of several effects that are robust across crops: *(i)* the magnitude of the IR tends to increase when using GPS measurements rather than self-reported measures, *(ii)* the IR is robust -in fact, even stronger- when using panel fixed effects estimation, and *(iii)* the IR persists even when accounting for whether a crop is intercropped and/or is the main crop on a plot.

These results, however, are to be interpreted with caution when assessing whether an IR exists or not: they point towards the possibility of an IR within the specific context of Tanzanian agriculture, i.e., within a relatively narrow size distribution and in a situation of rain-fed small-scale agriculture. However, the inherent limitations of agricultural data (limited information on soil quality and measurement errors in size in particular) warrant caution. Perhaps the best message to take from this analysis is one of *constistency* in the results, by which we mean that the coefficient on area is significantly negative whatever the crop, specification and estimation procedure one looks at.

Given our results, we should reflect on why the IR persists at this new level of analysis and whether this could be due to empirical biases not explored. Recent research, although still very preliminary, has suggested that the IR could be driven by wrongly reported output by farmers (something we cannot test for in the LSMS data yet). By using precise cross-cuts and remote sensing estimates for maize plots in Uganda, Gourlay, Kilic and Lobell (2017) find that these 'objective' measures of output have a dramatic effect on the existence of an IR. However, remote sensing measures of output (just like GPS measures of size) depend on weather conditions and can be biased too. More importantly, their study only looks at maize in pure-stand context in a small part of Uganda. As we argue in this study, intercropping may play an important role, and focusing on pure-stand cases is not representative of farming practices for most smallholders (at least in the case of Tanzania). Hence, more research needs to be done before concluding that the IR is driven by reporting biases and data issues. Over the past fifteen years, the literature on the IR has largely focused on the empirical side of the debate, exploring how data biases and problematic estimation strategies could explain the IR. While this is of obvious importance, perhaps it would be beneficial to bring back theoretical arguments from political economy in the debate. By focusing exclusively on more and more precise and micro-level empirical approaches, there is a risk that the substance of the question gets lost. Alongside empirical developments, we could reconsider traditional political economy arguments to assess the validity and existence of the IR. For example, does structural poverty play a role? Are the poorest farmers with little bargaining power compelled to over-supply labour on their parcels of land? From an agrarian perspective, we also need to understand better the planting decision, which is a joint decision. Are crop mixes similar for small-scale and large-scale farmers? If not, studying the farming endeavour of different types of farmers could help us understand what the IR -if it persists- really entails for small-scale farmers.

This new focus at the crop/plot level pushes the research frontier towards new directions. In particular, it should be clear by now that more research on intercropping needs to be done to clearly understand farming practices in Tanzania. This study hints at in important effect of intercropping on yields but data limitations do not allow us to go further. What this does tell us, however, is that embracing a more holistic perspective on farming may be beneficial for the debate on the IR. In agrarian studies, farming is understood as a 'total concept' where one crop or plot cannot be understood in isolation from the

operating principles of the farm itself. From an empirical viewpoint, this opens a whole new set of possibilities for studying the IR. In particular, one possible research pathway lies in exploring more flexible ways to estimate production or yield functions. This in turn requires deeper knowledge of the agrarian and agronomic literatures to understand how different modes of farming can influence the presence (or absence) of an IR.

Chapter 3

Exploring Participation in Agricultural Markets

'The need for promoting smallholder market participation has been increasingly recognized in efforts to bring about agricultural transformation in developing countries' (Alene et al. 2008:318)

'Instead of facing the question of what one means by the concept of the "market" as an integral part of the price-quantity relations, neoclassical development theory tends to take the notion of the "market" for granted' (Bhaduri, 1986:267)

3.1 Introduction

The literature on output marketing in sub-Saharan Africa has been abundant over the past 20 years, and the push for greater market integration arguably became one of the main vehicles considered for poverty reduction in rural areas: 'Integrating traditional smallholder peasants into the exchange economy is therefore important for stimulating growth, economic development, food security and poverty alleviation.' (Heltberg and Tarp, 2002:104). The theoretical foundations of this literature rely on the imperfect (or missing) markets narrative, which posits that market failures inhibit farmers' response and push them towards subsistence (de Janvry *et al.*, 1991). This is usually considered within a framework that pays particular attention to transaction costs in rural economies (Key *et al.*, 2000).

Within this framework, overcoming market failures and facilitating market participation become key mechanisms to reduce poverty.

This paper argues that while understanding the determinants of output supply through the estimation of supply equations is important, the literature has largely ignored the study of the determinants of market participation itself. We argue this is partly a methodological concern: the concept of the market in standard theory promotes a rather abstract and homogeneous understanding of markets across time and space, unlike other traditions of thought, such as agrarian political economy. The narrative on market failures can be seen as pushing for a circular understanding of the nature of agricultural output markets: high transaction costs push farmers to opt out of the market, thus stressing their very failure. Instead, agrarian political economy does not assume an a priori commercial nature of those markets, nor does it make any assumptions regarding the possible profit-maximising endeavour of peasants. We propose to estimate the determinants of both participation and supply conditional on participation for a set of important crops in Tanzanian agriculture. Although we follow the conventional estimation methods in this literature (thus facilitating comparability with existing studies), we pay particular attention to the process of participation into the markets to enquire whether results points towards different structural features across markets. For each crop, we evaluate results in light of both standard theory and agrarian political economy theory and assess whether a given market seems to fit any of these approaches better.

Results show that the determinants of participation differ across markets. The markets for food crops and export crops seem relatively consistent with the concept of markets in standard economic theory. In particular, participation into those markets is partly driven by a positive effect of the shadow value of production: the higher the value, the more likely farmers are to enter those markets. In the case of food crops, we find evidence of expectation mechanisms driving the decision to participate: lagged values have a positive effect on participation. Food crops can be retained (and often are) for home consumption if not sold. Hence, high past prices can drive the decision to plant and market food crops, explaining the presence of price expectation mechanisms. Export crops, on the other hand, cannot be retained for home consumption.

Results for maize and cassava are very different in nature. The markets for these crops are characterised by *negative* price responsiveness. While these results can be conceptualised in terms of market failures, we argue in favour of an alternative explanation. Most farmers do not sell maize, and we claim negative price responsiveness reflects an increase in the shadow value of home consumption of maize, which tends to be preferred over cassava. For cassava, we argue results are consistent with distress sales and a forced commerce hypothesis, as developed in Skarstein (2005). Our results thus call for a flexible conception of agricultural markets: while the standard concept of markets relying on commercial motive and positive effects of prices on marketing seem a priori appropriate for some crops, other concept seem useful for other crops. We thus contribute to the existing literature by showing that the rationales for entering different agricultural markets vary, and that, as a result, a thorough study of the processes of participation is necessary.

The structure of this study is as follows: we first present the theoretical and empirical background on the topic by partly reproducing the seminal model of transaction costs by Key *et al.* (2000) and explaining how it has framed subsequent empirical research in terms of estimation strategies. We further argue that the literature has generally paid less attention to participation than supply in the market, and we take this issue in section three, in which we review how standard economic theory and agrarian political economy conceptualise the market differently. The estimation strategy is detailed in section four and key summary statistics and details on the data are presented in section five. Section six presents the empirical results. Section seven concludes.

3.2 Background and Methodological Issues

3.2.1 Theoretical background

The issues of market participation and output supply have traditionally been framed within the market failure narrative, particularly so in the context of developing rural economies. A seminal contribution to the theoretical literature on market failures in poor rural areas is de Janvry *et al.* (1991), which argues that market failures in rural economies are household specific. As market failures increase, the resulting price bands within which peasant households do not sell increase, thus reducing the likelihood for those households to enter the market: self-sufficiency becomes a more advantageous option than engaging

in the trading of factors (labour) or goods (agricultural output). These price bands are an increasing function of the gap between the price at which peasant households can sell factors or goods and that at which they can buy them. This framework was subsequently adapted into a theory of transaction costs in which heterogeneous market participation is conceptualised as a result of fixed and proportional transaction costs that affect households differently (Key *et al.*, 2000). This framework became a theoretical landmark in empirical studies concerned with the issue of market participation.

Key *et al.* (2000) develop a household model with transaction costs to explain market failures that push farmers to opt out of the market, which we partly reproduce below. It is households' relationship with these transaction costs which defines their market status. Hence, following de Janvry *et al.* (1991), market failures are considered as household specific. This implies that participation into the market can be treated as a choice variable. Under **proportional transaction costs (PTCs)**, the household cash constraint is:

$$\sum_{i=1}^{N}\Big((p_m^i - \underbrace{t_{pi}^s(z_t^s))\delta_i^s}_{\text{PTC}^{seller}} + (p_m^i + \underbrace{t_{pi}^b(z_t^b))\delta_i^b}_{\text{PTC}^{buyer}}\Big)m_i + T = 0 \tag{3.1}$$

where p_m^i is the market price for good i, m_i is the amount of good i marketed and T is an exogenous source of revenue. Subscripts s and b stand for seller and buyer respectively. Equation 1 shows that under PTCs, the usual cash constraint has to be modified to allow for an unobservable amount t_{pi}^s which will decrease the price received by a seller. Similarly, it has to allow for an unobservable amount t_{pi}^b which will increase the price paid by a buyer. Variables δ_i^s and δ_i^b are dummies that take the value of 1 and 0 or 0 and 1 for seller and buyer respectively.

Under **proportional and fixed transaction costs (PTCs and FTCs)** the cash constraint further modifies to:

$$\sum_{i=1}^{N}\Big((p_m^i - \underbrace{t_{pi}^s(z_t^s))\delta_i^s}_{\text{PTC}^{seller}} + (p_m^i + \underbrace{t_{pi}^b(z_t^b))\delta_i^b}_{\text{PTC}^{buyer}}\Big)m_i - \underbrace{t_{fi}^s(z_t^s)\delta_i^s}_{\text{FTC}^{seller}} - \underbrace{t_{fi}^b(z_t^b)\delta_i^b}_{\text{FTC}^{buyer}} + T = 0 \tag{3.2}$$

where, independently of the quantity marketed, the household now incurs fixed costs $t_{fi}^s(z_t^s)$ and $t_{fi}^b(z_t^b)$ for sellers and buyers respectively that affect participation into the market.

Solving the household model with this cash constraint leads to a set of decision prices under the three possible regimes:

$$p_i = \begin{cases} p_i^m - t_{pi}^s & \text{if } m_i > 0 \text{ (seller)} \\ p_i^m + t_{pi}^b & \text{if } m_i < 0 \text{ (buyer)} \\ \tilde{p_i} = \frac{\mu_i}{\lambda} & \text{if } m_i = 0 \text{ (autarkic)} \end{cases} \tag{3.3}$$

Equation 3 states that a seller will receive the market price minus amount t_{pi}^s and a buyer will pay a price greater than the market price by amount t_{pi}^b. In case of self-sufficiency, the price is a shadow price defined as the ratio between the Lagrange multiplier from the resource constraint (μ_i) and that from the cash constraint (λ).

Under FTCs and PTCs, there will be switch decision prices, at which the household is indifferent between selling and self-sufficiency in good i, and another at which it is indifferent between self-sufficiency and buying. This defines an 'optimal path' to follow for the household. The supply curve under the three possible regimes is then expressed as:

$$\begin{cases} q^s = q(p^m - t_p^s, z^q) & \text{(seller)} \\ q^b = q(p^m + t_p^b, z^q) & \text{(buyer)} \\ q^a = q(\tilde{p}, z^q) & \text{(autakic)} \end{cases} \tag{3.4}$$

where z^q is an exogenous shifter in productivity. As equation 4 shows, FTCs do *not* affect the quantity supplied of a good once the participation decision has been made. Although FTCs do not affect the supply curve as such, they 'delay' entry in the market by further decreasing the price at which a household buys good i and increase the price at which it sells good i. In other words, they extend the domain over which autarky prevails.

This theoretical framework had a large influence on empirical studies looking at market participation in developing countries. By stipulating that some costs typically affect participation while others typically affect both participation and intensity of supply, it has led to a large number of econometric applications using either truncated or censored data models.

3.2.2 Literature and empirical applications

The theoretical model briefly described above implies that variables affecting participation and intensity are not the same (though there may be overlaps). Heltberg and Tarp (2002) is a landmark study in the empirical application of this theoretical framework. Their paper was the first we are aware of to take this theory to the data to study market participation in Mozambique. To capture FTCs, they use a dummy for radio, TV or telephone ownership, the education level of the head of household and the district population density. These are thought to capture access to information, ability to make use of that information and access to networks, i.e., they are proxies for unobservable fixed costs affecting the decision to participate in the market. For PTCs, they use a dummy for ownership of a means of transport, the log of distance to the nearest railway station and that to the provincial capital.

Alene *et al.* (2008) follow a similar strategy, and define the difference between FTCs and PTCs as follows: 'In general, while information variables are expected to determine FTCs, measures of distance and transport are expected to determine PTCs' (2008:320). Their paper looks into the determinants of maize marketing for smallholder farmers in Kenya. Both Heltberg and Tarp (2000) and Alene *et al.* (2008) adapt the theory of transaction cost into an empirical analysis using Heckman selection model, thereby treating the participation decision into the market as a selection process. It is now widely accepted that to perform well, Heckman models need strong candidates to fulfil the exclusion restriction criteria (see for example Puhani (2000), or Madden (2008) on theoretical requirements of Heckman models). In this context, both papers logically use the variables capturing FTCs as exclusion restrictions, which only affect the participation decision into the market, but not the quantity supplied conditional on participation.

There is, however, an ambiguity regarding which estimation strategy should be used: it is not obvious whether a Heckman selection model or a slightly simpler two-part model (henceforth TPM) should be favoured. While Heltberg and Tarp (2002) or Alene *et al.* (2008) favour Heckman procedures, other papers stress the tension regarding the empirical method to follow that arises from the treatment given to the zero observations (no market sales). For example, Handschuch and Wollini (2015), studying the marketing of finger millet in Kenya, acknowledge that the choice of method is not obvious. Therefore, while

their preferred specification is a TPM, they also estimate a Heckman model for robustness purposes. Olwande *et al.* (2015), in a study of maize, kale and dairy marketing in Kenya argue that the use of Heckman models is not adequate to study market participation because it is not consistent with treating participation as a discrete household choice as implied by the theoretical narrative on market failures: 'The Heckman model fits poorly with our conceptual approach, and our data collection process, in which we have treated both aspects of market participation (entry and quantity) as a choice variable that results from farm production, and the zero quantities are not the outcome of a latent, unobserved decision' (2015:24).

There is a large body of theoretical econometric literature about the respective merits and weaknesses of TPMs and Heckman models. One criterion of choice between the two estimation strategies is whether one wants to model actual or potential outcomes. To model the former, TPMs should be favoured, while Heckman is more suited to the latter (Madden, 2008). In the context of agricultural output marketing, there is no clear-cut answer, because the extent to which a positive latent market supply exists for a self-sufficient household is hard to estimate. It is also commonly accepted that the performance of Heckman models may be seriously undermined when exclusion restrictions are weak, creating problems of heavy collinearity among regressors and causing the Inverse Mills Ratio to be linear over a large range of observations (see Leung and Yu (1996); Puhani (2000) or Madden (2008) for a thorough treatment). In practice, Monte Carlo simulations have shown that very often the predictive power of a TPM is as good as that of a Heckman, and that it is precisely when censoring is high and Heckman models are justified that their performance is most problematic (Puhani, 2000).

Despite the existing tension regarding which method to favour, most of the literature has relied on either one method or the other without really making explicit why. Often, studies using Heckman models have not assessed in detail the validity of their estimation strategy. For example, in the Heckman models estimated in Heltberg and Tarp (2002), the selection parameter is significant for the 'all crops' and 'cash crops' models, but not for the 'food crops' one. The exclusion restrictions (variables proxying FTCs) are not significant, except for a positive effect of the education level of the head of household in one of three models. This implies that either selection is not always an issue, and hence

Heckman models should not systematically be used, or that the model is misspecified, thereby undermining the validity of their results. In Alene *et al.* (2008), the selection parameter in the supply equation is only significant at the 10% level. Further, the paper explicitly commits to a focus on actual, rather than potential outcomes, which calls for a TPM estimation rather than a Heckman one, as explained in the econometric literature.

In their study of market participation in Mozambique, Heltberg and Tarp (2002) find that maize prices have no effect on participation nor intensity, but that groundnut prices do have an effect on intensity, which could reveal the commercial nature of groundnut -usually considered a cash crop- and the more subsistence nature of maize. Regarding the effects of proportional transaction costs, they find that the distance to the provincial capital has a *positive* and significant effect on the quantity supplied. Although this result seems at first counter-intuitive, they interpret it as an effect of better off-farm employment in the capital city. Alene *et al.* (2008) study the determinants of marketing for maize in Kenya and find that female headed households are more likely to market the crop. In terms of price effects, one of their key findings is that maize price does not influence participation but has a positive and significant effect on quantity supplied. This effect is considered to be consistent with the fact that many households invariably sell after their harvest in order to satisfy cash needs. Also studying the agricultural sector in Kenya, Handschuch and Wollini (2015) study the marketing of finger millet, a cereal still widely grown despite the predominance achieved by maize in the country. They find that poorest households are more likely to participate in the market for finger millet, potentially because it is easier to 'break' into this market than markets for other crops. Olwande *et al.* (2015) also focus on Kenya and study the marketing of maize, kale and dairy products. They find higher participation rates for kale and milk than for maize, which, although not interpreted this way in the paper, could be due to households aiming at achieving self-sufficiency in maize which is a key component of local diets.

However, while all the studies we have cited use an estimation procedure that accounts for the fact that a large portion of farmers do not sell their crops, we argue that the attention given to the process of selection is largely 'instrumental'. We develop this point in the next section.

3.3 A Focus on Market Participation

3.3.1 Market participation and market failures in standard theory

By arguing that transaction costs inhibit farmers' participation in the market and create imperfect markets, the literature implicitly follows the normative commitment that selling output on the market is a better alternative than home consumption (or any other form of economic exchange). Standard economic theory assumes that market participation is a desirable outcome and assumes a rather homogeneous market structure across space and contexts. As such, it is commonly held that market participation is a key factor in poverty reduction and that policies must aim at mitigating market failures. The following quotes summarise well this view:

> 'The need for promoting smallholder market participation has been increasingly recognized in efforts to bring about agricultural transformation in developing countries' (Alene *et al.* 2008:318)

> 'For agrarian households, whose primary activity is crop production, the ability to participate in agricultural markets especially as net sellers of crop produce is a strong indicator of the potential for achieving economic progress' (Marenya *et al.* 2017:1)

These quotes are good examples of the commonly held view in standard economic theory that output commercialisation, *regardless of the type of market entered*, contributes to poverty reduction and development in poor countries. This in turn comes from theoretical models of rural households in which farmers are assumed to be profit maximising (and where the family unit is often considered as efficient). Following these models, under the perfect case of separability between consumption and production decisions, farmers would grow crops which maximise their profits and derive their income and livelihood from market exchanges. Whenever market failures prevail, these decisions are no longer separable (Singh *et al.* 1986) and policies considered appropriate for development are policies that mitigate market failures. This theoretical approach thus assumes that peasants endeavour profit maximisation and treat the market as a rather abstract concept that is relevant across contexts.[1]

[1] A literature on 'perverse supply response' in agriculture exists, but its aim is more to acknowledge deviations from the perfect market case than to propose new theoretical departures. For a (now rather dated) survey of the historical developments in this literature, see Ozanne (1999).

From an empirical perspective, commitment to the narrative just outlined means that the process of selection is acknowledged but is usually treated as a necessary step before moving to the estimation of supply equations. In other words, it is only given importance to the extent that it corrects for a deviation from the perfect market theoretical case (in econometrics terms, to the extent that it corrects for selection). For example, Heltberg and Tarp (2002) find that in Mozambique, the price of maize has no effect on selection into the maize market and that the price of groundnuts (a cash crop) has no effect on selection into the cash crops market. Their treatment of this result, which is clearly at odds with standard theory predicting positive effect of prices, is that the price data is not good enough: 'too much emphasis should not be put on these results' (Heltberg and Tarp, 2002:111). While it is clear that cross-sectional price data is problematic, this is nevertheless an example of how a methodological commitment to the ideal of perfect market and peasants' profit maximisation effectively rules out an alternative understanding of the process of selection and the role of prices in it.

However, standard theory has largely evolved in the past two decades, mainly under the influence of new-institutional economics. While the normative aim of entering the market and generate poverty reduction via commercialisation still prevails, the literature has gradually come to accept several key facts about rural peasantries that need to be accounted for, and has incorporated them into a modified theory that emphasizes incomplete markets, prevalence of uncertainty for farmers and importance of transaction costs (Jan and Harris-White, 2012). For example, it is now generally acknowledged that price increases often hurt the majority of (small) farmers because these are typically net buyers of a crop over the course of a year (Barrett (2008), Jayne *et al.* (2010), Marenya *et al.* (2017)). As such, price increases would only be beneficial to the largest and most commercial farmers: 'policy makers and many development researchers continue to discuss development policy for rural Africa as if all farmers were net sellers of the crops they produce and thus stood to benefit from increased prices. The evidence against that popular belief is by now overwhelming' (Barrett, 2008:307). Similarly, it is no longer assumed that autarky is a characteristic of the poorest households: 'Autarky is not the domain of the

[2]This has, however, long been acknowledged in agrarian political economy. See for example Deere and de Janvry (1979) and their study of Peruvian peasantries: 'Only the middle peasants exhibit any important degree of self-sufficiency' (1979:606).

poorest, but rather an option only for those with adequate resources to disengage from the market when transaction costs and the risk associated with commercial exchange prove too great' (2008:308).[2] Recent developments in standard theory have thus somewhat loosened the level of abstraction and rigidity in the concept of markets by incorporating into the theory key stylised facts at odds with neo-classical theory. However, the normative commitment to the market as a superior form of economic activity prevails, and hence implicitly rules out alternative understandings of the process of participation. Consider for example the study on maize marketing in Kenya by Renkow *et al.* (2004) who also frame the issue of market participation in a theory of fixed and proportional transaction costs. In their conclusion, they state that: 'Our empirical results support a generally held belief that transactions costs are a significant deterrent to market participation by agricultural households. This, by itself, is not surprising, and c*an be inferred by simply noting the substantial number of households in our sample that neither purchased nor sold maize*.' (Renkow *et al.*, 2004:364, emphasis added). This is an example of circular reasoning: by trying to show that transaction costs inhibit participation, they argue that failure to observe participation proves the existence of transaction costs. Other literatures, such as agrarian political economy, explore more flexible ways to enquire into the rationales for entering agricultural markets.

3.3.2 The conception of markets in agrarian political economy

The issue of market participation and output marketing has also received heavy attention in agrarian political economy. In many instances, assessments are quite close in spirit to what modified standard theory insists on (see quotes by Barrett above), but the causes invoked and the theoretical framework used are very different. Crucially, the issue of power is given full importance in the mechanics of market participation in this literature. We focus on this difference to compare agrarian political economy and standard economic theory.

Skarstein's description of a forced commerce hypothesis in maize marketing in Tanzania (see Skarstein 2005, 2010) shares the view with orthodox economists such as Barrett that price increases are likely to hurt small farmers who are net buyers over the course of the year. However, such dynamics are grounded in political economy considerations of power and subordination: 'For lack of money as well as storing facilities -in other words *because of their poverty*- many smallholders, among them a large number of deficit producers, sell

so much of their crop (at low prices) at harvesting time that they do not have enough food grain until the next harvest. Later on they therefore have to buy food grain (at high prices) -often with expensive credit- in order to survive' (Skarstein, 2005:357, emphasis added). According to White (1993), a distinction must be made between *behavioural power* and *structural power*. One could argue that standard and modified-standard economic theories tend to over-rely on the notion of behavioural power, which 'tends to take the initial endowments of power resources of each agent as given and is not concerned to inquire whence they came' (White, 1993:5). Accounting for notions of structural power, on the other hand, calls for a wider structural analysis that analyses how and why 'each real market is a patterned set of social relations' (White, 1993:5). This view of markets, often coined 'real markets' studies, is in sharp contrast with the more abstract view of markets in standard (and modified standard) theory: 'When markets are stylised like this [in neoclassical fashion], the question of whether a given market is efficient reduces -*as a corollary of the method*- to the question of how competitive that market is - and thus to the degree to which it conforms to the neoclassical ideal of perfect competition' (Jan and Harris-White, 2012:41, emphasis added). Agrarian political economy emphasises that markets are historically and culturally contingent structures (Bhaduri, 1986), and selection can be conceptualised in many different ways depending on the specific context one is looking at. In Tanzania, for example, maize is a crucial contributor to diets in many regions. As such, trade in maize may not be voluntary and reflect instead possible economic distress and cash needs. Further, there are clear crop inter-dependencies. A household may retain maize in order to ensure a given supply of food, and once this supply is satisfied it may grow other crops with a specific profit making motive for these crops only. Complex crop mixes are another reason why the process of selection should not be overlooked. Typically, farmers in sub-Saharan Africa are engaged in a mix of cash and subsistence crops, as well as export crops in certain regions. The publication of ever more precise agricultural data at the crop level makes it possible to disentangle the different reasons a farmer may enter the market for a given crop but not for another.

Therefore, a more flexible conception of agricultural markets must give full attention not only to the supply equations but to the processes of participation themselves. By giving equal weight to the processes of selection and that of supply conditional on it, our approach is driven by the view that a methodological commitment to conceptualising markets as

homogeneous institutional structures driven by profit motives is misguided, which does not mean that it does not exist (and indeed, it may well exist within a given structure contingency). Rather, it suggests that different types of selection processes may co-exist and tell us more about the nature of agricultural marketing.

3.4 Estimation strategy

Our empirical strategy is based on the estimation of two-part models. The process of participation into the market for a given crop is modelled via the estimation of a Probit model. We then estimate supply equations with OLS models, using subsamples made of sellers only. Although close in spirit to Heckman models, two-part models are different in the sense that the OLS regressions do not incorporate a selection parameter (as explained below, we also esimtate Heckman models for robustness purposes but they are not part of the main analysis). Following the empirical literature on output marketing, we use proxies for fixed transaction costs in the participation equations only. Fixed transaction costs are supposed to affect the decision to sell only and not the amount supplied, unlike proportional transaction costs, which have a direct effect on quantity sold. Formally, the participation equation is given by:

$$\begin{aligned} P(Entry = 1|X) = \Phi(\alpha + \boldsymbol{\beta_1 FTC_j} + \boldsymbol{\beta_2 PTC_j} + \beta_3 ln(Harvest)_{ij} + \beta_4 ln(Price)_{ij} \\ + \boldsymbol{\beta_5 HH_j} + \boldsymbol{\beta_6 Nutrition_j} + \beta_7 Farm_j + \boldsymbol{\varphi Sales_j} + \boldsymbol{\delta Zones_j}) \end{aligned} \tag{3.5}$$

where $\Phi(.)$ is the standard normal distribution function. Conditional on selection, quantity supplied of crop i by household j is then:

$$\begin{aligned} E(Supply_{ij}|Supply_{ij} > 0) = \phi + \boldsymbol{\gamma_1 PTC_j} + \gamma_2 ln(Harvest)_{ij} + \gamma_3 ln(Price)_{ij} + \boldsymbol{\gamma_4 HH_j} \\ + \boldsymbol{\gamma_5 Nutrition_j} + \gamma_6 Farm_j + \boldsymbol{\theta Sales_j} + \boldsymbol{\delta Zone_j} + \varepsilon_{ij} \end{aligned} \tag{3.6}$$

We estimate the participation and supply decisions for each wave of data using cross-sectional analysis. Although the data could be pooled and time dummies included in the pooled regressions, looking at each wave separately is more suited to our research question. The whole idea behind this study is based on the consideration that a homogeneous and socially disembedded concept of markets blurs the specific dynamics associated with

the trading of each crop. Although time dummies in a pooled regression would pick up specific time effects, this is arguably not enough to understand the year-specific dynamics of markets. Our analysis also calls for a crop-level estimation: only by looking at a given crop at a given time can we understand the factors driving participation and supply.

To model participation (equation 5), we follow Heltberg and Tarp (2002) and use ownership of a radio and the education level of the head of household as variables capturing fixed transaction costs.[3] The ownership of a radio is meant to capture access to information about prices, traders and markets. In the missing market framework, access to information is key to make an informed decision on selling. Similarly, the education level of the household is considered a proxy for the ability to process relevant information. We express education as a set of three dummies. The first takes the value of one if the head has not completed primary school. The second takes the value of one if he/she has completed primary school, and the third takes the value of one if he/she has completed secondary school or more.[4] The vector of proportional transaction costs is made of a dummy taking the value of one if the household owns a means of transportation, as well as the average distance from the household's plots to the nearest marketplace (in logs).

The harvest variable captures the total harvest of a crop across all plots on which it is grown, measured in kilograms (similarly, the dependent variable in equation 6 captures total sales across all plots). The price variable is the price per kilogram at which a sale was made. Whenever a household does not market a crop, we use the the average village price as a proxy (when there are not enough observations at the village level we use the district average instead). However, because the food and export crops categories are made of nine crops each, we slightly change the estimation strategy for these. While we can use both harvest and price in maize and cassava regressions, doing so for categories of crops is problematic.[5] For food and export crops we use instead the value of production (harvest times price). Because the resulting variable is a monetary value, it can then easily be compared across crops within a given category.

[3]However, we do not possess the population density at the district level and cannot include it as an exclusion restriction.

[4]Only 20 heads in our sample have gone into tertiary education, so that creating a category 'secondary education or more' is justified.

[5]For example, comparing price and harvest of cloves and coffee has very limited relevance, even though both qualify as export crops.

The vector of household related controls is made up of the following variables: the dependency ratio, a dummy taking the value of one if the head of the household is female, and the age of the head (in logs). The female dummy is not included in Heltberg and Tarp (2002). However, it is plausible to assume that the gender of the head of household has an effect on both participation and supply decisions. In some regions, for example, female headed households are those headed by a widow. As such, the household may possess less resources than their male-headed counterparts, which can influence the degree of subsistence. The dependency ratio is expected to influence participation and supply to the extent it captures the weight of non-working age individuals in a household.[6] Intuitively, the higher the number of dependants, the higher the likelihood of a household retaining a greater share of its production.

We depart from the existing literature by adding a vector of two nutrition related variables. Although dietary considerations have an obvious effect on the decision to sell and the amount sold, such variables have generally been ignored in studies on output marketing. Many households aim at achieving self-sufficiency in a given crop (for instance maize or cassava, which constitute the backbone of diets) but not in others (food crops being a good example). Households may want to achieve a minimum nutritional bundle before deciding to enter the market and sell any surplus that exceeds this bundle. However, using nutritional variables at the household level would lead to potential endogeneity biases: nutritional variables are likely to correlate with unobserved household level variables affecting participation. As a result, we take the average of the variables at the district level. Doing so removes the concern for endogeneity while capturing the specificities of local environments. The first variable is the nutritional contribution of a given crop to households' diet. This variable is useful in identifying subsistence or semi subsistence households which rely heavily on staple food such as maize. It was calculated by computing the total calorific values of households' diets over a reference period using food composition tables, and then obtaining the share of this value coming from any given crop. The second nutrition variable is the household dietary diversity score (HDDS). This index is a categorical variable ranging from zero to 12. A household scores a category whenever any food within this category is consumed by the household during the reference period, no matter the quantity. This is used as a measure of dietary diversity and

[6]The dependency ratio is defined as the ratio of non- working age adults (younger than 16 or older than 65) to the total number of persons in the household.

as a proxy for nutritional status (Kennedy *et al.*, 2011; Jones *et al.*, 2014). To compute this variable, every food item consumed by the household over the reference period was put into one of the 12 categories before counting how many categories were scored. We use this vector of nutritional variables for all crops.[7] The variable $Farm_j$ is measured in acres and represents total cultivated area in a given year.

Because planting and marketing decisions for crops are not independent at the household level, it is important to account for crop mixes when looking at the marketing of a given crop. Therefore, we also include a vector of dummies to capture this dimension. The vector $Sales_j$ captures whether the household is a seller of any other crop than the one marketed. For example, when estimating marketing decisions for maize, we account for whether the household is also a marketer of cassava, food crops and export crops.[8]

Finally we include a vector of agro-ecological zones fixed effects, which helps accounting for the large climatic heterogeneity in Tanzania. Six agro-ecological zones are found in the country: tropic-warm/semiarid, tropic-warm/subhumid, tropic-warm/humid, tropic-cool/semiarid, tropic-cool/subhumid and tropic-cool/humid.

Despite the criticisms discussed with respect to the performance of Heckman selection models, one could still argue that there is a potential issue of selection bias into marketing, and hence that selection models are more appropriate. We address this concern together with other robustness checks in a specific sub-section after presenting the main results.

3.5 Data and Summary Statistics

The data used in this study comes from the Tanzanian National Panel Surveys (NPS) for the years 2008/2009, 2010/2011 and 2012/2013, referred to as waves one to three. This is the same dataset used for the study on the inverse relationship between area cultivated and productivity in the first essay. We first present basic information on the different

[7] The only exception to this is export crops, for which we cannot use the variable on average contribution to diet because most export crops do not form part of diets. Hence, we only use the HDDS variable for export crops.

[8] We have also considered a vector of production dummies in addition to the vector of sales dummies. However, we do not include it in the analysis because it does not impact the results in any way and uses up three additional degrees of freedom in the regressions. See section 3.6.5. on robustness checks.

crops studied, followed by statistics on households.

3.5.1 Crop statistics

Table 3.1 presents statistics at the crop level for the pooled data for maize and cassava. Our analysis also includes food crops (non-staples) and export crops but because each of these categories contains nine crops, we report information for these in the appendix. Food crops are crops that are typically partly consumed and partly sold. Although a commercial endeavour tends to be attached to them, we name them food crops rather than cash crops to avoid confusion with export crops (which are full cash crops). Our food crops category includes: sweet potatoes, Irish potatoes, beans, cowpeas, pigeon peas, Bambara groundnut, sunflower, groundnut and sugar cane. Our export crops category includes: simsim, cashew nuts, cotton, sisal, coffee, tea, cocoa, cardamom and cloves. The first variable in

Table 3.1: Summary statistics for maize and cassava

	Maize		Cassava	
	mean	sd	mean	sd
Contribution to diet (%)	35.3	26.0	19.4	22.8
Harvest (kg)	599	765	491	1251
Price (Tshs/kg)	344	182	419	548
Sales (kg)	133	374	93	372
Sales (Tshs 1000s)	43	160	22	91
N	4047		1776	

Table 3.1 reports the average contribution to households' diet of each crop.[9] The table shows that maize is a key contributor to households' diets in Tanzania, with an average contribution of more than 35%. This is highly consistent with estimates of the contribution of maize to calorific intakes for Tanzania reported in Ardnt *et al.* (2012). Note however that the standard deviation is quite large, reflecting the fact that in some regions, other staples are available and form the backbone of diets. One such staple food is cassava, which is also a key contributor to diets, with an average contribution of just below 20%. This is therefore a preliminary indicator of the subsistence -or semi subsistence- character or these crops. In terms of physical production of the crop, maize has the highest average

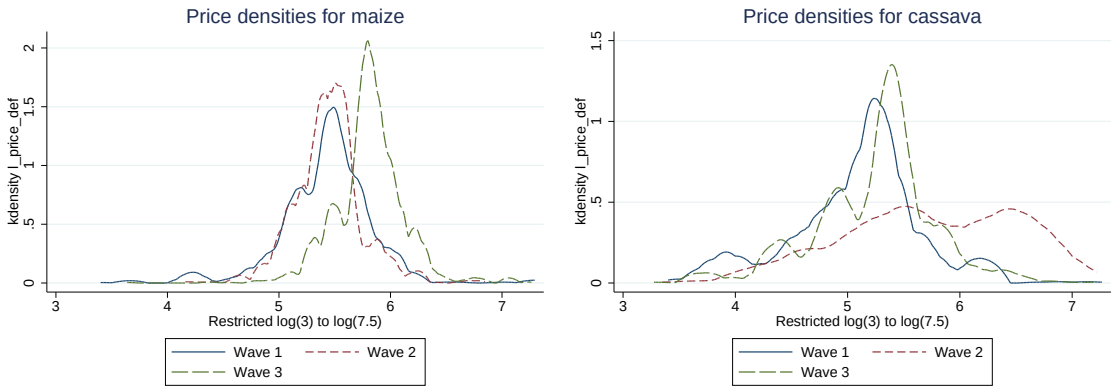
[9]More precisely, it measures their contribution to calorific intake, where we take calorific intake to be a proxy for diet. This is obviously limited for the quality of a diet does not boil down to calorific intake but it is sufficient as a rough proxy for our analysis.

around 600 kg. Out of this, 133 kg are on average sold. Therefore, these statistics show that maize is largely retained for home consumption, with an average marketing surplus of 22% only $((133 * 100)/599)$. Cassava has an even lower marketing rate of 19%. Note that cassava has an average price unexpectedly higher than for maize. However, this is due to a very high selling price in the second wave of data for cassava, which is picked up by the high standard deviation.

Food crops tend to have a much lower contribution to diets (see Table C.1 in Appendix), between around 6 and 9%. Harvests are also much lower, with the exception of sweet and Irish potatoes. Average prices for food crops are relatively heterogeneous: prices are low for Irish and sweet potatoes at around 250 Tshs/kg, but much higher for legumes. For example, beans have an average selling price of 755 Tshs/kg. The proportion of output sold also varies across food crops. For export crops, the proportion of harvest sold is, as expected, very high for all crops. Cardamom and cloves have the highest average selling price. The total value of sales for export crops is much larger than for maize, cassava or food crops (see Table C.2 in Appendix).

Table 3.1 presents pooled results and hence does not capture important differences between different waves of data. Figure 3.1 reproduces superimposed kernel densities of prices for maize and cassava (densities for food crops and export crops are not reproduced due to heterogeneity present in each category). To account for possible inflation, prices in the second and third waves have been deflated.[10] Price distributions for maize are fairly close to each other for waves one and two with a mean of about log(5.5) (approximately 245Tshs/kg), but the distribution for wave three is characterised by a higher mean just below log(6) (approximately 400 Tshs/kg). Given that prices have been deflated, the shift in the distribution for the third wave suggests a real price increase for maize. The variances of these price distributions are lower than for cassava. For the latter, it is striking to see how different the price distribution is in the second wave of data compared to the first and third waves. While distributions for waves one and three are relatively clearly centred around the mean, wave two is not. Instead one could argue the distribution is close to being bimodal. One possible reason is the occurrence of drought in several regions between

[10]Because the CPI index for Tanzania is usually considered to be of poor quality, we use instead the exchange rate with US dollars. The exchange rate values were obtained from the World Bank databank. Since each wave of data runs over two years (2008/09 etc.), we take the average over two years of each yearly average exchange rate.



(a) Maize (b) Cassava

Figure 3.1: Deflated price distributions for maize and cassava

2009 and 2011 which may have caused scarcity for other crops, triggering an increase in the price of cassava (cassava is drought resistant and very easily storable).

3.5.2 Household statistics

Summary statistics regarding household characteristics for the pooled sample are presented in Table 3.2.

Table 3.2: Summary statistics at the household level

	mean	sd	min	max
Dependency ratio	52.53	22.64	0.00	100.00
Female head (0/1)	0.24	N=1281	0.00	1.00
Age of head	49.15	15.76	19.00	105.00
Distance to market town	9.61	12.88	0.00	133.00
Transport ownership (0/1)	0.49	N=2614	0.00	1.00
Radio ownership (0/1)	0.60	N=3209	0.00	1.00
Diversity score [0-12]	8.16	1.93	2.00	12.00
N	5130			

About a quarter of households in the data are female-headed. The average age of a head of household is 49 years.[11] The distance variable is defined as the average plot distance to the nearest market (in km). Its average value is quite high at almost 10 km. However, many farmers sell at the farm or to friends/relatives, so that it is not (always) necessary

[11]The maximum age for a head of household is 105 years, which may appear surprising, but there is

to access the market to sell.[12] About half the households own a means of transportation (defined as ownership of at least one of the following: bike, motorbike or car), and 60% of them own a radio. In terms of access to varied diets, the average Household Dietary Diversity Score (HDDS) is slightly above 8. The minimum value of 2 for this variable suggests the presence of very poor and monotonous diets for some households. On the other hand, the maximum value is 12, which is the highest possible value for the HDDS. We use district averages of HDDS to capture the local nutritional environments and their possible effect on the decision to enter the market for a particular crop, together with the contribution of any given crop to the household's diet presented in Table 3.1.

Finally, we report the proportion of households not entering any of the four output markets studied in this chapter (maize, cassava, food crops and export crops). This is therefore a measure of autarky in our sample. In the first wave, the proportion of farmers not entering any of the four markets is 43%. It is higher in wave 2, at 46%. In wave three, the proportion decreases to 38%. The difference in these proportions across years suggests that participation and autarky are fluid concepts. There are a few important differences across those two subgroups. For example, the head of household is on average slightly older in autarkic households than in households entering any market (50.8 years old for the former, 47.8 for the latter). Similarly, female-headed households are more likely to be autarkic (27% of autarkic female-headed households versus 22% for male-headed ones).[13] For other variables, such as owning a radio or the average household dietary diversity score, the differences in means are not significant.

3.6 Empirical Results

We report results of estimation of two-part models at the crop level in Tables 3.3 to 3.6. Since the participation decision is modelled via a Probit model, coefficients cannot be interpreted as marginal effects. Therefore, we present average marginal effects in the output tables. We estimate average marginal effects rather than marginal effects at the mean since the former provide more realistic measures, especially for dummy variables (Bartus, 2005).

nothing in the data to suggest this is a coding issue.

[12] This was verified during the fieldwork conducted for the last essay. For many crops, the presence of a physical marketplace is not crucial for sales.

[13] The difference in means is statistically significant at the 5% level.

Note that for the education variable, the omitted category is 'not completed primary school', and we report dummies for having completed primary education and having completed secondary education. In all regressions, we use deflated prices to account for the possible impact of inflation on the results.

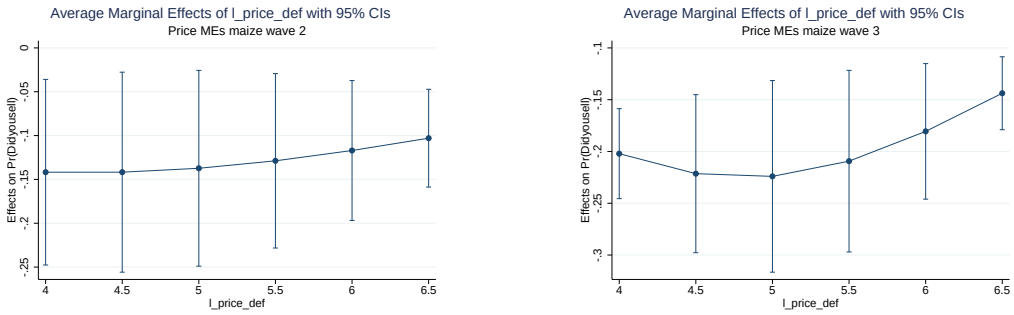
3.6.1 Maize

As can be seen from Table 3.3, the samples for maize are much larger for the participation equation than for the supply one: only about 30% of households market the crop in each wave. This indicates widespread autarky in maize, which further justifies the idea that the participation process must be given full attention.

The most striking result is the consistently negative effect of prices on participation into the market (significant in waves two and three), and their insignificant effect on quantity supplied. This is a priori counter-intuitive, as standard economic theory posits that output responds positively to an increase in price. Although both maize and cassava are key crops in local diets, maize tends to be preferred to cassava in terms of consumption by farmers in Tanzania.[14] As such, an increase in the selling price of maize raises the shadow value of home consumption, which explains the negative coefficients in the participation equations. Further, this is also consistent with the idea that poor farmers are often *net buyers* of a crop over the course of the year, so that price increases are likely to hurt a majority of farmers who are sellers of the crop, despite being net buyers (Barrett, 2008). Conditional on entering the market, supply is largely driven by harvest and the price coefficients are insignificant. Our results are not entirely consistent with the forced commerce hypothesis developed by Skarstein (2005, 2010) because he argues that farmers are compelled to sell their output at low prices after harvest to generate cash needed for household expenditures. However, they are consistent with the idea that trade in maize is not commercial in nature, and that price increases are likely to hurt small-scale farmers.

To examine in greater detail the effect of price on the participation decision, we plot average marginal effects of price at different price levels for waves two and three.
All marginal effects invariably negatively affect participation. In wave two the probability of not entering the market slightly decreases in magnitude as price increases. In wave three,

[14] In particular, *ugali* made with processed maize is much more valued that *ugali* made with processed cassava.



(a) Wave 2

(b) Wave 3

Figure 3.2: AMEs of price on participation in maize market at different price levels

for farmers facing low unit prices, marginal effects of prices further increase the probability to be autarkic until ln(5). The basic insight from these graphs is that marginal effects of price remain significant and negative across a large distribution of prices.

Another interesting result is the effect of farm size: while it has no significant effect on participation, it has a consistently positive and strong effect on supply, particularly so in wave two (in which a one percent increase in farm size leads to a 0.3% increase in supply). This corroborates the idea that farm size does not matter for 'breaking into the market'. Hence, the idea that commercialisation and small scale farming are negatively correlated seems misguided here. Farm size only matters in determining the quantity supplied. Conditional on being maize marketers, bigger farms will be likely to market higher amounts of the crop.

The dummy for female-headed households does not have a consistent effect across time in the participation decision. However, conditional on market entry, female headed households tend to supply less. This may capture lack of resources in female-headed households. Finally, note that the level of education of the head of household has no effect on participation in the market. This implies that no particular ability to process information captured by the level of education is required to supply maize. This is plausible, given that sales most often happen within the village, which does not require any particular commercial skills or ability.

Table 3.3: Maize: two-part models

	Participation equation			Supply equation		
	Wave 1	Wave 2	Wave 3	Wave 1	Wave 2	Wave 3
Price	-0.046	-0.128**	-0.187***	0.025	0.065	-0.039
	(0.033)	(0.050)	(0.036)	(0.145)	(0.106)	(0.101)
Harvest	0.135***	0.139***	0.138***	0.554***	0.469***	0.597***
	(0.012)	(0.012)	(0.009)	(0.061)	(0.052)	(0.052)
Farm size	-0.019	0.028*	0.018	0.199***	0.301***	0.180***
	(0.015)	(0.016)	(0.012)	(0.065)	(0.063)	(0.056)
Dependency ratio	-0.001	-0.001	-0.001**	-0.003	-0.003*	-0.003
	(0.001)	(0.001)	(0.000)	(0.002)	(0.002)	(0.002)
Female head	-0.017	0.078**	-0.001	-0.423***	-0.132	-0.339***
	(0.032)	(0.033)	(0.024)	(0.161)	(0.121)	(0.113)
Age head	-0.091**	-0.033	-0.110***	-0.134	0.166	0.197
	(0.041)	(0.045)	(0.030)	(0.190)	(0.169)	(0.121)
Distance	0.000	0.003	0.006	-0.095	0.026	0.003
	(0.013)	(0.012)	(0.009)	(0.058)	(0.044)	(0.039)
Transport	-0.046*	-0.035	-0.062***	0.090	0.129	0.153*
	(0.028)	(0.028)	(0.021)	(0.111)	(0.104)	(0.086)
Nutrition district	-0.001	-0.001	-0.002	0.005	0.008**	0.006*
	(0.001)	(0.001)	(0.001)	(0.004)	(0.004)	(0.004)
HDDS district	-0.014	-0.033*	-0.002	0.040	-0.033	-0.084*
	(0.013)	(0.017)	(0.013)	(0.059)	(0.061)	(0.050)
Radio	0.046	-0.052*	-0.001			
	(0.028)	(0.030)	(0.020)			
Primary educ	0.017	0.018	-0.006			
	(0.030)	(0.030)	(0.020)			
Secondary educ	0.038	0.032	0.047			
	(0.064)	(0.065)	(0.039)			
N	1087	1105	1627	304	369	467
R^2				0.46	0.39	0.47
Zone dummies	Yes	Yes	Yes	Yes	Yes	Yes
Sales dummies	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

3.6.2 Cassava

As for maize, Table 3.4 shows that samples are much larger for participation than for supply equations. This is expected since cassava is largely a subsistence crop which forms the backbone of diets in many regions. Hence, many households retain all their production. Further, it is relatively easy to keep large amounts of cassava by smoking the crop: once it has been smoked, it can be kept for months in jute bags without rotting. In that sense it contrasts with maize, which does not store as easily and comes at a risk of loss, notably because of rotting or insect attacks.

Results for cassava are consistent with the forced commerce hypothesis. Given the subsistence status of cassava, one can expect prices not to be strong drivers of the participation process under 'normal' circumstances. As such, sales may reflect abnormal situations of economic distress during which households may be compelled to sell the crop to satisfy urgent cash needs. Under such a scenario, we would thus expect price coefficients in the participation equation to matter less than in the supply equations: because of economic distress, households must enter the market regardless of the selling price. However, *once participating*, price should have a negative effect on supply if the aim is to achieve a given cash target. Results are consistent with this possibility: price is only significant in the second wave of data for participation, but it is significant and negative in every wave in the supply equations (with much higher magnitude than for maize). Note however, that harvest is still a key driver of supply conditional on participation.

The negative significance of the price coefficient in the participation equation in wave 2 suggests potential scarcity of cassava for that year. In addition to the previous reasoning, if cassava gets scarcer, then price can affect participation of households who need to retain the crop for their consumption. In waves one and three, the median price per kg of cassava is 185 and 263 Tshs/kg respectively, while median harvest is 200 and 180 kg respectively. In wave two, median price/kg is much higher at 600 Tshs/kg while median harvest is 190 kg. Therefore, while average harvest in wave two is close to averages for other waves, the average price is not. This strong negative price effects on market participation for cassava could be explained by relative droughts in some regions causing some other crops to fail and increasing reliance on cassava, it being more drought tolerant than other important crops such as maize. Policy reports seem to confirm this intuition. See

for example the IFRC policy report from September 2011 'Emergency appeal Tanzania: Drought and Food Insecurity', which reports that several regions suffered a major drought in 2009/10, the season prior to the second wave of data. Cassava is often sold dry for conservation purposes, and very high selling prices in wave 2 could reflect scarcity.

The average contribution of cassava to diet at the district level has a negative effect on supply in waves one and two. Cassava is a strong contributor to diets and a subsistence crop: on average, it makes up to 20% of the calorific value of diet over the reference period. In districts where reliance on cassava is strong, supply tends to be less.

Table 3.4: Cassava: two-part models

	Participation equation			Supply equation		
	Wave 1	Wave 2	Wave 3	Wave 1	Wave 2	Wave 3
Price	-0.041	-0.121***	0.039	-0.244**	-0.353**	-0.201**
	(0.032)	(0.019)	(0.031)	(0.102)	(0.143)	(0.081)
Harvest	0.100***	0.079***	0.128***	1.036***	0.758***	0.813***
	(0.014)	(0.016)	(0.012)	(0.059)	(0.120)	(0.078)
Farm size	0.034*	0.005	0.007	-0.059	0.315**	0.109
	(0.019)	(0.023)	(0.015)	(0.073)	(0.142)	(0.070)
Dependency ratio	-0.001*	-0.001	-0.001	0.007*	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.004)	(0.003)	(0.003)
Female head	0.059	0.004	0.056	-0.306	0.185	-0.075
	(0.046)	(0.047)	(0.036)	(0.197)	(0.228)	(0.135)
Age head	-0.065	-0.047	-0.097**	0.012	-0.073	-0.257
	(0.059)	(0.065)	(0.045)	(0.206)	(0.309)	(0.201)
Distance	0.029	-0.024	0.014	0.058	0.058	-0.015
	(0.018)	(0.017)	(0.014)	(0.063)	(0.095)	(0.063)
Transport	-0.015	0.060	-0.001	-0.047	0.363*	-0.230*
	(0.036)	(0.040)	(0.031)	(0.160)	(0.215)	(0.129)
Nutrition district	-0.002	0.002	-0.003**	-0.022***	-0.027***	-0.002
	(0.002)	(0.002)	(0.001)	(0.005)	(0.007)	(0.006)
HDDS district	0.023	0.079**	0.029	-0.077	-0.302	0.134
	(0.022)	(0.039)	(0.023)	(0.059)	(0.210)	(0.098)
Radio	-0.009	-0.063	-0.030			
	(0.038)	(0.040)	(0.030)			
Primary educ	0.012	-0.100**	-0.001			
	(0.040)	(0.044)	(0.031)			
Secondary educ	0.033	-0.105	0.049			
	(0.056)	(0.071)	(0.046)			
N	501	430	714	106	102	158
R^2				0.77	0.69	0.63
Zone dummies	Yes	Yes	Yes	Yes	Yes	Yes
Sales dummies	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses

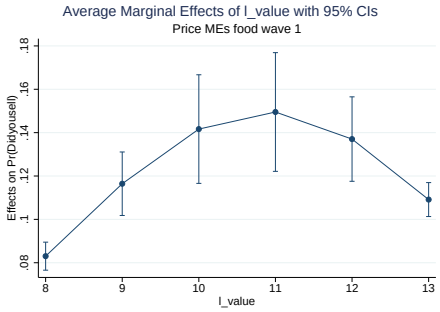
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

3.6.3 Food crops

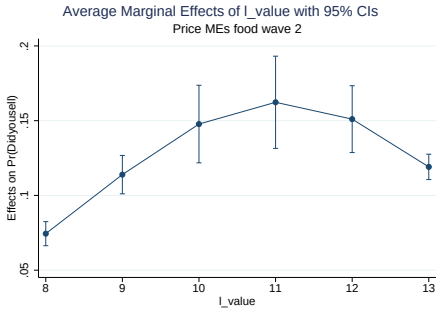
Although participation for food crops is, as expected, higher than for maize or cassava, it is worth noting that it is not much higher. In all waves, participation is around 40%. This is because food crops can be both consumed and sold. Given that these crops are grown with the aim to be at least partly sold, we expect the value of production to have a positive impact on the participation decision. The effect on quantity supplied is more ambiguous. Intuitively, standard theory predicts that quantity supplied should respond positively to value. However, households can also endeavour to attain a given level of revenue passed which they retain whatever surplus is left for home consumption. There is also the possibility of a 'perverse supply response' where households decide to store more output when the shadow value of their production is increasing in order to sell at a later date. Therefore, we expect a positive effect of value on participation but have no a priori expectations for quantity supplied.

In the participation equation, value is positive and significant throughout. This is in line with expectations for food crops, and stresses the commercial endeavour attached to these crops. Also note that the effect is very consistent across waves. Figure 3.3 plots the average marginal effects of value on participation at different value levels. Marginal effects of values are all significant. More interestingly, the effect is very strongly positive and increasing in magnitude until the value of production reaches ln(11). Once this shadow value of production is reached, the magnitude of the effects decrease, although they are still positive and significant. This suggests that shadow value of production acts as a push factor towards participation. To the extent that food crops can be both eaten and sold, an increase in the value of production is likely to increase, at the margin, the probability to sell. Passed a certain value, the value of production is so high that an extra increase in value at the margin has a smaller effect on participation. In the robustness checks in which we include lagged value, we also find the latter to be positive and significant in wave two, where the magnitude of the coefficient is seizable (more than half the magnitude of the baseline coefficient). This can be interpreted as evidence for price expectation mechanisms, further stressing the commercial aspect of the market.

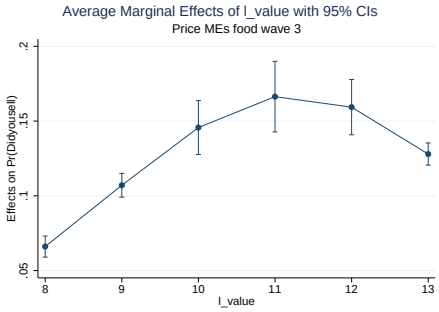
When it comes to supply, the marginal effects of value are also positive and significant throughout with very stable coefficients across time.



(a) Wave 1



(b) Wave 2



(c) Wave 3

Figure 3.3: AMEs of value on participation in food crops market at different value levels

An interesting result is how the level of education of the head of household does not consistently affect participation. In the theory of rural market failures, higher education is meant to proxy the ability to make informed trade decisions, to process price information and to develop trade networks. But we only observe a mildly significant effect of having primary education in the third wave of data. In the case of maize and cassava, the general insignificance of the education variable was not too surprising since they are subsistence crops. However, it is more so in the case of food crops. The negative effect of owning a radio on participation is also hard to interpret, because in theory, this variable is meant to capture households' access to price information. Hence, one would expect a positive effect of this variable whenever significant. However, the coefficient is only significant in the third wave of data.

The age of the head of household has a consistently negative and significant effect on participation but not on supply. Hence, households with an older head are less likely to sell food crops. One reason may be that younger households are more risk-taking that their older counterparts. Heltberg and Tarp (2002) find a similar result for participation

into the cash crops market in Mozambique: 'This finding may be explained by variation in cash need, variation in farming ability across the life cycle, or both' (2002:114). Another is that crops mixes can correlate with age. For example, younger households may cultivate and sell a particular crop more because its cultivation for commercial purposes was favoured by a policy.

Table 3.5: Food crops: two-part models

	Participation equation			Supply equation		
	Wave 1	Wave 2	Wave 3	Wave 1	Wave 2	Wave 3
Value	0.132***	0.140***	0.141***	0.704***	0.659***	0.690***
	(0.010)	(0.011)	(0.008)	(0.041)	(0.052)	(0.035)
Farm size	0.027*	0.035**	0.005	0.150***	0.110	0.064
	(0.016)	(0.017)	(0.012)	(0.052)	(0.069)	(0.044)
Dependency ratio	-0.000	-0.001	-0.001***	0.004**	0.002	-0.001
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)
Female head	-0.021	-0.014	-0.006	-0.035	-0.048	-0.238***
	(0.034)	(0.036)	(0.026)	(0.123)	(0.132)	(0.088)
Age head	-0.173***	-0.183***	-0.119***	-0.153	0.193	0.073
	(0.043)	(0.046)	(0.033)	(0.143)	(0.172)	(0.111)
Distance	-0.007	0.019	0.021**	0.060	0.091**	0.046
	(0.014)	(0.013)	(0.010)	(0.048)	(0.046)	(0.036)
Transport	-0.050*	-0.065**	-0.065***	0.107	0.141	0.053
	(0.030)	(0.030)	(0.023)	(0.090)	(0.101)	(0.077)
Nutrition district	-0.006	-0.002	0.005	-0.015	-0.033**	-0.017
	(0.004)	(0.004)	(0.004)	(0.018)	(0.016)	(0.013)
HDDS district	-0.012	-0.030*	-0.034**	0.129**	0.023	-0.044
	(0.015)	(0.018)	(0.015)	(0.051)	(0.069)	(0.057)
Radio	-0.046	-0.021	-0.050**			
	(0.029)	(0.032)	(0.022)			
Primary educ	0.019	-0.031	0.042*			
	(0.032)	(0.033)	(0.022)			
Secondary educ	-0.073	-0.091	0.016			
	(0.069)	(0.063)	(0.044)			
N	1250	1089	1848	522	441	707
R^2				0.50	0.44	0.47
Zone dummies	Yes	Yes	Yes	Yes	Yes	Yes
Sales dummies	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

3.6.4 Export crops

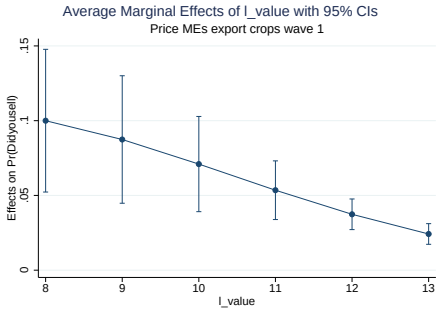
The distinctive feature of export crops is that virtually all farmers grow them for purely commercial motives. Unlike food crops, export crops do not form part of traditional diets or cannot be eaten as such.[15]

In the participation equations, value has a positive and significant impact throughout. Although the pattern of significance and sign of coefficients is the same as for food crops, the magnitude of the coefficients is much lesser. As we have explained, an increasing shadow value of production can have a strong effect on the probability to sell food crops (at the margin). For export crops, this effect is lesser because the alternative option of home consumption does not exist. Figure 3.4 plots the average marginal effects of value for each wave of data. All marginal effects are positive and significant. Both the markets for food and that for export crops are characterised by positive marginal effects of value on the decision to participate. However, Figure 3.4 shows that AMEs on the probability of entering the market for export crops *decrease* in magnitude as value increases: at high values, virtually everyone is a seller and the magnitude of marginal effects is very small (particularly so in waves one and three). For food crops on the other hand, Figure 3.3 shows that AMEs on the probability of entering the market *increase* in magnitude as value increases (until ln(11)), implying that the shadow value of production acts more as a push factor than for export crops. This suggests a more timid logic behind the marketing of food crops, partly explained by the fact that food crops are typically vegetables and legumes that can be eaten if not sold.

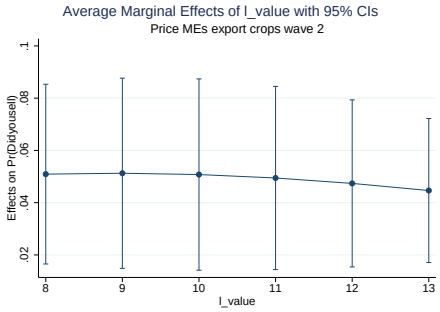
In the robustness checks in which we include lagged value, we do not find any significant effect of this variable on the participation decision. This is not a surprise, given that export crops are only grown to be sold. However, it is significant in the supply equations, indicating that lagged prices are driving supply, rather than the decision to sell itself.

As for maize and food crops, we find that farm size is a key driver of supply conditional on participation, but not on participation itself.

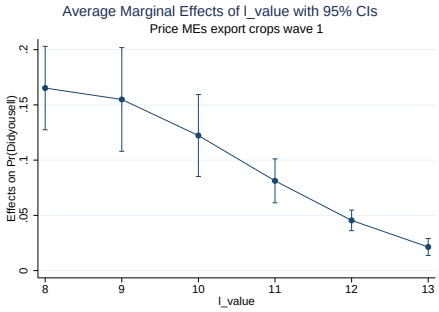
[15]This is particularly stringent for cashew in the Mtwara region. In our primary data collected for chapter 4, around 98% of the crop is sold.



(a) Wave 1



(b) Wave 2



(c) Wave 3

Figure 3.4: AMEs of value on participation in export crops market at different value levels

Table 3.6: Export crops: two-part models

	Participation equation			Supply equation		
	Wave 1	Wave 2	Wave 3	Wave 1	Wave 2	Wave 3
Value	0.054***	0.049***	0.072***	0.723***	0.745***	0.711***
	(0.010)	(0.017)	(0.008)	(0.044)	(0.066)	(0.042)
Farm size	-0.030*	-0.042	-0.005	0.205***	0.237**	0.462***
	(0.018)	(0.032)	(0.013)	(0.051)	(0.094)	(0.054)
Dependency ratio	0.001	0.001	0.002***	0.002	0.006	0.000
	(0.001)	(0.001)	(0.000)	(0.002)	(0.004)	(0.002)
Female head	-0.069**	-0.034	0.024	0.055	0.112	0.105
	(0.035)	(0.062)	(0.027)	(0.107)	(0.160)	(0.097)
Age head	-0.053	-0.035	-0.099***	-0.124	-0.088	-0.384***
	(0.057)	(0.088)	(0.035)	(0.151)	(0.239)	(0.124)
Distance	-0.002	0.001	0.026**	-0.028	-0.010	0.075*
	(0.014)	(0.022)	(0.011)	(0.042)	(0.051)	(0.040)
Transport	-0.007	-0.025	-0.007	0.198**	0.235	0.022
	(0.034)	(0.055)	(0.026)	(0.092)	(0.153)	(0.088)
HDDS district	-0.009	0.014	-0.025*	-0.283***	-0.302***	-0.434***

	(0.015)	(0.036)	(0.015)	(0.053)	(0.110)	(0.064)
Radio	-0.003	-0.111**	-0.006			
	(0.034)	(0.055)	(0.024)			
Primary educ	-0.054	0.042	0.035			
	(0.037)	(0.061)	(0.023)			
Secondary educ	-0.127**	0.042	0.039			
	(0.061)	(0.115)	(0.051)			
N	396	389	692	344	235	599
R^2				0.73	0.65	0.66
Zone dummies	Yes	Yes	Yes	Yes	Yes	Yes
Sales dummies	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

3.6.5 Robustness checks

The analysis presented in this chapter is based on the estimation of two-part models, which model participation via a probit and supply conditional on participation via OLS regression. We have favoured TPMs on the ground that the econometric literature has stressed the numerous issues associated with Heckman selection models. Further, it has also shown that the performance of the two estimation methods tends to be very similar, even with selection. However, one could still argue that if selection is a serious concern, this may affect the empirical results. As a robustness check, we also estimate Heckman models for all crops and report those in the Appendix. Under a Heckman model, the supply equation is given by:

$$E(Supply_{ij}|Supply_{ij}>0) = \phi + \boldsymbol{\gamma_1 PTC_j} + \gamma_2 ln(Harvest)_{ij} + \gamma_3 ln(Price)_{ij} + \boldsymbol{\gamma_4 HH_j} + \boldsymbol{\gamma_5 Nutrition_j} + \gamma_6 Farm_j + \boldsymbol{\theta Sales_j} + \boldsymbol{\delta Zone_j} + \underbrace{\gamma_7 \lambda_{ij}}_{\text{added term}} + \varepsilon_{ij} \tag{3.7}$$

where λ_{ij} is the Inverse Mills ratio (ratio of standard normal density function to cumulative distribution function).[16] Results show that selection is not a consistent phenomenon across crops. For maize and export crops, the significance of the selection parameter is not consistent across waves. For food crops, it is significant throughout except in one model with lagged prices (see below); for cassava, it is not significant in any model. Hence, we find no evidence of clear a selection mechanism in the different output markets we study. In practice, results across the two estimation methods are very similar, thus confirming insights from the theoretical econometric literature. The general pattern of significance is preserved, and the difference in magnitude of the effects observed is not large enough to raise concern on the estimation method.

A second robustness check we carried was to include lagged prices in the second and third waves of the data (equivalently, lagged value for food and export crops). Regression outputs for models with lagged prices (for both TPMs and Heckman models) are presented in the Appendix. Models with lagged prices suffer from much smaller sample sizes because they require a household to grow and sell the same crop over time. However, they constitute a useful check and allow us to enquire into the existence of price expectation

[16] In models for food and export crops, we use the monetary value of production rather than price and harvest as explained previously.

mechanisms. The inclusion of lagged prices in waves two and three does not alter our empirical results in any major way. For maize and cassava, the coefficients are not significant at the 5% level or more. For food crops, lagged value is positive and significant in wave 2, showing that expectation mechanisms are at work in this market. This confirms the idea that the market for food crops is underpinned by a stronger commercial logic than those for maize and cassava. In the case of export crops, lagged value has no effect on participation and does not alter our interpretation of results.

One novelty of the analysis is the inclusion of variables related to nutrition, which have traditionally been omitted from the literature on market participation and output supply. In this essay we have included two variables capturing the nutritional environment of households: the household dietary diversity index and the total contribution of a given crop to household's diet in percentages. Both variables are averaged out at the district level to remove concern for endogeneity. For robustness purposes, we also ran the analysis adding a third nutritional variable: the total calorific value of the household's diet over the reference period, also averaged out at the district level. Results are robust to the inclusion of this additional variable and do not change our conclusions.

Finally, we also considered the inclusion of a vector of production dummies, in addition to the vector of sales dummies. Because it uses an additional three degrees of freedom, we did not include it in the main regressions. The rationale for its inclusion is that the production of a given crop (rather than its sales) may influence the marketing of another crop. Again, results are robust to this check: adding this vector of dummies has no significant effect on the results and does not impact on the interpretation.

To summarise, we have considered several robustness checks. The main robustness check is the estimation of Heckman selection models instead of two-part models. We show that the behaviour of the selection parameter is erratic, and that even if one favoured specifications based on Heckman models, results would be very similar. We also consider three extra robusntess checks by adding lagged prices, an additional nutritional variable and a vector of production dummies, none of which has a significant effect on interpretation either.

3.6.6 Interpreting empirical results

In the remaining part of this section we discuss in more depth the empirical results presented above by looking at how the market for each crop can be conceptualised according to the two theories briefly presented in the literature review: standard economic theory with a focus on market failures, and agrarian political economy. One crucial dimension of the results is the effect of prices on participation. Table 3.7 summarises the main empirical results with respect to the price/value variable for each crop studied in this analysis. The

	Price/value coefficients	Consistent or irregular effect?	Price expectation mechanisms?
Maize	negative	irregular	no
Cassava	negative	irregular	no
Food crops	positive	consistent	yes
Export crops	positive	consistent	no

Table 3.7: Effect of prices/value on the participation decision

table summarises the patterns of signs of the price or value variable (whenever significant), whether this effect is consistent across models/waves, and whether lagged prices or value have a consistent effect on the decision to enter the market (price expectations).

Price coefficients in participation equations for maize are negative and highly significant in waves two and three. This is consistent with both standard theory and agrarian perspectives, for they both allow for the possibility of a negative effect of prices on participation. From the market failure point of view, price increases for major staple crops can have a detrimental effect over supply for poor households who are net buyers over the course of the year. From the perspective of agrarian political economy, a similar idea is expressed, but with the important difference that a notion of subordination and power is associated with being a net buyer over the course of the year. However, the crucial aspect of maize is that many households have a stronger preference for maize than for cassava, the latter often being considered an inferior crop. For households who do sell maize, the supply is almost entirely driven by harvest and prices do not have a significant effect. This is partly due to poor storage capacity of maize. Households with a bumper harvest in maize may thus enter the market to sell the excess harvest that is not consumed by the household, regardless of the price level.

The market for cassava is also non-commercial in nature, but in a different way from maize: price effects are only significant in wave two for participation. On the other hand,

they are negative and significant in all supply equations. Cassava tends to be heavily retained for home consumption and typically sells at a low price. In many regions, it is a staple. To the extent that cassava sales are nonetheless observed, results are consistent with the forced commerce hypothesis. The strong negative effect of prices on supply conditional on participation suggests the possibility of cash targets to be satisfied. When poor households enter the market for cassava, the decision is driven by distress, for the crop has very little commercial aspect. Having entered, cassava is sold until a target is met. This explains the pattern of price coefficients, and implies that one should not always assume that participation in the market is voluntary (Akram-Lodhi, 2000). Because price is only a driver of marketing in wave two for cassava, this lends support to the idea that under 'normal' circumstances, cassava is less marketed and more retained for home consumption. Marketing may be driven by what Akran-Lodhi calls *structural subordination*: a situation where, under incomplete markets, we observe marketing rather than subsistence fall-back. This structural subordination constitutes a crucial difference between the orthodox narrative on market failure (from which the concept is missing) and the literature in agrarian political economy.

One could argue that the market for food crops is much closer in spirit to the orthodox understanding of markets than the markets for maize or cassava. Indeed, our results for food crops show a positive effect of the shadow value of production on participation. Further, we find evidence of expectation mechanisms in waves two, underpinning the more commercial nature of this market. We have also shown that the marginal effects of value tend to increase strongly until a high value of production is reached. This stresses the fact that value acts as a push factor towards participating in the market. In that sense, the market for food crops is not purely commercial either, because households can always consume their production if prices are too low. This, to some extent, reflects the limitation of the label 'food crops'. In practice, most food crops are widely sold and consumed. Hence, it is logical to expect some degree of commercial endeavour for these crops, but they should not be conceptualised either as purely commercial.[17]

The market for export crops is also more consistent with standard theory than that of

[17]When collecting data for the last essay of this thesis, I found groundnut to be a good example of that. Groundnut is typically seen as an important cash crop. In Mtwara, it is a source of revenue and it is widely commercialised, with established marketing channels. However, a third of the production is still retained for home consumption, on average.

maize or cassava. While it shares a commercial aspect with the market for food crops, an important difference with the latter is that export crops cannot be consumed by farmers if the output is not sold. This explains the insignificance of lagged value on participation. Value and prices act less as a push factor for export crops than for food crops.

In this chapter, we discuss how the literature on missing markets has constrained empirical analyses of supply by not devoting full attention to the economic meaning of market participation. In contrast to orthodox theory, agrarian political economy emphasizes issues of subordination and power in economic exchange. The political economy foundation of this approach implies that the nature of markets (rather than 'the market') varies across time and space. In practice, insights from agrarian political economy can be included in standard approaches (such as ours), in several ways. One starting point is simply to stop treating the participation process as a 'correction' step towards the estimation of unbiased supply equations. Rather than being a measure of the prevalence of market failures, participation in different markets can tell us a lot on the nature of economic exchange. This in turn requires some knowledge at the crop level. For example, only when we understand the role played by an inferior crop such as cassava can we conceptualise forced sales. Agrarian political economy engages with the possibility of subordination in economic exchange, and does so by looking at particular specificities of each country. In the case of Tanzania for example, the progressive phase of liberalisation has entailed growing power for private traders who are now able to regulate the timing of sales so as to maximise their profit. Such political economy considerations can help us understand why a household may be forced to sell a crop, or may on the contrary try to keep its production as long as possible because it is a net buyer of the crop over the course of the year. Unlike what is implicit in standard theory, participation *per se* is not treated as either either 'good' or 'bad'. This is why a crop level focus looking at each data wave separately is necessary to understand the specificities of economic exchange.

Another implication of using an agrarian political economy lens lies in redefining what we consider to be the factors influencing participation. As explained in Section 3, standard theory posits that market participation is a desirable form of exchange. Hence, any household level characteristics picking up availability of information and capacity to process it (i.e., education level) will play a positive role in influencing participation. One

would thus expect to find a positive and significant effect on participation of these variables when following the standard viewpoint. However, we know from agrarian political economy that sales may be forced for some crops (subsistence or semi-subsistence ones especially). If this holds, then we should precisely expect a *negative* effect of education, availability of information etc. on the participation decision, because those households participating in the market are the ones with least bargaining power. Thus, careful attention needs to be paid to the choice and interpretation of exclusion restrictions, and our *a priori* expectations regarding sign and significance of these variables should not be too strong.

3.7 Conclusions

This study focuses on the issue of market participation and output supply for a set of important crops in Tanzania: maize, cassava, food crops and export crops. We start by explaining how recent literature approached this topic by framing it into the missing market and transaction costs narrative, following the seminal contributions by de Janvry *et al.* (1991) and Key *et al.* (2000). We further explain how this led to empirical applications using either Heckman selection models or slightly simpler two-part models, which we argue have tended to focus more on supply equations (corrected for selection when using Heckman models) that on the process of selection *itself*. Along this study, we make the case that over-reliance on the market failure narrative tends to blur the reasons why farmers may enter radically different markets (for instance: cassava versus food crops), because it assumes entry to be a naturally desirable outcome and hence has difficulties treating non-entry as the result of anything but market failures.

By taking the data to the crop level, we examine the the determinants of both participation and supply conditional on entry for several crops. Our results show no strong and stable evidence of selection into those markets, and hence we favour two-part models over Heckman ones (in practice there are no major differences between the two estimation strategies). The markets for maize and cassava are both characterised by negative price responsiveness on participation, stressing the non-commercial nature of these markets. Results for cassava seem to point towards the possibility of a forced commerce hypothesis, originally theorised by Bhaduri (1986) and more recently revisited by Skarstein (2005,2010). On the other hand, the markets for food crops and export crops are both

characterised by positive effect on the value of production on participation. Results for these crops are consistent with a commercial endeavour. This is clear in the case of export crops, which are grown with the almost exclusive aim (and possibility) to be sold. For food crops, farmers have both the possibility to sell or to retain for home consumption, which explains the importance of the value of production as a 'push factor' towards commercialisation. We also reflect in more detail on those empirical results by comparing the treatment of markets in standard economic theory and in agrarian political economy. We highlight important differences between these two approaches. While both theories are able to conceptualise participation driven out of economic distress, agrarian political economy puts a heavier weight on the structural subordination of poor farmers to market exchange. Such a concept may be useful in understanding in greater detail the dynamics associated with the markets for maize and cassava.

Chapter 4

A Mixed-methods Study of Bambara Farming in Mtwara

'Strategies adopted to address the ongoing problem of food security, particularly in developing countries, continue to narrow the diversity of the food supply by neglecting indigenous and traditional food systems' (Cloete and Idsardi, 2013:903)

4.1 Introduction

Social science research on food crops in developing countries has tended to focus only on the major crops, such as wheat, maize or paddy rice, as these are the most important for production and consumption, and have wide coverage in national farm household surveys. This is justified because major grains are a focus of agricultural policy and contributors to diets and income. An unfortunate consequence is a lack of research effort on minor indigenous food crops, often referred to as under-utilised (because there is unrealised potential) or marginal crops. However, these indigenous crops are often grown widely in local areas, where they are particularly suited to agro-climatic conditions, and are important for livelihoods and consumption. This chapter provides a socioeconomic study of Bambara groundnut in the Mtwara region of Tanzania to assess its potential for production and as a nutritious food, and to understand why it remains under-utilised despite being long established in the region.

Marginal crops possess attractive features from an economic, agronomic and biological

point of view, and their potential is even more important in food insecure areas: 'Many of these traditional crops grown for food, fiber, fodder, oil and as sources of traditional medicine play a major role in the subsistence of local communities and frequently are of special social, cultural and medicinal value. With good adaptation to often marginal lands, they constitute an important part of the local diet of communities providing valuable nutritional components, which are often lacking in staple crops' (Ebert, 2014:323). Research in plant sciences has comparatively paid more attention to marginal crops and has highlighted their biological advantages, such as high yield potential or low input requirements. These advantages make them promising candidates in the design of food security strategies and their improved use could help acheive the Sustainable Development Goals (Mabhaudhi *et al.*, 2016). The recent Bioversity International (2017) publication on mainstreaming agro-biodiversity makes a similar point by stressing that only three crops (maize, wheat and rice) account for half of plant-derived calories consumed over the globe. Marginal crops have a role to play in improving diets and nutrition as they tend to have a high nutritional content.

This study aims at addressing this relative neglect with respect to one marginal crop, the Bambara nut (henceforth BG). Despite being often considered a poor man's crop, BG is an important leguminous crop grown in many countries across sub-Saharan Africa and frequently competes with other legumes such as pigeon pea. Although the crop is cultivated in several regions, varieties bred have not fully been established yet, and most farmers still rely on landraces (Azam-Ali, 2001; Mkandawire, 2007). However, BG possesses very attractive features, notably its high protein content (higher than groundnut), as well as its ability to grow in relatively arid environments (Hillocks *et al.* 2012). Yet knowledge of the socio-economic dynamics associated with BG remains very limited.

The analysis in this mixed methods study is based on quantitative and qualitative primary data collected in the Mtwara region of Tanzania between September and November 2016, where Bambara is commonly cultivated. As little is known on the crop and why it is grown, exploratory research constitutes an important step and a case study focusing on one specific district is appropriate. At a national level, BG is a minor crop (in terms of

[1]There are only 89 plot/crop observations for BG in the first wave of the TNPS, about 1.56% of the total dataset. Figures are even lower for wave 2 and 3: 54 observations in wave 2 (0.90% of total dataset) and 71 for wave 3 (0.89%).

production or consumption) and hardly features in national farm surveys.[1] In designing the fieldwork we aimed to collect data that would permit analysis of BG in the context of issues addressed using the TNPS, so we sought information on market structure and plot sizes. The interest is in determining to what extent Bambara contributes to local livelihoods; perceptions of the crop by growers, including a comparison with nongrowers; and understanding what prevents increased utilisation. Is there evidence that Bambara provides a good source of income or is it grown primarily to supplement diets? What factors influence how much is sold on the market? Most importantly, can we get any insight into why a potentially useful crop like Bambara is not grown more widely? Although our case study is limited to the Mtwara region, we believe that small-scale studies are an important first step in consolidating the emerging literature on underutilised crops. This is particularly true for quantitative analysis as such crops by their nature are under-represented in national level surveys.

Section 2 reviews the scarce socio-economic literature on underutilised crops. Section 3 describes in details the organisation of the fieldwork and challenges faced. Section 4 first compares growers to non-growers, then presents the main results on the factors influencing the decision to become a grower, and finally examines the constraints to marketing the crop. Section 5 concludes.

4.2 A Nascent Research Framework on Underutilised Crops

Research on agriculture and food is subject to paradigm shifts that are linked to public debates within economic and political spheres. In the context of food and agriculture, one can refer to the dominant paradigm as the dominant food regime, which encapsulates the dimension of food in a broad sense: from input suppliers to farming practices and from agribusiness to public policy. The current food regime is characterised by the importance of transnational agribusinesses and of international financial institutions ruling trade across countries (McMichael, 2013), the evolution of patenting and property rights in favour of private transnational companies and a research agenda largely influenced by those. This 'corporate' food regime prioritises a particular set of crops in terms of research and general interest (including media attention), notably the 'big four': wheat, rice, maize and soy (Bernstein, 2010). By doing so, it de facto leaves aside a vast array of crops that receive little attention in research. While marginal crops tend to be widely grown,

the term 'underutilised' refers to the idea that they could constitute greater sources of income and be more commercialised than they currently are (i.e., that their potential as cash crops is not as developed as it could). The fact that the potential of these crops is not as high as it could be is also linked to few efforts in applied research at exploring this potential: 'It is axiomatic that underutilized crops are also under-researched crops' (Azam-Ali *et al.*, 2001:434)

The term 'underutilised' is one among the many used to characterise those crops, which are also referred to as 'marginal', 'indigenous', or sometimes even 'orphan'. Each of these terms in fact captures a given dimension of these crops but none is fully satisfying. The label underutilised mainly refers to the idea that these crops do not currently possess the commercial aspect they deserve, and that they have the potential to generate higher income. On the other hand, it is problematic as the term implies they are seldom 'used' (i.e., planted/consumed/sold), which goes against empirical evidence at the local level. The term marginal accurately reflects the fact that these crops do not form part of the set of crops prioritised within current agricultural policies and food security strategies. However, they are not (necessarily) marginal in their effects on livelihoods as the quote from Ebert above suggests. Finally, the term indigenous is appealing because it correctly emphasizes that these crops are locally grown and benefit from local autonomous farming knowledge and are well adapted to local climatic conditions. However, the word can be misleading in the sense that an indigenous crop can easily be grown in a different area from which it originates. For example, it is believed that the Bambara nut originates from parts of Nigeria and Cameroon, although it is widely grown in other parts of Africa and can be grown in some Asian countries (Azam-Ali *et al.*, 2001).

In this context, it is therefore not surprising that there is only a nascent literature on indigenous crops in socio-economic research. A recent strand in the literature has been concerned with the economic viability of agricultural diversity. However, the focus has been on assessing the effectiveness of conservation policies (Bellon *et al.* 2015) or the relationship between diversity and risk management or poverty (Di Falco and Perrings, 2005, Michler and Josephson, 2017) rather than developing detailed knowledge on specific crops and their embeddedness in local economies.

Among the few existing studies dedicated to marginal crops is Mabhaudhi *et al.* (2016), exploring the mechanisms by which underutilised crops could help countries in southern Africa reach the Sustainable Development Goals (SDGs) in the context of the Post-2015 Development Agenda. They identify four key specificities of these crops. Firstly, they are resilient as they are grown in an environment for which they are suited, which is directly relevant in the context of global climate change. Secondly, they typically contribute to dietary diversity and can improve households' nutrition. Thirdly, they present a large pool of genetic resources that are preserved by farmers' practices and directly contribute to maintaining biodiversity of species. Finally, they can contribute to income generation processes as a stable demand for these crops exists, and hence a stable market. Focusing on BG, Adzawla *et al.* (2016a) study the determinants of adoption in Ghana, and how adoption impacts the welfare of growers. Using a monetary definition of welfare, their study finds that BG growers have a higher welfare than non-growers, although the difference is small. The paper stresses the need to assess more closely the contribution of indigenous crops to household welfare as it is still unclear how the four advantages identified by Mabhaudhi *et al.* (2016) translate in practice. Focusing on South Africa, van der Merwe *et al.* (2016) argue that indigenous crops should be considered as part of national food security strategies for they de facto constitute an important part of household diets. This approach towards the food security question received no attention from public authorities, despite the obvious importance of indigenous crops for local livelihoods. In a study of the North-West province of South Africa, Cloete and Idsardi (2013) show that underutilised crops enter the diet of 52% of households.[2]

Not only do marginal crops not receive enough attention in national food strategy plans, they do not receive enough attention in food security research either. For example, a heavily cited and influential paper by Godfray *et al.* (2010) identifies several ways to guarantee food security in the future (such as closing yield gaps, or reducing waste) but nowhere are indigenous crops mentioned as important factors towards achieving food security. In that sense, it can be argued that marginal crops are 'excluded' from the current agricultural paradigm when it comes to identifying viable solutions to guarantee food security.

[2]Cloete and Idsardi (2013) and van der Merwe *et al.* (2016) use the label *'indigenous and traditional food crops'* (ITFCs), which they further break into conventional and less conventional ITFCs. The 'less conventional ITFCs' category roughly corresponds to our definition of underutilised crops in this study.

Hillocks *et al.* (2012) review the utilisation and market potential of BG in Africa, and argue that it is the third most important legume in SSA (after cowpea and groundnut). They survey the many ways BG is prepared/cooked in SSA (fresh, roasted, as a soup etc.), and identify possible promising developments in terms of processing, notably the high potential for BG malting. In terms of market potential, the authors conclude: 'Closer examination of the few examples of commercial exploitation of Bambara, suggests that compared to groundnut and some other legumes, the issue is rather a lack of promotion of Bambara and little investment in the development of functional value chains, than lack of demand' (Hillocks *et al.*, 2012:8). Greenhalgh (2000) also explores the market potential of BG as part of a DFID funded project on the crop. The study stresses the need to generate more knowledge about the crop, for governments or other public bodies do not seem to collect data on BG regularly, unlike for other important legumes. Another important issue that has received little attention in socio-economic research is that of traditional beliefs influencing BG farming and marginal crops more generally. Forsythe *et al.* (2015) for Malawi is the only paper - to the best of our knowledge - which looks into detail at how traditional beliefs affect BG production. Their methodology is based on focus groups in villages and one-to-one interviews with traditional doctors. They show that BG production is significantly hindered by those beliefs. However, while it is traditionally understood that BG can only be grown by specific segments of the population, such as older women who lost a child, there is evidence that the taboo is less and less stringent. Their analysis also reveals that taboos could further be weakened if the marketing potential of the crop was to increase.

Despite a nascent interest in underutilised crops in the social sciences, interest in economics remains extremely marginal. Table 4.1 reports the number of studies referenced on the Scopus database for journal articles in the *economics, econometrics and finance* category between 2000 and 2017 which contain the keyword in either the title, abstract or keyword section.

This study contributes to the nascent effort at expanding knowledge on under-utilised crops into the development and agricultural economics literature, and to show that such research attention is justified for several reasons. Their climatic resilience, capacity to grow with very little or no chemical inputs and their nutritional properties could turn

Table 4.1: Number of publications referenced in the Scopus Database

Keyword entered in seach	Number of corresponding publications
Maize	710
Rice	1006
Soybean	489
Underutilised crops	1
Bambara groundnut	2

Note: search period: 2000-2017. Accessed 04/06/17

these crops into good candidates towards achieving food security.

4.3 Fieldwork Organisation and Data Collection

4.3.1 Timeline and location

Fieldwork took place in the Mtwara rural district, one of the districts in the Mtwara region of Tanzania, in the southernmost part of the country. Data collection started on the 19th of September 2016 and ended on the 3rd of November 2016. Mtwara district is characterised by a warm climate and a rainy season starting around early December and finishing around March. Planting for most annual crops happens during those months, while harvest usually takes place between May and July. Therefore, fieldwork was conducted in a period of the year in which farmers were not busy planting or harvesting annual crops. The Mtwara region is one the poorest regions of the country where agriculture is largely subsistence based. However, it is a large producer of cashew nuts, an export crop grown by many farmers in the area, for whom it is the main source of agricultural income. The region of Mtwara was chosen because it is one of the two mainland regions of the country (together with Dodoma) where the crop is widely grown.

Fieldwork was conducted in partnership with the Naliendele Agricultural Research Institute (henceforth ARI), a public research institute very active in the area. The ARI has several research units, including a socio-economic unit, and focuses on practical research aimed at improving living conditions for farmers in the area by providing improved seeds, agronomic advice etc. ARI teams frequently survey villages in the region for research purposes. A team with two enumerators and a driver was formed to implement the fieldwork. Figure 4.1 shows a map of the study area. The dark-shaded units are the wards in which we conducted the study.

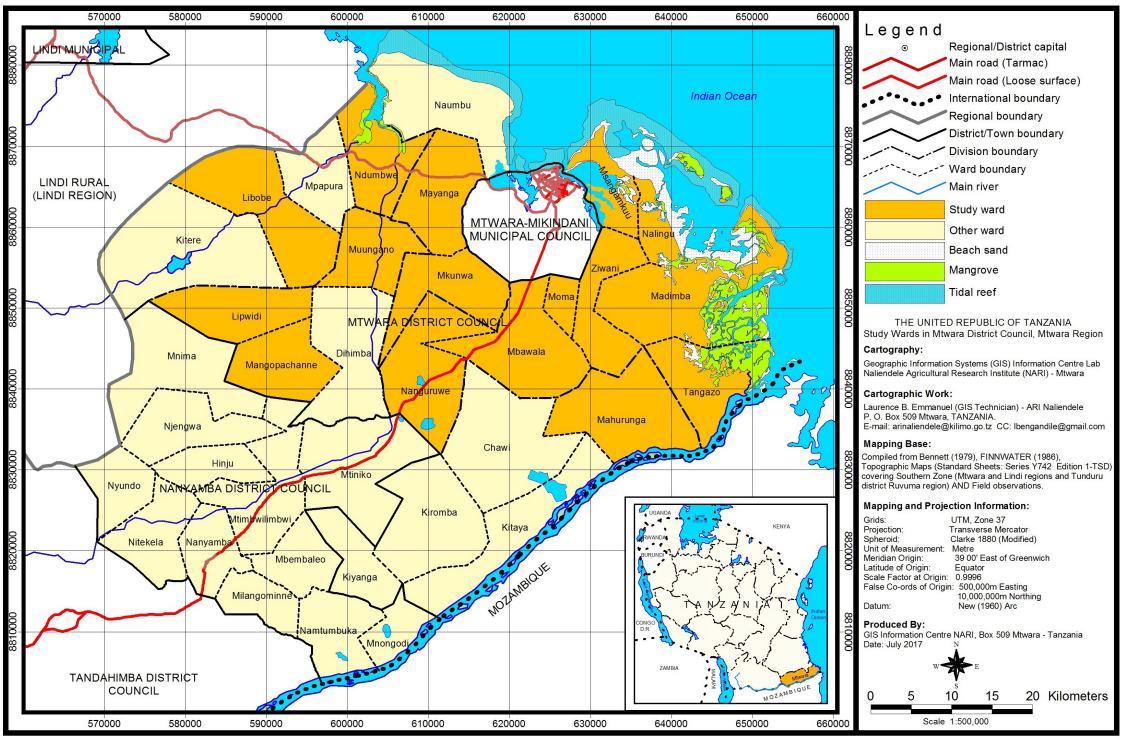


Figure 4.1: Study wards (Mtwara rural district)

4.3.2 Data collection

This research project included both quantitative and qualitative data collection. We chose to focus on the Mtwara rural district for two reasons. First, focusing on one district allowed us to survey each single ward within that district in which BG can be grown (16 in total), and hence get a representative picture of this geographical area. Second, with limited budget and time available for fieldwork, focusing on this particular district allowed to keep expenses in check as it did not imply additional expenses in terms of spending nights outside Mtwara and reduced travelling time.

Collection of quantitative data was based on household and agricultural surveys. No register of farmers for the whole district was available, so we relied on the knowledge of the extension officers to select a representative set of farmers within villages. In each of the 16 wards of the Mtwara rural district where BG can be grown, we contacted the agricultural extension officer (a State employee whose task is to link the villages with administration for any matter regarding agriculture, as well as facilitating research activities, promotion of farming advice etc.). We commissioned the extension officer to select two villages in his/her ward in which both growers of BG and non-growers live. In practice,

any village features both growers and non-growers since we only surveyed wards in which the crop can be grown. In each village, eight farmers were selected. Surveying eight farmers roughly corresponds to a full day of work, including travel time. Given that this research pays particular attention to the farming and socio-economic practices associated with BG, we selected 5 growers and 3 non-growers per village (equivalently, 10 growers and 6 non-growers per ward) in order to ensure we would have enough information on growers to conduct statistical analysis. We also aimed at achieving gender balance in respondents (4 women and 4 men per village), but this could not always be enforced. In practice, this should not impact results because most female respondents are not the head of household (only widows are heads). In the few instances where a farmer failed to show up to the meeting, the officer and the head of village would find a farmer with similar characteristics (i.e., grower or non-grower, and male or female) before the start of surveying. Our final sample was 258 households.

One may object that one possible bias is that extension officers may have selected the farmers who typically engage more with extension services than the average. To the extent that this is the case for both growers and non-growers, it should not have a systematic effect on our comparisons between the two groups. Another bias could have arisen if extension officers were implicitly pushing farmers to grow BG over other crops, which could have affected the selection process. However, our experience in the region provides no evidence that extension officers are strongly pushing farmers to grow marginal crops.[3] In fact, it is hard to claim that these officers constitute a homogeneous group, notably in terms of effort and commitment towards their assigned ward. In the next section we present summary statistics showing that households growing the crops are not statistically significantly different from those not growing it in terms of family structure.

The first day was a pilot study to identify the main challenges in administering surveys, and hence, the data for that day was discarded. An extra day was added at the end to return to the same ward (but to a different village) to compensate for that 'lost' data. Altogether, 33 villages across 16 wards were surveyed (two villages per ward except for the first ward where three villages were surveyed instead of two). Each day, prior to starting the surveys, a common introductory meeting was held in the village office, in the

[3]Extension officers are state employees whose main purpose is to link farmers with the administration. In that sense, the role of these officers is *not* to push for any particular agricultural strategy.



(a) Surveying team



(b) Typical interview set-up

Figure 4.2: Data collection pictures (1/2)

presence of farmers, the survey team, the ward agricultural extension officer, as well as village officials (village head and village chairman). During these meetings, the purpose of the research was explained to the farmers and the opportunity was taken to answer any questions before starting the individual surveys. These usually took place outside the village offices.

To collect qualitative data, we ran a series of focus groups on BG in four villages. While quantitative surveys are useful in capturing the degrees of subsistence or commercialisation in agriculture, they cannot easily capture issues relating to customs and traditions as these are difficult to quantify. Focus groups, on the other hand, allow for a discussion with farmers about the issues surrounding the farming of BG, from traditions and village norms to household use of the crop and comparisons with other crops. In that sense, we treat focus groups as a complement to quantitative surveys, rather than as preliminary work that leads to subsequent design of questionnaires. Doing the focus groups after the surveys also allowed us to discuss concerns and issues that farmers had raised in all villages surveyed, and get explanations for some quantitative patterns observed during the first phase of data collection. For example, while BG is very widely grown in this district, it is typically planted on small areas, with correspondingly small harvests. Focus groups allowed us to enquire why, and how could BG be such an important crop in terms of frequency (numbers growing), but a relatively minor crop in terms of output.

The four villages for focus groups were selected to reflect the diversity of environments found in the Mtwara rural district. The first was conducted in Nanguni (Mayanga ward), a village close to infrastructure networks (large tarmac road to city) but relatively far



(a) Focus group in Mtama



(b) Mtwara central grain market

Figure 4.3: Data collection pictures (2/2)

from an urban centre as such. The second took place in Mtama (Lipuidi ward), a village far inland and not accessible via tarmac road with no urban centre close by. The third focus group was organised in Mwindi (Mbawala ward), and represents a location with good infrastructure and connection to a close-by urban centre (Mtwara town). Finally, the fourth session was run in Mnazi (Nalingu ward), a coastal village where livelihoods depend not only on agriculture, but also largely on fishing, an activity exclusively carried out by men.

For each focus group, we aimed at bringing together a group of six farmers. This is in line with the qualitative literature on focus groups which suggests an ideal group size comprised between 6 and 8 persons (see for example Bloor (2001)). Each session ran for about an hour and a half. The only requirement we specified for the focus groups was to have a mix of growers and non-growers, and a mix of male and female farmers (i.e., we did not require fixed proportions to be maintained in each focus group). In 2 of the 4 villages, we had a balanced group in terms of gender (3 males and 3 females).

Further, to capture the commercial aspect of the BG at higher levels along the value chain, we conducted a group interview of three agricultural traders at the central grain and legumes market of Mtwara. Doing so allowed us to capture a dimension of this crop which is largely missing from surveys and focus groups.

4.3.3 Challenges in data collection

A number of challenges arose during the data collection process. During the quantitative data collection phase, the main challenge was to maintain the balance of five growers and three non-growers. Indeed, there was some confusion in the farmers' selection process regarding who was a grower and who was not. We came to understand later that this was due to a misunderstanding of the meaning of 'last agricultural season'. The last *fully completed* harvest was that of summer 2015 (with planting late 2014 and early 2015), but most farmers had already harvested most of their crops for the 2016 harvest, which led to some confusion. However, in most cases, this issue could be rectified by adding a new farmer to the group to make sure the balance was maintained, or by maintaining the balance at the ward level (if the balance could not be maintained in the first village in a given ward, the group of farmers could be altered in the second village so as to maintain 10 growers and 6 non-growers within that ward). In rare occurrences, the balance could not be maintained. During focus groups, the main challenge was to get everyone to talk, especially women, who participated very little in the Mtama village. In Mnazi, we faced the challenge that too many people turned up to the meeting. After explaining several times that this meeting was intended for a group of six farmers only, no farmer seemed to be ready to leave the room so we had to conduct the focus group with 11 farmers which was impractical and partially hampered in depth discussion on BG. However, this was the last focus group and by then we were reaching saturation of information. No problem was faced for the group interview of traders at Mtwara central market.

Apart from the general and organisational issues mentioned above, a more practical problem encountered during quantitative data collection relates to issues of measurement of agricultural variables. Since we collected primary data for this project, we are able to comment directly on issues associated with the measurement of key agricultural variables that are often encountered in agricultural datasets, such as physical harvests, physical sales, or selling price (usually per kg). Very often, further complications arise because measurement problems are crop specific, since quantities for one crop can be naturally expressed in many ways which differ across crops. For instance, nut crops (such as groundnut) can be weighed in terms of shelled or unshelled produce, while root/tuber crops (such as cassava) can be measured in their fresh or dry forms. In the part of the questionnaire concerned with agricultural variables, physical quantities needed to be coded in kg. Very often, farm-



(a) Tanga measurement units



(b) Viroba measurement units

Figure 4.4: Example of local measurement units at Mtwara Central Market

ers use alternative measures of quantities, each suited to a particular crop. For example, cassava is typically measured in terms of baskets (*tanga*), while cashew will be measured in terms of large polyester bags (*viroba*). Conversion to kg units is not straightforward for several reasons. The first is that each container filled with produce after harvest is 'more or less' full, which creates variation in weights (as can be inferred from Figure 4.4, which shows *tanga* and *viroba*). The second is that different varieties of a same crop will give a different weight per unit of produce. Yet the most important reason is the fact that even farmers do not consistently agree on how much a full container of a given crop weighs. Therefore, in the absence of the possibility of weighing the physical harvest of every farmer, agricultural physical variables will all come with a bias, the magnitude of which can hardly be estimated. However, there is no reason to believe the bias is not systematic across villages. More generally, approximations needed to be made for general physical magnitudes as farmers needed to recall how much was harvested, how much stored, and how much sold.[4]

4.4 Analysis and Discussion

Results from both the surveys and the focus groups reveal the popularity of Bambara among growers and non-growers. Table 4.2 reports the pattern of responses to eight statements about the crop for growers and non-growers separately. The statements are adapted from Adzawla *et al.* (2016b).

[4]This is an important limitation of agricultural datasets. See Gourlay, Kilic and Lobbell (2017).

Table 4.2: Distributions of responses to statements about BG (in %)

	Growers			Non-growers		
	Agree	*Disagree*	*Undecided*	*Agree*	*Disagree*	*Undecided*
Bambara has good yields	84.89	11.00	4.11	71.06	8.36	20.58
Bambara needs little rainfall	72.25	24.14	3.61	67.10	14.98	17.92
Bambara requires little amount of fertiliser	80.62	4.76	14.61	66.88	4.50	28.62
Bambara requires little amount of labour	46.80	53.20	0.00	43.73	39.87	16.40
Bambara tastes good	97.04	1.81	1.15	97.43	0.00	2.57
Bambara is a nutritious crop	73.07	0.33	26.60	59.81	0.64	39.55
Bambara has a good market	41.54	40.23	18.23	42.77	27.33	29.90
Bambara can be sold under several different forms	98.03	0.66	1.31	93.25	0.64	6.11

Table 4.2 shows that even though the proportion of 'undecided' answers is larger among non-growers than growers, there is nonetheless wide agreement regarding the positive properties of the crops in both groups. The rate of agreement with the statement on yields is particularly strong, especially among growers (85%). This shows that despite recurrent problems of pests and diseases affecting the crop (as commented upon in focus groups), BG is considered a reliable crop in terms of yield. Both growers and non-growers also largely agree with the statements regarding the low rainfall and fertiliser requirements of the crop. BG is relatively drought tolerant and can fix nitrogen in the soil, thereby improving yields of other crops such as maize (Ani *et al.*, 2013). The pattern of responses for 'BG requires little amount of labour' is different: there is no consensus among growers as to whether it requires lots of work or not. One possible explanation is that some farmers follow recommended agronomic practices (which encourage weeding two to three times a year, ploughing as well as ridging) while others do not.[5] Regarding the statement about whether there is a good market for BG, responses are mixed. In the case of growers, 42% of respondents agree, 40% disagree and 18% are undecided. Being a grower and yet undecided about availability of market is consistent with the evidence that the crop is often retained for home consumption, or sold outside formal market networks, as explained later in this section. Finally, the large agreement rates regarding the nutritious aspect of BG are consistent with its high protein content.[6]

The high levels of agreement with the statements 'BG has high yields', 'BG requires little amount of fertiliser', and 'BG needs little rainfall' are consistent with the literature on underutilized crops which insists on the climatic resilience and good production capacity of these crops. These response rates suggest that the advantages of indigenous crops described in the literature are also perceived by farmers.

The focus groups also highlighted the importance of the crops in local livelihoods. For example, it is a very popular crop during the month of Ramadhan and it is easily digested. It is also praised for its heartiness: it can sustain farmers through a full day of work in the fields.

[5]However, there may also be some confusion in the way the statement is asked, because of the negative included in the question, which in some instances made the task of agreeing or disagreeing with the negation slightly hard to understand for farmers.

[6]BG is richer in proteins that groundnut, cowpea and pigeon peas, the other legumes grown in the region. Its protein content varies between 16 and 25% (Azam-Ali *et al.*, 2001).

In this section, we therefore examine why BG is not more widely grown, despite evidence of its popularity in the villages. We first begin by examining whether growers and non-growers differ in important socio-economic characteristics, housing conditions and access to energy. We then look at the factors influencing the decision to grow the crop. Finally, we explore the drivers of market participation and the constraints to marketing the crop.

4.4.1 Are BG growers different from non-growers?

Demographic and farming characteristics

Our sample is made of 61.2% of growers and 38.8% of non-growers (this is indeed very close to the target we had set of having 5 growers and 3 non-growers per village, which is equivalent to 62.5% and 37.5% respectively). Table 4.3 presents summary statistics for demographic data and household structure, and Table 4.4 presents statistics for key farm-related variables.

Table 4.3: Demographic Summary Statistics

	Non-growers				Growers				Diff in means
	mean	sd	min	max	mean	sd	min	max	P-value
No of members in HH	5.16	1.86	1.00	11.00	5.47	2.69	1.00	28.00	0.27
No adults aged 16-65	2.54	1.26	1.00	9.00	2.59	1.43	0.00	14.00	0.77
Adults over 65	0.20	0.49	0.00	2.00	0.35	0.65	0.00	3.00	0.07*
Children (under 16)	2.46	1.44	0.00	7.00	2.56	1.78	0.00	13.00	0.50
Age of head	48.37	12.91	22.00	72.00	50.63	13.42	23.00	86.00	0.19
Gender of head (1=female)	0.14	-	0.00	1.00	0.13	-	0.00	1.00	0.66
Educ of head (1=primary or more)	0.60	-	0.00	1.00	0.62	-	0.00	1.00	0.66
Observations	99				152				

Note: Full definitions of variables are reported in Table D.1 in the Appendix

* indicates significant at 10%, *** at 5%, *** at 1%

Table 4.4: Farm Summary Statistics

	Non-growers				Growers				Diff in means
	mean	sd	min	max	mean	sd	min	max	P-value
Had farming training? (1=yes)	0.23	-	0.00	1.00	0.28	-	0.00	1.00	0.38
Farm size (acres)	3.87	3.11	0.25	19.00	4.68	3.70	0.25	20.00	0.03**
No. plots	1.90	0.93	1.00	5.00	2.28	1.15	1.00	9.00	0.00***
Rent land? (1=yes)	0.21	-	0.00	1.00	0.20	-	0.00	1.00	0.89
Number of plots you own	1.64	1.06	0.00	5.00	2.08	1.22	0.00	9.00	0.00***
Years spent farming?	21.71	12.66	2.00	50.00	23.73	14.87	2.00	68.00	0.29
No. of crops grown on farm	3.11	1.41	1.00	7.00	3.84	1.28	1.00	8.00	0.00***
Agricultural revenue (Tshs 1000s)	535	806	0	4720	642	908	0	6819	0.31
Cashew grower (1=yes)	0.45	-	0.00	1.00	0.58	-	0.00	1.00	0.04**
Observations	100				157				

Note: Full definitions of variables are reported in Table D.1 in the Appendix

* indicates significant at 10%, *** at 5%, *** at 1%

The last column of the table reports the p-values for t-tests which establish whether the differences in means across the two groups are statistically significant. P-values for the t-test reported in Tables 4.3 and 4.4 are those for the alternative hypothesis that the difference in means is different from zero (i.e.: $mean(non-grower) - mean(grower) \neq 0$).[7] The average number of persons normally resident in the household and the number of working-age adults is very close across the two groups. The head of household is slightly older on average for BG growers, but this is not statistically significant. The only variable for which there is a significant difference in means is the number of adults over 65, but it is only significant at the 10% level.

While there are no marked differences in means of demographic variables, there are important difference in farming characteristics. Farm size, number of plots farmed and number of plots owned are larger for BG growers and all have a statistically significant difference in means. However, farm size tends to be extremely low, at 3.9 acres and 4.7 acres for non-growers and growers respectively (equivalent to 1.2 and 1.6 hectares).[8] The number of plots farmed and owned is also very small on average for both subgroups. Also note that the total number of crops grown on the farm is significantly larger for growers. This difference is consistent with the information contained in the last row of the table: BG growers are significantly more likely to be growers of cashew. Cashew is a main source of cash for farmers in the area as it is an export crop. The average total agricultural revenue is larger for growers, although the difference in means is not significant.[9] These statistics show that growing and non-growing households are very similar in terms of demographics, but that growing households tend to have slightly larger farms, and may be slightly less cash constrained than non-growers as they are more likely to grow cashew.

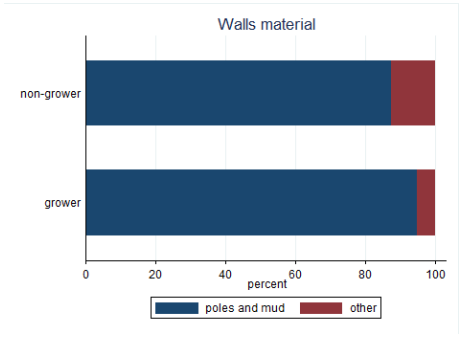
Housing conditions and access to energy

The previous summary statistics tables show that there are no important differences between growers and non-growers in terms of socio-economic and demographic characteris-

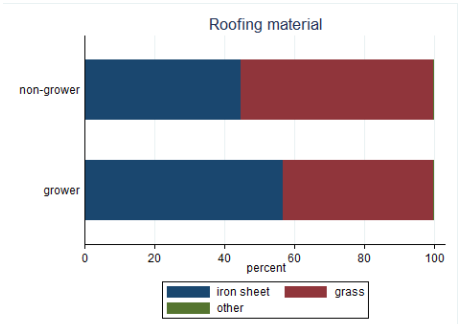
[7] Using a Wilcoxon non-parametric test instead of the standard t-test gives the same results for all summary statistics presented here.

[8] Farm size in this study is understood (and measured) as the total size of land which was farmed during the 2014/2015 season (i.e., it does not include any land that a household may own but did not farm that year). This distinction also applies for number of plots.

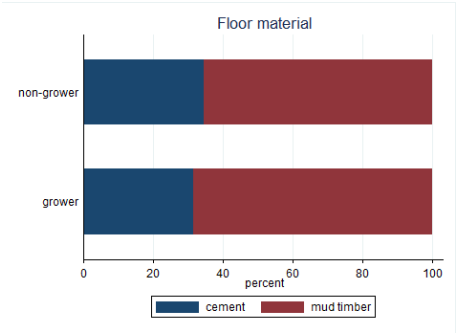
[9] By total agricultural revenue we refer to the revenue derived from direct sales of crops during the 2014/2015 season. Therefore, this include all sales of primary produce but does not include any income derived from the processing or agricultural produce subsequently sold. To calculate this revenue, we evaluated sales using price per unit for each crop, aggregated at the farm level.



(a) Walls



(b) Roof



(c) Floor

Figure 4.5: Distribution of Housing Variables

tics, but that growers tend to have bigger farms (both in terms of area grown and number of plots). We now present summary statistics related to housing and living conditions. Part of our questionnaire was specifically designed to assess whether housing and energy access conditions differ between growers and non-growers.[10] Figure 4.5 presents distributions of responses regarding housing conditions, while Figure 4.6 presents those relating to access to energy.

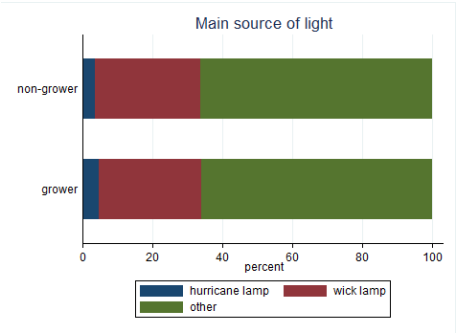
In the case of wall and floor materials used to construct houses, answers reported are largely similar across the two subgroups. There is more variation for materials used for roofing, with a larger proportion of roofs built with iron sheet (more solid than grass) among growers than non-growers. The difference in means is significant at the 5% level using a *t-test*. This suggests that growers are slightly better off that non-growers in terms of living standards, since iron roofs constitute a better roofing than grass.[11]

In terms of energy related variables, Figure 4.6 reports bar charts for the distribution of answers to questions about the main source of light, cooking energy and drinking water

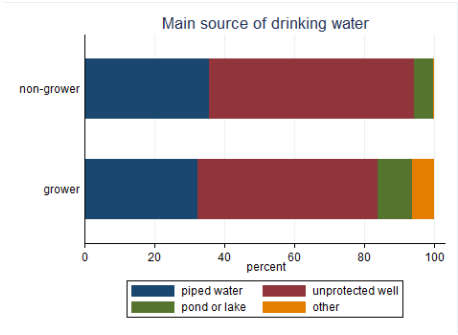
[10]This part of the questionnaire draws upon questions asked in the 2002 Tanzania population census.

[11]This is not a causal claim but an observation in the data. It could be that farmers will larger farmland decide to add BG to their crop mixes.

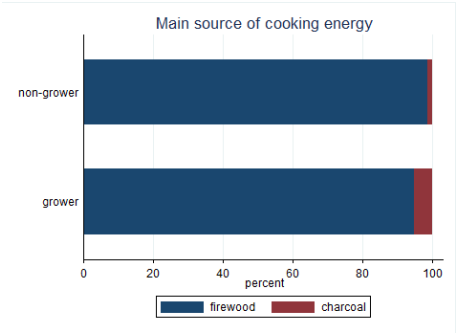
used by households. The distribution for the main source of light is very similar across groups, as are sources of cooking energy and drinking water. An overwhelming majority of farmers use firewood to cook, and use either tap water or unprotected wells as a source of water. The fact that a household uses a tap as a main source of water should not be understood as a sign of personal wealth: this refers to village taps where the village has collectively invested in a tap system (usually because a major source of drinking water is located nearby). In some villages, villagers must pay a fee for each bucket of water collected at the tap.



(a) Main course of light



(b) Main source of drinking water



(c) Main source of cooking energy

Figure 4.6: Distribution of Energy-related Variables

We have shown that there are no significant differences between growers and non-growers in terms of demographic status. Summary statistics for farm and housing conditions variables reveal that the two-subgroups are largely similar, even though BG growers seem to be slightly better off: they tend to have bigger farms, and are more likely to have an iron roof than non-growers. For completeness we also produced summary statistics for assets (ownership of a means of transport, of animal power and of a phone). The means

[12]Therefore, if a farmer said he/she started growing BG for food consumption, while another said he/she started for food consumption and income generation, both answers are reported as belonging to the 'Food consumption' category on the graph because food consumption is either the only or the main reason reported.

are very close across subgroups and no statistically significant difference between them is found (see Table D.2 in the appendix).

4.4.2 Why do farmers grow BG?

Figure 4.7 reports the main reason why growers started planting BG.[12]

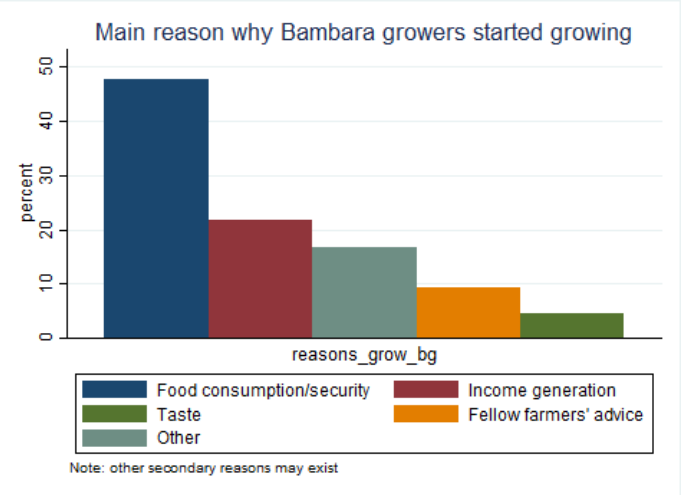


Figure 4.7: Distribution of the main reason why farmers started growing BG

Almost half of growers reported food consumption or food security as their main reason for growing. Income generation is the second highest response with 20% of observations, confirming that BG serves both consumption and income purposes, albeit it seems to be more often used for food consumption. Fellow farmers' influence seems to be a driver of moderate importance, for 10% of growers. Focus groups and short interviews with farmers confirm that BG is primarily considered as an important crop in terms of food consumption and security, and that, as a secondary feature, it also serves for income generation purposes (although that may be constrained due to poor marketing channels as explained in section 4.4.3). For example, one farmer in the Mwindi village said the following: '*Bambara is a good crop, it is good for health, and it helps for food consumption and also as a source of income*'.

To study the factors that differentiate growers and non-growers, we estimate a model of the determinants of being a grower. Since the dependent variable is a binary variable, we estimate a probit model and report average marginal effects. Formally, the estimated

model is:

$$Pr(Grower = 1|x) = \Phi(\alpha + \beta_1 Market_j + \boldsymbol{\beta_2 Farm_i} + \boldsymbol{\beta_3 HH_i} + \boldsymbol{\beta_4 Assets_i} + \gamma_w) \quad (4.1)$$

The variable *Market* captures the presence of a marketplace in village j (binary variable). The vector of farm-related variables includes the total number of workers on the farm (family and hired labour), and whether the household received farming training (binary variable). In model 1, it further includes farm size, and in in model 2 a dummy taking the value of 1 if the household grows cashew. The vector of household variables includes the dependency ratio, the total number of persons in the household, the age and gender of the head of household, as well as a dummy taking the value of 1 if he/she has completed primary school. In the last variant of the model, we use a dummy taking the value of 1 if the household has an iron roofed house. The regressions include ward fixed effects (γ_w) to account for unobserved heterogeneity across wards.

Farm size (model 1), being a cashew grower (model 2) and having an iron roof (model 3) are all alternative proxies for relative wealth. Hence, we run these three different models as a robustness check exercise to see whether results hold with different measures of relative wealth.

Table 4.5: Determinants of being a grower: marginal effects

	Grower	Grower	Grower
Farm size	0.022**		
	(0.011)		
Cashew grower		0.142**	
		(0.068)	
Iron roof			0.168**
			(0.067)
Market	-0.074	-0.073	-0.065
	(0.087)	(0.088)	(0.088)
Dep ratio	-0.024	-0.019	-0.025
	(0.032)	(0.031)	(0.033)
Number HH	0.017	0.019	0.016
	(0.016)	(0.015)	(0.015)
Age head	0.004	0.004	0.004*
	(0.003)	(0.003)	(0.003)
Female head	-0.025	-0.024	-0.059
	(0.099)	(0.098)	(0.099)
Primary educ	0.065	0.075	0.082
	(0.069)	(0.068)	(0.068)
Workers	-0.011	-0.007	-0.006
	(0.012)	(0.011)	(0.011)
Farm training	0.036	0.028	0.023
	(0.075)	(0.075)	(0.075)
Transport	-0.060	-0.059	-0.072
	(0.073)	(0.072)	(0.072)
Phone	-0.018	-0.019	-0.055
	(0.074)	(0.073)	(0.074)
Formal job	-0.162	-0.124	-0.171
	(0.191)	(0.194)	(0.196)
Seasonal job	0.065	0.067	0.085
	(0.072)	(0.072)	(0.072)
N	243	243	243
$Pseudo - R^2$	0.06	0.06	0.07
Ward fixed effects	yes	yes	yes

Robust standard errors in parentheses (clustered at the farm level)

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

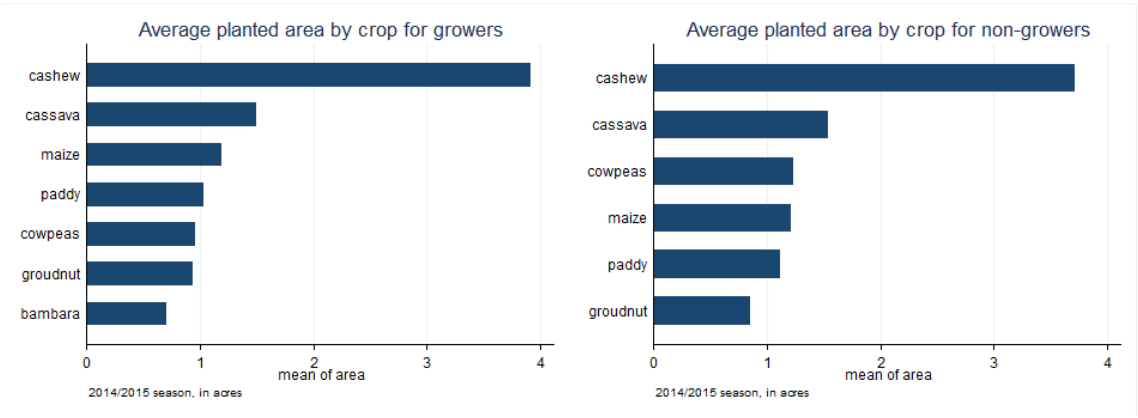
Results, shown in Table 4.5, are consistent with evidence from the summary statistics reported in the previous section. In particular, we see that there are no differences between growers and non-growers in terms of household characteristics or assets. The only difference we find is that growers tend to have larger farms (column 1), which correlates with being a cashew grower (column 2). Because growers tend to have larger farms, they may be slightly wealthier: the coefficient on iron roof is also positive and significant in column 3. The presence of a marketplace in the village has no impact on the decision to become a grower: commercial motives are not the main driver of BG cultivation.

The surveys and focus groups also reveal two other potential factors constraining the growing of Bambara: the labour required and access to a market for sales. Most farmers, irrespective of being a grower or not, do not think Bambara requires little labour or has a good market (Table 4.2). The majority either disagree or are undecided regarding both statements (disagreement is higher among growers while indecisive answers are higher for non-growers). The focus groups highlight the problem of a lack of a reliable, permanent market where large quantities can be sold as a reason why farmers do not grow, or stop growing Bambara. However, as with the surveys, responses were not unanimous and a number of others did respond stating Bambara had a good market. Similarly for labour input, there were some who stated Bambara was easy to grow while others found the crop to be quite tedious to grow, requiring a lot of ploughing and preparation. Nevertheless, although many growers do think Bambara is quite laborious and has a poor market they were undeterred from growing.

To understand how does BG compare with other crops in contributing to local livelihoods, we can compare it with the other main crops grown in Mtwara. The number of crops grown in Mtwara rural district is relatively small: seven crops constitute 88% of observations in our agricultural dataset.[13] These are: BG, cashew, cassava, cowpeas, groundnut, maize and paddy.

Figure 4.8 shows that BG has the smallest average cultivated area among the most im-

[13]However, note that garden crops grown around the house are not included in the analysis if the surface is less than 0.25 acre (the minimum surface we used to qualify as a plot). In practice, farmers often grow some crops around the house that are not listed here, such as potato leaves or amaranth (marginal crops themselves).

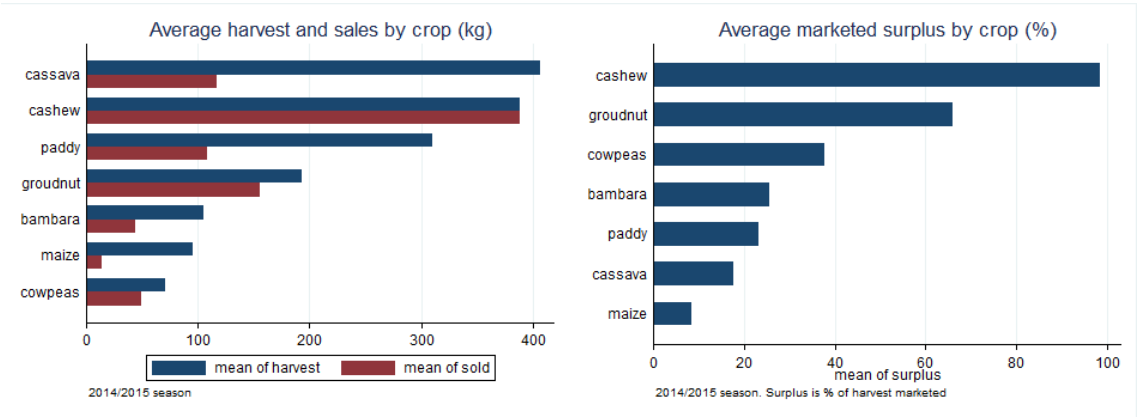


(a) Growers (b) Non-growers

Figure 4.8: Average planted area for the main crops

portant crops, at about 0.7 acres planted. Cashew and cassava have, on the other hand, the highest average planted areas, which can be explained by the fact they are the main source of cash and food respectively. This holds for both growers and non-growers. This is also largely explained by the fact that cashew plots tend to be much larger than any other plots, and that when intercropped, cashew is most often intercropped with cassava. Non-growers of BG have an average cultivated area of 1.26 acres for cowpeas, larger than the average for growers, at 0.96 acres. Although this difference is not statistically significant it may indicate that non-growers tend to rely on other legumes such as cowpea if they do not grow BG. For both growers and non-growers groundnut is cultivated on small areas (less than one acre on average for each subgroup).

While these graphs start bringing a more precise picture of local farming, they are not enough to describe precisely the nature of each crop for two reasons. The first is that area planted and harvest levels are not highly correlated. Some crops, typically legumes, bring a physically small harvest, while cereals or export crops give much higher harvests in terms of physical product. The second is that to understand the nature of each crop, one must look at both physical harvest and sales. Figure 4.9a reports average physical harvest and sales for each crop. We also present a graph of average marketed surplus (Figure 4.9b), which is another way to present the information contained in Figure 4.9a. Marketed surplus is defined as the percentage of physical harvest which is sold. It is thus a measure of commercialisation and helps assess the degree of marketability of a given crop. Intuitively, export crops, or crops clearly identified as cash crops will have a marketing surplus approaching 100% while subsistence crops will have a very low marketed surplus.



(a) Harvest and sales

(b) Marketed surplus

Figure 4.9: Average harvest and sales and corresponding marketed surplus

On the one hand, cashew is a cash generating export crop virtually only grown for sales. As a result, sales and harvest are almost identical (Figure 4.9a). It has a marketed surplus of almost 100% (Figure 4.9b). On the other hand, cassava is not heavily sold by farmers because it is the backbone of local diets (Figure 4.9a), and hence has a low marketed surplus. A similar reasoning applies to maize. However, for the other crops in the analysis, the picture is not so clear. Although groundnut is seen as a cash crop, with a large marketed surplus of 66%, one third of the harvest is still, on average, retained for home consumption. For cowpeas, BG and paddy the picture is even more complicated. All these crops have a non-negligible average marketed surplus between 23% and 38%, but are mainly retained for home consumption. Their primary function is thus to satisfy household food requirements and contribute towards food consumption/security, while also serving a secondary purpose in terms of income generation. One could object that farmers' storage can be used for both consumption *and* future sales, thus undermining our interpretation of Figure 4.9a. However, clarifications during the quantitative surveying phase as well as anecdotal evidence from the focus groups reveal this is not a major concern. Virtually all produce stored is kept for home consumption. The only exception to this is when farmers store a few kilograms of the crops to be used as seeds for the next planting season. These are usually kept in plastic bottles and represent a negligible proportion of total storage. We assume in the rest of this chapter that storage is used for home consumption only.

The information contained in Figure 4.9 is useful in getting an idea of the status of each individual crop. However, average marketed surplus or sales may be driven by a few

outliers (for example, a few farmers entirely selling a large harvest). To bypass this possible shortcoming, Figure 4.10 shows the proportion of households retaining their whole harvest, that of households mostly consuming, and that of households mostly selling.[14]

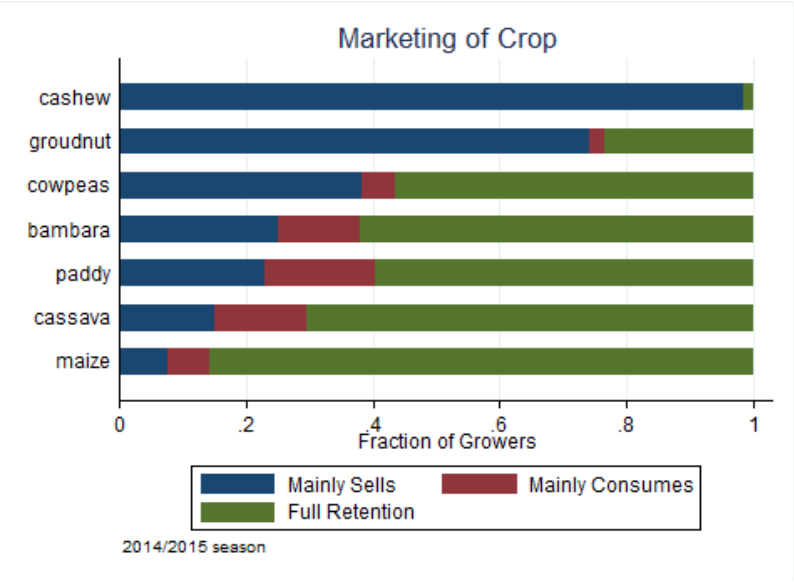


Figure 4.10: Degree of commercialisation of different crops

Figure 4.10 confirms the export status of cashew. More interestingly, it reveals that the large majority of households fully retain production of cassava and maize, the basic staple foods. It also helps to provide a clearer picture of the difference between BG and groundnut. More than 70% of farmers growing groundnut sell at least half of their production, with only about a fourth of groundnut farmers fully retaining their production, thus more clearly revealing the cash status of the crop (more so than Figure 4.9b could do by simply plotting average surplus). On the other hand, a fourth of BG farmers mainly sell, while more than 60% of them fully retain the crop. There is also a larger proportion of 'mainly consumers' among BG growers than among groundnut growers. Cowpea seems to occupy an intermediary position between groundnut and BG.

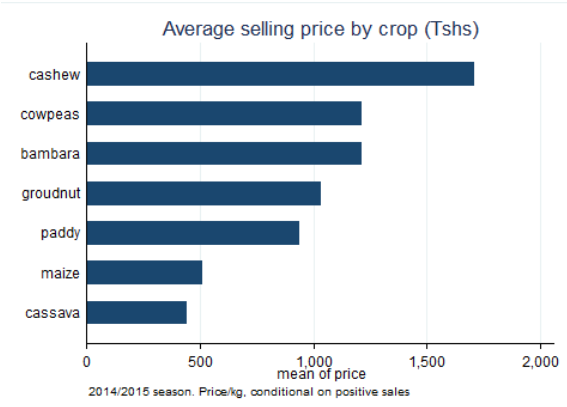
This interpretation is consistent with qualitative evidence on BG gathered during focus groups. BG is an important contributor to diets because it helps solve the side dish (*mboga*) problem. Farmers' meals largely rely on *ugali*, (processed cassava or maize flour), for which they often lack side dishes. BG is a useful food because it constitutes a good

[14] We define households as mostly consuming when at least half of the production is kept for consumption, and mostly selling when at least half of the production is marketed.

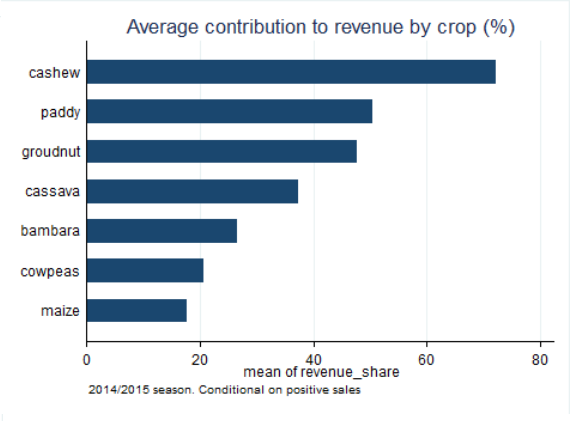
side dish to *ugali*, and it is a strong source of protein, which complements the heavy carbohydrates content of *ugali*. Further, it can be eaten as *futari*, a small meal of its own before working in the field. BG is also heavily consumed during the holy month of Ramadhan, because it is a soft food easy to eat and digest. Further, there is also evidence that BG is sold to generate cash but this is of secondary importance due to the market not being well developed. As explained in more detail in the next section, trade often happens between farmers in the village, outside formal market structures. The following quote from a farmer in Namgumi village sums up this issue well: 'It's a good crop for food consumption, sometimes a good source of income too, but there is no permanent market for it, which is a problem' (Rachid Abdulrahman).

4.4.3 What are the constraints to marketing Bambara?

In the previous section we provided evidence that BG is an important contributor to diets and thus contributes towards households' food security. However, we have also given shown that it has a secondary purpose of income generation, with a marketed surplus of 25%. Both quantitative and qualitative evidence confirm the idea of BG being a secondary source of income. In fact, most farmers showed a great willingness to market more of BG provided they have access to improved seeds and marketing channels. In this section, we examine the marketing constraints specific to BG in Mtwara. A good starting point to assess this potential is to look at the average selling price of BG in Tanzanian shillings (henceforth Tshs) and see how it compares with other crops, as well as the average contribution made by crops to total agricultural revenue. This is shown in Figures 4.11a and 4.11b respectively.



(a) Average selling price per kg



(b) Average contribution to agricultural revenue in %

Figure 4.11: Selling price and crops' contribution to agricultural revenue

Figure 4.11a reports average selling price per kg of produce conditional on positive sales. Cashew has the highest selling price at approximately 1711 Tshs/kg, followed by cowpeas (1216 Tshs/kg) and BG (1214 Tshs/kg). The average selling price of groundnut, the closest crop to BG, is lower at 1037 Tshs/kg. Therefore, despite the fact that farmers tend to grow less BG than groundnut and tend to market a smaller surplus, the former has a higher selling price than the latter on average. One possible reason for such high price is a clear shortage of supply before planting season when seeds are not easily available and sell at a high price. In the focus group in the Nangumi village, farmers explained that after harvest (May-June), Bambara sells at around 500 Tshs per kg, but that around January prices can reach 2,500 Tshs due to scarcity. Similarly, the focus group in Mtama, reported that post-harvest price oscillates between 1,000 and 1,500 Tshs per kg while it lies between 2,000 and 2,500 before planting. This is a first indication that improving storage capacity would allow farmers to retain a higher share of the production right after harvest to sell later in the year when farmers need seeds for planting.[15]

Figure 4.11b shows average contribution to total agricultural revenue conditional on positive sales of any crop. For example, if paddy has a contribution of 50% for a given household, this means that out of all the agricultural revenue obtained from crop sales by paddy sellers, half of that amount comes from paddy sales. Cashew is, as expected, the main contributor. Groundnut has the third highest contribution, which confirms its strong cash crop features. The second highest ranked is paddy. Although this may appear counterintuitive given its rather low marketed surplus, this is because it is typically sold in large amounts, which mechanically makes it an important contributor to revenue.[16] Cassava is also a relatively important contributor because, despite having a low selling price, it is also sold in large quantities, with average sales of 418 kg. BG has a more modest contribution to revenues, although a non-negligible one at 27%.

To understand the economic and market potential of BG we can use regression analysis to study the determinants of market participation. To do so we estimate Probit models, and report average marginal effects. Key goodness of fit measures of the Probit models

[15] Current storage capacity for BG is very low. The crop is usually stored in sealed clay pots which do not contain large volumes, or in plastic buckets/containers.

[16] Average sales of paddy amount to 286 kg, higher than groundnut (203 kg), BG (126 kg) or maize (106

are reported in table D.3 in the Appendix.

We estimate the following specification:

$$Pr(Seller = 1|x) = \Phi(\eta + \gamma_1 ln(Harvest_c) + \boldsymbol{\gamma_2 HH_j} + \boldsymbol{\gamma_3 Farm_j} + \gamma_4 Market_j) \quad (4.2)$$

Where $\Phi(.)$ is the normal distribution function. As shown in the chapter on output marketing, studies looking into market participation usually include a price variable. However, the latter is excluded here as there is little variation in prices given the small geographic area used and any variation there is would be subsumed by village or ward fixed effects. The harvest variable measures the total physical harvest, in kilograms, of the crop on the farm (i.e., across plots if a crop is grown on several plots). The vector of household characteristics includes: the dependency ratio, the total number of persons in the households, the age, sex and education level of the head of household, and dummies taking the value of one if the household owns a means of transport, and a phone. The vector of farm related variables includes the following: the number of household members working on the farm, the number of hired workers, farm size, a dummy taking the value of one if the household rents one or more plot(s), a dummy taking the value of one if it uses chemical inputs, the total number of crops gown, a dummy taking the value of one if it is a cashew growing household, and a dummy taking the value of one if anyone in the household received farming training. Finally, the *Market* variable is a dummy taking the value of one if there is a physical marketplace in the village.

The dummy capturing farming training can be seen as a proxy for farming and commercial knowledge which may influence participation. The dummy capturing chemicals usage proxies access to an important variable input. As explained in the previous chapter, such variables can help mitigate transaction costs and hence facilitate market participation. By 'market participation', we refer to the process of selling crop output, no matter in which quantity, and more importantly, no matter how and where. Hence, one call sell output (i.e., participate in the market) even though there is no physical market in the village as such.

For each crop (category of), we estimate a specification without ward fixed effects and

kg), conditional on positive sales.

another with fixed effects. Table 4.6 presents the marginal effects on the probability of becoming a seller.

Table 4.6: Drivers of market participation: marginal effects from probit models

	All crops		BG		Cassava		Other legumes	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Market	0.046	0.070	0.270***	0.249***	-0.022	-0.031	-0.079	-0.127
	(0.034)	(0.045)	(0.070)	(0.086)	(0.068)	(0.074)	(0.072)	(0.096)
Harvest	0.129***	0.125***	0.154***	0.128***	0.163***	0.143***	0.200***	0.209***
	(0.012)	(0.012)	(0.030)	(0.036)	(0.036)	(0.033)	(0.020)	(0.026)
Dep ratio	-0.000	0.005	0.041	0.012	-0.007	-0.003	0.044	0.045
	(0.019)	(0.016)	(0.039)	(0.038)	(0.033)	(0.027)	(0.031)	(0.028)
Number HH	-0.009	-0.015**	-0.002	-0.006	-0.018	-0.020	0.007	-0.003
	(0.006)	(0.007)	(0.010)	(0.011)	(0.018)	(0.014)	(0.008)	(0.010)
Age head	-0.002*	-0.002	-0.003	-0.001	-0.001	0.002	0.000	-0.003
	(0.001)	(0.001)	(0.002)	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)
Female head	-0.076*	-0.004	-0.333***	-0.308**	-0.037	0.042	-0.104	-0.105
	(0.046)	(0.046)	(0.121)	(0.122)	(0.108)	(0.103)	(0.115)	(0.096)
Primary educ	-0.011	-0.022	-0.173**	-0.149**	0.090	0.069	-0.116*	-0.029
	(0.038)	(0.033)	(0.070)	(0.067)	(0.075)	(0.064)	(0.068)	(0.056)
Transport	-0.068*	-0.029	-0.175**	-0.127	0.044	-0.015	-0.102	-0.035
	(0.037)	(0.039)	(0.071)	(0.083)	(0.076)	(0.079)	(0.075)	(0.065)
Phone	-0.055	-0.009	-0.175***	-0.127*	0.011	0.026	-0.028	0.034
	(0.036)	(0.035)	(0.068)	(0.075)	(0.069)	(0.078)	(0.071)	(0.070)
Family workers	0.009	0.020	-0.016	0.011	0.072	0.098*	-0.132**	-0.084
	(0.027)	(0.025)	(0.048)	(0.044)	(0.050)	(0.053)	(0.055)	(0.051)
Hired workers	0.002	0.001	-0.016*	-0.032***	0.020**	0.029***	0.005	0.019
	(0.006)	(0.005)	(0.009)	(0.011)	(0.010)	(0.010)	(0.012)	(0.012)
Seasonal job	-0.068*	-0.060*	-0.158**	-0.143**	-0.030	0.002	-0.005	0.048
	(0.035)	(0.033)	(0.070)	(0.067)	(0.070)	(0.060)	(0.071)	(0.073)
Farm size	0.004	0.005	0.030***	0.027**	0.001	0.015	0.003	-0.007
	(0.005)	(0.005)	(0.011)	(0.011)	(0.010)	(0.011)	(0.011)	(0.011)
Rented plot(s)	0.085*	0.087*	0.135*	0.023	0.021	0.143*	0.082	0.046
	(0.046)	(0.046)	(0.079)	(0.087)	(0.082)	(0.079)	(0.079)	(0.082)
Chemical use	0.078*	0.118***	0.125	0.203**	-0.050	-0.005	0.252***	0.331***
	(0.041)	(0.041)	(0.090)	(0.093)	(0.080)	(0.076)	(0.078)	(0.073)
Number of crops	0.013	0.007	0.065**	0.063**	0.035	0.016	-0.003	-0.017
	(0.016)	(0.013)	(0.030)	(0.029)	(0.026)	(0.025)	(0.026)	(0.024)
Cashew grower	0.130***	0.130***	-0.241**	-0.238**	-0.022	-0.076	-0.177*	-0.165*
	(0.039)	(0.041)	(0.099)	(0.108)	(0.081)	(0.083)	(0.096)	(0.085)
Farm training	0.001	0.034	0.078	0.111*	-0.167**	-0.178***	0.112	0.141*
	(0.036)	(0.033)	(0.068)	(0.065)	(0.070)	(0.064)	(0.076)	(0.079)
N	828	828	141	133	168	162	148	142
Ward FE	no	yes	no	yes	no	yes	no	yes
Pseudo-R^2	0.14	0.18	0.36	0.44	0.24	0.38	0.38	0.51

Standard errors in parentheses (clustered at the farm level)

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The main result is that the presence of a market has a strong positive and significant effect on market entry only for BG: the presence of a marketplace in the village increases the probability of farmers selling some of their produce by 25 percentage points in the model with fixed effects. Given that the average participation rate for BG across the whole sample is 38%, this represents a substantial increase. In contrast the presence of a market has little impact on the marketed surplus of other crops, remaining insignificant in all the other regressions. These results confirm the idea that the commercial environment is particularly limited for BG; many producers wish to market more but are unable to do so due to poor marketing channels. Also note the important difference with results from Table 4.5, in which we found no significant effect of the presence of a market on the decision to become a grower: marketing potential is not a key driver of the decision to plant, but it has a strong impact on the decision to sell.

The size of harvest has a significantly positive effect on market participation, for all other crops and not just BG, which is expected as commercial intent increases with output. The magnitude of coefficients on harvest is remarkably similar to the magnitudes obtained in participation equations in the previous chapter using the World Bank data.

In terms of household characteristics, female-headed households are less likely to enter the market for BG, where the effect is robust to inclusion of fixed effects: female-headed households have a probability of entering the market for BG about 31 percentage points lower than their male counterparts in the model with fixed effects.[17] This reflects the fact that subsistence farming is more prevalent among female-headed households than male-headed ones, a commonly held view in development economics: 'Cash cropping is considered a male domain in most parts of sub-Saharan Africa, while women are often responsible for the production of subsistence food crops'(Handschuch and Wollni, 2016:314). Note, however, that our results do not imply that BG is a women's crop, but that female-headed households are less likely to sell the crop (indeed, anecdotal evidence from the fieldwork suggests it is widely grown by both male and female farmers). This contrasts with preliminary evidence from neighbouring Malawi, where BG is largely farmed by women (Forsythe *et al.*, 2015).[18] Given that female-headed households are those headed by a widow, one

[17] However the size of the effect needs to be interpreted with caution due to small sample sizes, with only 18 female-headed households growing BG of whom three sold some portion of their harvest.

[18] Although reality is arguably more complicated than a simple dichotomy between cash and subsistence crops. On this issue, see for example the study by Doss (2002) on the limitations of concepts such as

can conjecture that these households tend to be poorer and rely excessively on subsistence farming. In fact, average total agricultural revenue is significantly lower for female headed households (just below 250,000 Tshs) than for male-headed ones (almost 660,000 Tshs).[19]

The marginal effect of having a phone has a large and significant negative effect on the participation decision for BG, and for BG only, which is quite puzzling and hard to interpret, although the significance of this effect decreases to the 10% level with ward fixed effects. Many of the input variables linked to higher productivity and output (such as size of the farm, use of chemical fertiliser, and having farm training) are positive and significant. Although the number of hired workers on the farm has a significantly negative effect for BG, the size of the effect is quite small. The strong negative and significant effect of being a cashew grower on the selling of BG reflects the fact that households who grow for sales choose to grow cashew, the main cash crop in the area with established marketing channels.[20]

Contrasting BG and other legumes (groundnut, pigeon pea and cowpea), its direct 'competitors', the latter benefit from established national and international markets. For example, the consumption of groundnut is spread across Tanzania, unlike that of Bambara, which is much more regional. Cowpea benefits from an expanding international market, as Indian imports are on the rise. Hence, marketing channels for these crops exist, and trade does not depend as much on the presence of a physical marketplace within village boundaries (hence the insignificance of the market dummy for this category). Also note the stronger marginal effect of harvest for these crops, suggesting a more commercial endeavour behind their growing than for BG. Similarly, the dummy for use of chemicals is highly positive and robust to fixed effects, further stressing the more commercial nature of other legumes (for BG, the effect is only significant in the model with fixed effects, with a lesser magnitude).

Farm training only has a clear negative impact on participation in the cassava market. Given that cassava is mainly a subsistence crop with a low selling price, this shows that

'men's crops' and 'women's crops'.

[19] A t-test in difference in means for the alternative hypothesis that revenue is larger in male headed households than female headed ones gives a p-value of 0.005.

[20] This also explains why the coefficient is positive and significant for the 'all crops' category, since the latter includes cashew.

farmers with training may direct their commercial endeavour towards crops with more marketing potential. As such, having received training may indeed be a valid proxy for the mitigation of transaction costs.

The most important result is the effect on selling of having a formal market structure in the village. This confirms that unlike other crops, the market for BG is not well-developed and that formal trading structure in the village can enhance its economic potential. This quantitative result is consistent with qualitative evidence gathered during focus groups and interviews which also reveal that the absence of a market is a crucial barrier hindering the production and marketing of the crop. We now turn our attention to these qualitative aspects.

Qualitative evidence on marketing constraints

The above econometric analysis shows the dramatic effect on commercialisation of BG of the presence of a market-place in the village. To the extent such an effect is not observed for other crops, indicates marketing issues specific to BG. The evidence gathered during focus groups is consistent with results from regression analysis. Indeed, the two major constraints hindering BG marketing are the absence of a market and the unavailability of improved seeds. The following quotes from farmers illustrate this:

'Bambara is a good crop, but we do not have a good market for it, and some farmers stop growing because of that' (Salum Hamis from Nangumi)

'Bambara is a good crop, but the main problems with it are the absence of market and the diseases that can arise' (Adam Fwahili from Mwindi)

The absence of reliable markets

Many non-growers do not grow because of the absence of a market. Without any market structure, trade is very limited and takes place in small volumes.[21] Typically, farmers sell between themselves, and BG is sold to a neighbour, friend, or relative. The absence of well-established marketing channels means that farmers often sell in their fields, straight after

[21] Using all observations (i.e., sellers and non-sellers), average sales of BG amount to 44 kg only, much lower than the main competing legume, groundnut, at 156 kg.

harvest, where the nut is sold fresh. Alternatively, they bring the produce home and sell it boiled in small cups. While we have established that BG does contribute to agricultural income, it is now clear that it is only a secondary source of income. In fact, several farmers explained in the focus groups that BG was a source of cash for unexpected expenses, and was more a short-term source of income than a planned medium or long term one. In that sense, BG cannot compare with cash crops such as groundnut which constitute more established sources of cash, let alone cashew, the main crop from which farmers derive agricultural revenues. The absence of a physical market is particularly stringent for BG because it has very few alternative marketing channels, unlike other crops. For example, cashew is stored after harvest in a safe room and picked up by trucks which bring the harvest to town where auctions take place. Hence, the presence of a village market does not affect sales for this crop. Cassava and maize can also easily be sold to traders who supply restaurants in town with flour to make *ugali*.

There are buyers occasionally coming from town, but their visits are not regular enough to provide the security needed by farmers to treat BG as a commercial crop. During the focus groups, some farmers mentioned how some trading possibility looked promising but did not materialise. In Mnazi, a village official explained he started growing BG because he heard over the radio that traders from the Comoros Islands were coming to buy large volumes of BG. However, he could not manage to get into contact with them to sell his output. In Mtama, traders from Zanzibar sometimes come to buy BG before Ramadhan but not every year. The sales of BG is also complicated by the vast genetic heterogeneity in the varieties cultivated. In most villages there is a strong preference for the white/creamy looking variety, as opposed the red variety, which it typically kept for home consumption. Only the creamy variety is sold in its dried form. Beyond the colour of the nut, some varieties also have a black eye. Because varieties tend to be different across wards or villages, and because of strong local preferences for a given variety, trade of the crop can be further limited by this issue.

Therefore, BG trade is characterised by very low volumes of sales largely taking place within villages, although it is not unusual for farmers in some villages to bring their output to town, or for traders to come to the villages. The interview with traders at the central town market also reveal that the market for BG is largely under-developed at

higher levels along the supply chain. Customers are also irregular for them; for instance, traders from Pemba sometimes come and buy in very large amounts but not regularly enough for traders to be certain they will be able to sell their stocks. There is, however, a more regional trade taking place. Traders have been able to sell output to neighbouring Mozambique via intermediary agents as well as with the Lindi region over the past years. There is also some trade with markets in Dar-Es-Salaam. Trade with more northern regions rarely takes place, largely because buyers in the Comoros Islands or in Mombasa (Kenya) tend to buy from traders in Zanzibar, which is much closer geographically.

As a result, a trader explains that BG is not a priority crop among legumes. It has less importance than other traditional pulses such as cowpeas. It also fails to compete with pigeon pea, which was traditionally a crop with low price but has become more important due to rising exports to India, which have pushed its local retail price to about 2,000 Tshs/kg.

However, traders also identified some key attributes of BG that make it a crop with strong economic potential. First, it keeps a very good appearance, even several months after harvest. The nut stays 'clean' up to 12 months after harvest, while competing crops such as cow pea change colour and appearance as early as 3 months after harvest. A second advantage is that it can be eaten on its own or as a side dish, which makes it a popular food.

Improved seeds and the issue of pests and diseases

Another barrier identified in focus groups is the lack of availability of improved seeds as well as frequent pests and diseases. These two issues are linked, for improved varieties tend to resist better to some diseases as well as drought. The Naliendele Agricultural Research Institute has released several improved varieties in the past years and seeds are sold at a reasonable price. However, farmers in the area still largely rely on traditional landraces and do not frequently take up improved seeds. In terms of diseases, there is a frequent problem of pods wilting and crop destruction at the flowering stage. A disease affecting production which leaves spots on leaves is also common. Finally, harvest is sometimes destroyed by animals such as goats (which eat the leaves) or baboons. Note, however, that virtually all crops are affected by diseases or animals, so that this is not a

specific feature of BG, but more of a structural problem for agriculture in the region.

Traditional beliefs and taboos

Finally, an important element which is not captured in the quantitative analysis is the issue of taboos and traditional beliefs surrounding the farming of BG. Focus groups reveal that these are nevertheless stringent and hinder the development of BG farming. In Nangumi, farmers explicitly mentioned taboos alongside absence of markets as barriers to BG production. There is a belief that if a woman on her period walks past a plot of BG the production will dry up and produce no harvest. As a result, farmers have to buy a medicine produced by a witch doctor. That medicine costs around 1,000 Tshs and is a liquid in which pods have previously been soaked to immunise them. In that village, this belief also extends to simsin and groundnut. In Mtama, there is also a medicine, called *male*, used by farmers and sold at about 3,000 Tshs. Again, this medicine is not uniquely used for BG. The medicine is prepared by an old woman as an antidote to spells. Farmers believe spells were originally cast against farmers who were seen as too successful by other fellow farmers. In Mwindi however, the taboo is specific to BG. The medicine is called *numbati*, and costs between 500 and 2,500 Tshs depending on the amount bought. In this village, farmers agree that these traditional beliefs are less and less followed by farmers. In Mnazi, there was a strong belief that anyone who plants BG too early would delay the rain which would bring issues for all farmers in the village. As a result, some farmers plant in secret. In some instances, it was discovered they had planted too early and they were forced to uproot pods which were then thrown in a well to counteract the effect on rainfall. One issue with this belief is that it delays the planting of BG to late January or early February, which has a negative effect on yields (the optimal planting time being around early January). This belief was observed in several other wards in the district during surveying (notably Libobe).

Even though the influence of traditional beliefs is declining over time, they are still widespread and can have significant effects on BG production. In villages where it is believed that planting too early will cause drought, planting time is thus delayed so that other crops are not affected. To the extent that optimal planting time is not respected, this aspect should be borne in mind when discussing the *current* production level and

contrasting it with the *potential* production level, all else the same. It is likely that yields would increase if farmers planted BG at the right time of the year. The focus groups also reveal the difficulty for researchers to convince farmers of changing their planting habits. In Nangumi, a farmer explained that even if the agricultural research institute organised seminars to teach farmers about optimal planting time and agronomic practices regarding BG, villagers would listen but would still behave according to the traditional beliefs.

4.5 Conclusions

This study presents the results of a mixed-methods data collection project in the Mtwara rural district in Southern Tanzania. We collected primary data on socio-economic and agricultural variables with a special focus on BG, an indigenous crop widely grown in the region but largely under-researched. Growers of BG in Mtwara, although having similar socio-economic characteristics as their non-grower counterparts, seem to be slightly better off: they tend to have bigger farms, are more likely to be cashew growers (cashew being a major export crop) and are more likely to have iron roofs than non-growers.

We show that the presence of a market has no effect on the decision to become a grower. Hence, commercial motives are not the reason why farmers grow the crop. Evidence from the focus groups suggests instead that the crop is mainly grown for food consumption: BG is praised for its heartiness and its good taste. However, the crop is a non-negligible contributor to income, even though not a major one. To examine what drives growers to sell BG, we examine the factors influencing sales. The presence of a market has a dramatic effect on the probability to sell the crop, a result that does not hold for the other crops in our sample. In light of qualitative evidence from the focus groups, we believe this is due to absence of alternative marketing channels for BG, explaining the strong effect of the presence of a marketplace on the decision to sell. Farmers show a strong willingness to grow more of the crop and with a stronger commercial endeavour were marketing channels to improve. However, in the current situation, the absence of reliable marketing opportunities are a strong deterrent to sales, together with other aspects such as traditional beliefs or lack of improved seeds.

A caveat of our study is that its results can hardly be generalised as it is based on a small-scale case study. However, to the extent that our main aim is to learn something

about the socio-economics of underutilised crops, such case studies are a useful starting point. It is also one of the few existing studies generating primary data on BG. Another caveat is that we are not able to fully exploit the intra-household gender dynamics of BG. There is evidence that in certain regions of SSA, BG is a women's crop and as such has specific features. Unfortunately, our data is limited in terms of gender based evidence and we cannot say much about this issue, save the fact that female-headed households tend to rely more on BG for food security than their male counterparts, and are more sensitive to its high nutritional content.

By showing both that BG is an important contributor to local diets and that it has economic potential, our results are entirely consistent with the view that underutilised crops deserve more attention in socio-economic research, which should go beyond the 'Big four' (maize, wheat, paddy and soy). Developing research on marginal crops is important as these crops, by their suitability to the environment in which they are grown, directly contribute towards less intensive and more sustainable modes of agriculture, while also having the potential to become important source of income. Their climatic resilience and strong nutritional properties (protein content in the case of BG) make them attractive crops to fight malnutrition and fulfil several of the SDGs developed by the United Nations, such as the Zero Hunger, Good Health and Wellbeing, or Climate Action goals.

Chapter 5

Conclusion

This thesis covers a range of topics focusing on agricultural development in Tanzania with direct policy relevance. Although uniquely looking into Tanzania, the topics studied also have general relevance for other sub-Saharan countries. The literatures on the inverse relationship and output marketing have documented empirical evidence on the subject for the whole region and beyond. Similarly, the nascent literature on under-utilised crop covers a wide geographical scope. The first essay of this thesis proposes to revisit the debate on the inverse relationship by enquiring whether such relationship can be observed at a crop/plot level for a set of important crops at the national level: maize, paddy, beans and groundnut. The second essay investigates the issue of market participation and output supply for maize, cassava, cash crops and export crops, and reflects upon the effect of the theoretical market failure narrative on empirical applications. Both these essays use the National Panel Surveys for statistical analysis, which we describe in detail in the introduction. The third essay is based on primary data collected in the Southern region of Mtwara in Tanzania in 2016. It focuses on the socio-economic dynamics associated to the farming of the Bambara nut, a so-called underutilised crop. As such, it constitutes a step towards the consolidation of a growing literature on these crops, which have largely been ignored by policy makers and academics alike.

In the first essay, we introduce a crop/plot level of analysis to study whether an inverse relationship between cultivated area and physical productivity (i.e., yields) is observed. The literature on the inverse relationship goes a long way back, at least as early as the work of Chayanov following the Soviet Revolution in the 1920s. The publication and easy access to high quality agricultural data (the LSMS data being a good example) has pushed

for an empirical revival of the topic and has allowed researchers to explore the presence and effects of statistical biases and spurious relationships within this debate. We bring the data to a crop/plot level to test whether an inverse relationship still holds when size is defined as the area on a given plot on which a crop is grown. This is a more disaggregated level of analysis than farm or plot sizes, which have been the main level of analysis in this literature. Further, we explicitly account for intercropping, which is a widespread practice in Tanzania, and across sub-Saharan Africa more generally. We control for the three hypotheses developed in Barrett, Bellemare and Hou (2010) that may explain the inverse relationship: the household characteristics hypothesis, the plot-level characteristics hypothesis, and the statistical fallacy hypothesis. Following their methodology, we estimate yield functions from the most to the least naïve specification by gradually controlling for the above hypotheses. Further, our level of analysis makes panel estimation possible. Indeed, while farm size or plot size are largely invariant and hence do not lend themselves to panel specifications, our crop/plot focus does vary over time. For example, the area on a plot planted with maize does not have to be constant over time, even if plot size remains unchanged. Hence, we are able to control for unobserved plot heterogeneity, bypassing a criticism often made to studies that are based on OLS estimations only. Our results are unambiguous in pointing towards a negative relationship between cultivated area and yield: on average, yields are higher on smaller areas. This results holds for all crops in all models, in both OLS and panel regressions. A particularly interesting result which also holds for all crops is that the magnitude of the relationship increases when using GPS data rather than self-reported areas, consistent with recent empirical evidence on the subject. This is an important point as it shows the relationship does not arise out of pure statistical bias. We also propose to control for two new hypotheses that, to the best of our knowledge, have not formally been tested in the literature. The first one controls for the possible effect of intercropping on the relationship. To the extent that crops tend to have a lower productivity when intercropped, this may affect the relationship. Similarly, we find in the baseline models that the ranking of a crop (primary versus secondary) can have important effects on yields. Hence, we also control for this effect on the relationship. We do so by interacting the area measure with a dummy for intercropping in the first case, and a dummy for primary crops in the second. We also jointly control for these hypotheses. The inverse relationship is robust to these new controls for all crops.

From a broader perspective, this essay contributes to the issues associated with the measurement of 'size', which is a problematic concept in African agriculture. We further try to locate this research within the diversity of farming strategies adopted by farmers. The vast presence of intercropping is for example an important challenge that has not received enough attention yet in the literature. Typically, studies have also focused on one particular crop, or at aggregate output, and hence have not assessed enough whether such findings are robust for many crops. These issues mean that future research on the inverse relationship will have to pay more attention to diversity in cropping mixes, in cropping strategies (pure stand, share cropping, inter-cropping etc.) as these are key features of agricultural practices. The publication of more and more precise agricultural data will surely make more flexible explorations of this topic possible in the coming years.

The second essay proposes to combine a classic approach to market participation and output marketing with a reflection on how the theoretical narrative of market failures impacts this approach. We argue that over-reliance on the market failure narrative has resulted in too little attention being paid to the process of selection itself. This is because the theory of market failures assumes that not entering the market is precisely because of these failures. Although more recent theoretical developments have acknowledged that market entry may be driven by economic distress (notably through the work of Barrett), economic studies too often do not enquire in detail about the process of selection. Rather, the process is treated from a statistical point of view: because of a theoretical a priori that market failures inhibit participation, this results in a potential statistical selection bias into marketing. Hence, selection has been treated as a statistical issue that needs to be corrected to obtain non-biased output supply coefficients. While correcting for statistical bias is of obvious concern, it is nonetheless true that this has pushed for a heavier focus on supply equations than on market participation, thus blurring the diversity of reasons that may push farmers to enter (or not) a given market, beyond market failures. We contrast this theoretical approach with the literature on agrarian political economy, which criticises the market failure approach on the ground that it treats market entry as a natural and desirable outcome, and abstracts from the notion of subordination in economic exchanges.

We look into the determinants of participation and supply for a set of crops in Tan-

zania. Importantly, these crops have different statuses: maize and cassava, particularly the latter, are considered subsistence or semi-subsistence crops. On the other hand, food crops and export crops are considered to be strong commercial crops. We estimate participation with a probit model and output supply via OLS conditional on positive sales (we also show that results are very similar if one favours a Heckman approach instead). We show that the drivers of participation are highly heterogeneous across crops, and also across time for the same crops. Generally, the markets for cassava and maize reveal a negative (although irregular) effect of prices on the decision to enter the market, which goes against conventional wisdom in economics. Indeed, it is generally assumed that a rise in price increases participation. Participation in the market for cassava may be conceptualised in terms of economic distress and forced sales, stressing that participation may not be voluntary. On the other hand, participation in the markets for food crops and export crops does respond positively to the value of production. This is more consistent with the general conception of markets in standard theory. For food crops, we found evidence of price expectation mechanisms, further stressing the commercial aspect of this market.

These first two essays use the National Panel Surveys to study important mainstream crops which are heavily grown across the country, and hence receive a heavy weight in the datasets. However, as argued in the introduction, the datasets do not allow for econometric analysis of less important crops at the national level, despite strong regional significance. Because the law of large numbers for these crops does not apply, regression analysis is impossible. Hence, one is bound to focus on more mainstream crops in the dataset, unless one is willing to create a catch-up category of 'marginal crops' which aggregates all such crops together. Doing so would yield a highly heterogeneous category with very limited economic and agronomic relevance. Hence, after collaboration with the Crops for the Future Research Centre, a questionnaire with a special focus on one such marginal crop was designed to form the basis of the last chapter.

This third essay focuses on the Bambara nut, widely grown in the Mtwara region of Tanzania, even though it barely features in the National Panel Surveys. Despite anecdotal evidence suggesting that its farming is spread among many sub-Saharan African countries, such as Nigeria or Malawi, the crop has not received much attention from economists as of today. For this chapter, we conducted a mixed-methods fieldwork, collecting primary

data in 2016 in the Mtwara rural district. We used both quantitative methods (surveys) and qualitative methods (focus groups and group interview). Data was collected in all wards within the district in which the soil can accommodate the growing of Bambara. Two villages were surveyed within each district, and eight farmers per village were interviewed. Although this could not be enforced in every village, we tried to keep a gender balance in farmers. To the extent that the nature of this research is exploratory, Bambara growers were oversampled. With a final dataset of about 260 households and near 1,000 crop level observations, we carry simple statistical economic analysis of the data, informed by qualitative evidence from the focus groups and group interview.

The study reveals that growers of Bambara are very similar in characteristics to non-growers. Although they tend to have slightly larger farms, their socio-economic characteristics and living conditions are not significantly different. We reveal the importance of Bambara for local livelihoods. Farmers' willingness to grow more of the crop if they had more land or credit is very high (above 90%), even for non-growers. Virtually everyone consumes the crop on a regular basis, and most farmers not growing it over the previous year have nonetheless grown it in the past. We show that the main reasons growers grow the crop is for food consumption (half of growers), followed by income generation (around 20% of growers). Importantly, farmers largely agree with the advantages of underutilised crops identified in the literature, regarding for example its highly nutritious content, or its low water and fertiliser requirements. Marketed surplus for the crop low at 25%, much lower than groundnut, which has a more commercial aspect. However, we show that this is partly driven by the absence of market for the crop, especially physical marketplace in some villages. This was also a point stressed in the focus groups, in which farmers complained about poor marketing channels for the crop. The focus groups also shed light on important issues affecting production and marketing that cannot easily be captured by quantitative analysis. Among these are the stringency of traditional beliefs, which varies from one village to the other and can be pretty strong in some cases, but also the lack of improved seeds or frequent pests and diseases.

This study is the first of its kind that we are aware of in the development economics literature. By collecting primary data with a special focus on an important underutilised crop, we contribute to the nascent framework in socio-economic research that aims at

mainstreaming marginal crops. Because of their advantageous properties and suitability to local environments, they are natural candidates for the so called local 'climate-smart solutions' which aim at achieving a sustainable agricultural transformation using locally viable policies. Important organisations like the FAO are promoting such approaches with a commitment towards achieving the Sustainable Development Goals.

The three essays in this thesis are concerned with agricultural development in Tanzania and all contribute to the empirical literature in this area. However, several limitations of our work need to be stressed. An important issue that is not deeply addressed in this thesis is the gender imbalance in agriculture. Although we are controlling for female-headed households in the econometric analysis, this is arguably not enough. Evidence from the fieldwork in Mtwara showed that female-headed households are households headed by a widow. This may have a direct impact on household resources, but also available labour power within the household. Further, it may also affect inputs availability, bargaining power when selling the crop, or access to some important networks. Reflecting back on the design of the fieldwork, it is clear that the surveys could have focused more on gender issues to explore gender dynamics associated to the farming of Bambara, but also from a more general point of view. A deeper understanding of gender imbalance from a general rural setup would have provided a richer picture and enhanced our understanding of farming practices in the region.

From an empirical perspective, the analysis also comes with some limitations. For example, the way many variables are defined incorporates an important degree of arbitrariness. This is particularly the case when defining inputs, such as family and hired labour use. In the chapter on the inverse relationship, we had to arbitrarily assign inputs using a proportion rule: we allocated to each crop a quantity of inputs proportional to the area on the plot on which the crop was grown. In the absence of detail on inputs allocations at the crop level, such arbitrary allocations are necessary. Nonetheless they can be problematic. For example, farmers may use the fertiliser for only one crop on a plot rather than for all crops planted on it. Such issues could affect the estimation of the inverse relationship to the extent that inputs contribute to physical productivity. Other variables need to be interpreted with caution because of the way they were designed in the LSMS questionnaires, or because of coding issues in the data. Some variables will inherently come with a

bias. Soil quality is a good example, for the variable is self-reported. Similarly, production is only self-reported and hence likely comes with a heuristic bias which can affect results if the bias is not random (i.e., if it correlates with area cultivated, or farm size). In the chapter on output marketing, price coefficients need to be interpreted with caution since the variable has to be imputed when farmers do not sell the crop. Here again, an arbitrary rule must be applied, which also comes with its limitations. Results from the comparison of two-part models and Heckman models are also subject to the validity of the exclusion restrictions. We show that the usual restrictions in this literature may be problematic, as it is unclear how they affect participation in practice (exclusion restrictions which are consistent with a given theoretical framework are not necessarily suited to empirical applications). In the chapter on Bambara groundnut, the positive nature of the statements on the crop (eg. '*Bambara has good yields'*) could potentially bias rates of agreements from farmers (so-called 'leading questions').[1] In future research, the statements could be framed in a more neutral way. For example, we could have asked *'How would you describe BG yields?'* instead. Hence, there is a risk that the rates of agreement with these statements are somewhat inflated in our data.

In terms of extensions and future work, an interesting development on the inverse relationship may be to explore more flexible estimations of production or yield functions. To the extent that farming endeavours differ across crops, one can argue that estimating the same specification for different crops is a misguided 'one-size-fits-all' approach, although it facilitates comparisons across crops and studies. For example, the standard approach in the literature that we follow in this thesis is to assume that a set of given inputs affect yields. These are usually labour (family and hired) and fertilisers and pesticides. However, this set of inputs need not be relevant for every single crop. Qualitative evidence from focus groups or interviews could point to crop specific important factors affecting yields and hence provide ways to explore more flexible econometric analysis. The publication of data is also likely to incorporate more and more frequently 'objective' measures of production. While GPS measures of area are now partly available, objective production measures are not yet widely available. Very recent research suggests that strong biases in the self-reporting of production figures may have a strong effect on whether an inverse relationship exists or not. Hence, once such data becomes available, one will be

[1] Although high rates of *disagreement* were expressed for some statements.

able to compare specifications based on self-reported measures and more objective ones, just like we did when comparing self-reported areas with GPS ones. Future work could also use these datasets to carry research on production and productivity from a broader perspective. While the debate on the inverse relationship is framed around the issue of productivity, it ultimately is solely concerned with the area or size coefficient. In Leyaro, Boulay and Morrissey (2013), we conduct production analysis from a more general point of view and estimate production functions and supply response for the first wave of data. This work could for example be extended by incorporating other waves of data.

An interesting extension for the chapter on market participation lies in the re-definition of what we consider to affect participation. There is an important gap between what market failure theory suggests influences participation and what empirical evidence indicates. For example, the theory assumes education to be a proxy for the ability to process information and enter the market. In practice, if sales can arise out of economic distress, the education variable arguably loses appeal. Extending our understanding of market entry from a broader perspective than the missing market narrative means that variables considered to affect selection can –and should- be redefined accordingly. In fact, it is quite debatable whether the exclusion restrictions considered in the literature are very useful because they arguably have a greater effect on the ability to realise good sales than on the ability to sell itself (for example, through negotiating better prices, or getting to know traders integrated to large trade networks). If sales can arise out of distress, and it now clear they sometimes do, then one may instead expect the least educated households to be those participating in some markets. Hence, a more flexible approach to the topic should also be considered in future work.

Extensions for the essay on Bambara groundnut are countless, as the literature on the subject is extremely thin and our work is largely exploratory. Much remains to be done to consolidate the field, at every level of the 'research ladder': from primary data collection to publications. Data on Bambara nut is scarce and future work could include data collection in Dodoma, the other region of the country where the crop is widely grown. As explained previously, new data collection should be more careful about the gender dimensions of the crop. The research effort should be collaborative between researchers in the natural sciences and in social sciences to maximise visibility of the work being done and the possi-

bility to influence policy makers and academia. The fast-growing interest in sustainability issues provides a useful opportunity for researchers interested in these crops as they have a direct link with sustainable agricultural strategies and fit with local approaches to rural development, which are on the rise in important policy-making institutions, notably UN agencies.

Appendix A

Appendix to Chapter 1

Table A.1: Annual crops frequencies, wave 1

Item	Number	Per cent
Maize	1,999	35.05
Paddy	539	9.45
Sorghum	297	5.21
Bulrush Millet	74	1.30
Finger Millet	42	0.74
Wheat	23	0.40
Cassava	308	5.40
Sweet potatoes	228	4.00
Irish potatoes	55	0.96
Yams	28	0.49
Cocoyams	36	0.63
Onions	13	0.23
Ginger	1	0.02
Beans	609	10.68
Cowpeas	147	2.58
Green gram	43	0.75
Pigeon pea	151	2.65
Chick peas	16	0.28
Bambara nuts	89	1.56
Field peas	10	0.18
Sunflower	188	3.30
Simsim	72	1.26
Groundnut	363	6.37
Palm Oil	1	0.02
Coconut	8	0.14
Cashewnut	41	0.72
Soyabeans	10	0.18
Cotton	83	1.46
Tobacco	31	0.54
Sisal	7	0.12
Coffee	1	0.02
Sugar Cane	2	0.04
Banana	17	0.30
Mango	6	0.11
Papaw	1	0.02
Orange	5	0.09
Guava	1	0.02
Cabbage	8	0.14
Tomatoes	36	0.63
Spinach	7	0.12
Carrot	1	0.02
Chillies	3	0.05
Amaranths	22	0.39
Pumpkins	34	0.60
Cucumber	3	0.05
Egg Plant	1	0.02
Water Mellon	3	0.05
Bilimbi	2	0.04
Rambutan	2	0.04
Okra	12	0.21
Fiwi	12	0.21
Other	12	0.21
Total	5,703	100.00

Table A.2: Annual crops frequencies, wave 2

Item	Number	Per cent
Maize	2,368	39.46
Paddy	659	10.98
Sorghum	314	5.23
Bulrush Millet	60	1.00
Finger Millet	35	0.58
Wheat	21	0.35
Seaweed	1	0.02
Cassava	75	1.25
Sweet potatoes	223	3.72
Irish potatoes	68	1.13
Yams	33	0.55
Cocyams	91	1.52
Onions	12	0.20
Beans	654	10.90
Cowpeas	177	2.95
Green gram	51	0.85
Pigeon pea	170	2.83
Chickpeas	14	0.23
Bambara nuts	54	0.90
Field peas	4	0.07
Sunflower	147	2.45
Sesame	91	1.52
Groundnut	319	5.32
Coconut	2	0.03
Soyabeans	6	0.10
Cotton	76	1.27
Tobacco	39	0.65
Pyrethrum	10	0.17
Coffee	2	0.03
Cocoa	1	0.02
Passion Fruit	2	0.03
Banana	5	0.08
Pineapple	2	0.03
Plums	2	0.03
Cabbage	9	0.15
Tomatoes	45	0.75
Spinach	1	0.02
Carrot	3	0.05
Chilies	7	0.12
Amaranth	20	0.33
Pumpkin	46	0.77
Cucumber	2	0.03
Eggplant	1	0.02
Watermelon	4	0.07
Cauliflower	1	0.02
Bilimbi	3	0.05
Okra	15	0.25
Fiwi	22	0.37
102	1	0.02
Other	33	0.55
Total	6,001	100.00

Table A.3: Annual crops frequencies, wave 3

Item	Number	Per cent
Maize	3,079	38.81
Paddy	805	10.15
Sorghum	324	4.08
Bulrush millet	75	0.95
Finger millet	27	0.34
Wheat	24	0.30
Seaweed	8	0.10
Cassava	35	0.44
Sweet potatoes	364	4.59
Irish potatoes	66	0.83
Yams	28	0.35
Cocoyams	122	1.54
Onions	16	0.20
Beans	871	10.98
Cowpeas	244	3.08
Green gram	85	1.07
Pigeon pea	276	3.48
Chick pea	29	0.37
Bambara nut	71	0.89
Field peas	9	0.11
Sunflower	246	3.10
Sesame	114	1.44
Groundnut	472	5.95
Soyabeans	12	0.15
Cotton	204	2.57
Tobacco	62	0.78
Pyrethrum	19	0.24
Coffee	1	0.01
Cabbage	7	0.09
Tomatoes	45	0.57
Spinach	10	0.13
Carrot	3	0.04
Chillies	2	0.03
Amaranths	22	0.28
Pumpkins	56	0.71
Cucumber	9	0.11
Egg plant	8	0.10
Water mellon	5	0.06
Bilimbi	5	0.06
Okra	14	0.18
Fiwi	22	0.28
Other	37	0.47
Total	7,933	100.00

Table A.4: Distribution of frequencies by agro-climatic regions for the main crops (%)

	NPS 2008/09	NPS 2010/11	NPS 2012/13
Maize			
Tropic-warm/semi-arid	9.72	8.54	6.97
Tropic-warm/sub-humid	51.71	54.04	54.30
Tropic-warm/humid	0.40	0.32	0.59
Tropic-cool/semi-arid	5.66	5.07	5.06
Tropic-cool/sub-humid	32.19	31.51	32.65
Tropic-cool/humid	0.32	0.51	0.44
Paddy rice			
Tropic-warm/semi-arid	8.27	5.95	6.21
Tropic-warm/sub-humid	82.17	81.97	78.55
Tropic-warm/humid	0.00	0.00	0.00
Tropic-cool/semi-arid	0.52	0.67	0.30
Tropic-cool/sub-humid	8.79	11.71	14.64
Tropic-cool/humid	0.26	0.00	0.30
Beans			
Tropic-warm/semi-arid	4.51	4.25	3.01
Tropic-warm/sub-humid	23.99	23.94	26.47
Tropic-warm/humid	1.43	1.16	1.50
Tropic-cool/semi-arid	7.36	5.79	4.96
Tropic-cool/sub-humid	61.28	60.62	60.45
Tropic-cool/humid	1.43	4.25	3.61
Groundnut			
Tropic-warm/semi-arid	18.09	13.84	13.02
Tropic-warm/sub-humid	43.00	0.17	51.40
Tropic-warm/humid	0.34	0.00	0.00
Tropic-cool/semi-arid	3.75	2.08	2.79
Tropic-cool/sub-humid	34.81	33.22	32.33
Tropic-cool/humid	0.00	0.69	0.47
Cassava			
Tropic-warm/semi-arid	3.20	2.53	1.43
Tropic-warm/sub-humid	72.31	68.28	68.70
Tropic-warm/humid	2.29	2.74	2.96
Tropic-cool/semi-arid	0.00	0.00	0.36
Tropic-cool/sub-humid	19.91	22.76	21.97
Tropic-cool/humid	2.29	3.69	4.47

Appendix B

Appendix to Chapter 2

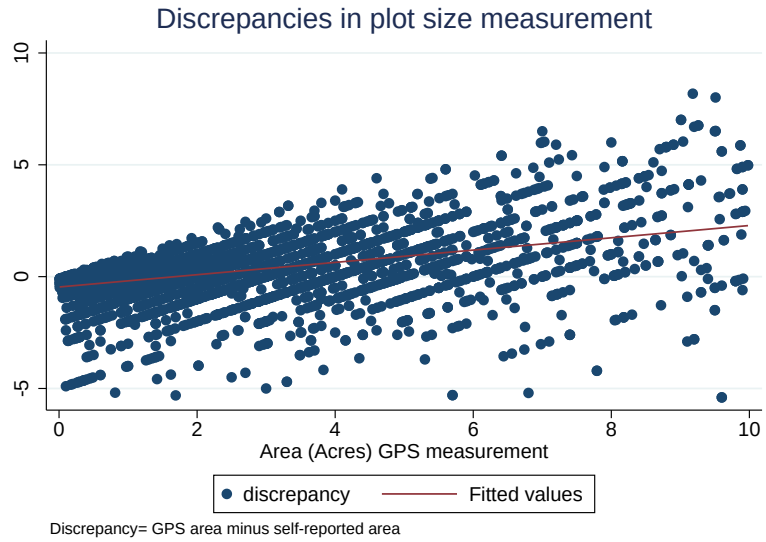


Figure B.1: Discrepancies in plot sizes

Note: Discrepancy is calculated as the difference between GPS measures and self-reported measures. Hence, a negative value of the discrepancy variable implies the farmer is overestimating size, while a positive value implies the farmer is underestimating it. This graph omits the largest plots and largest discrepancy values for scale purposes.

Table B.1: Definitions of variables used in analysis

Variable	**Definition**
Cultivated area	Refers to the area on a given plot planted with a given crop, which is obtain exploiting the information provided by farmers regarding the approximate surface on a plot on which the crop is grown (25, 50, 75 or 100%). When the crop is intercropped we use the area on which it is intercropped.
Family labour	Total number of days of household labour spent by acre on a given plot. E.g. if a plot is 2 acres and required 40 days of work, the number days worked per acre is 20.
Hired labour	Similar to the family labour variable but using days of hired labour instead
Organic fertiliser	Total amount of organic fertiliser,applied per acre of land on a given plot. E.g. if a plot is 2 acres and required 40 kg of organic fertiliser, the amount applied per acre is 20 kg
Inorganic fertiliser	Similar to the organic fertiliser variable but using inorganic fertiliser instead
Rainfall	Total rainfall in wettest quarter (mm) in the past 12 months at the district level
Maincrop	Dummy variable taking value 1 if the crop is the main crop on the plot, 0 otherwise
Soil quality	Categorical variable reported by farmers, takes value 1,2 or 3 for 'bad', 'average' and 'good' respectively
Steepness	Categorical variable reported by farmers, takes value 1,2, 3 or 4 for 'flat bottom', 'flat top', 'slightly sloped' and 'very steep' respectively
Elevation	Plot elevation in metres
Erosion	Dummy variable taking value 1 if the plot has an erosion facility, 0 otherwise
Irrigation	Dummy variable taking value 1 if the plot has an irrigation facility, 0 otherwise
Intercrop	Dummy variable taking value 1 if the crop is intercropped on that plot, 0 otherwise
Trees per plot	Number of trees planted on the plot
Crops per plot	Number of crops planted on the plot
Female head	Dummy variable taking value 1 if the household is headed by a woman, 0 otherwise
Saving group	Dummy variable taking value 1 if a household member is member of a saving group, 0 otherwise
Head education	Level of education of head of household, takes value 1,2, 3 or 4 for 'less than primary', 'primary', 'secondary' and 'university' respectively
Age	Age of the head of household
Transport	Dummy variable taking value 1 if the household owns a means of transport (bicycle/motorbike/car), 0 otherwise
Farm size	Farm size for each household measured in acres
Cooperative	Dummy variable taking value 1 if there is an agricultural cooperative in the village, 0 otherwise
Improved seeds	Dummy variable taking value 1 if improved seeds are available for sales in the village, 0 otherwise
Plots with crop	Number of plot on which a given crop is grown by the household
Crops on farm	Total number of crops grown on the farm by the household



(a) Large monocropped plot

(b) Small intercropped plot

Author's pictures (Morogoro region)

Figure B.2: Motivating proposition 4

The picture in Figure B.2a shows a large and densely planted mono cropped field of sisal, while that in Figure B.2b shows a small intercropped plot (with cassava and bananas, among others). The latter is an example of intercopping where several crops are planted on a given area, which is different from inter cropping understood as a process where two crops are densely planted in alternative rows. It also makes it clear that to the extent that we are measuring output per unit of land on which a crop is cultivated, intercropping mechanically pulls this measure of productivity down. This therefore justifies the need to interact area cultivated with a dummy capturing whether the crop is intercropped (proposition 4).

B.0.1 Controlling for P1-P3: full output tables

Table B.2: Yield functions for maize (full output)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Benchmark	P1	P2	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.221***	-0.254***	-0.224***	-0.259***	-0.358***	-0.637***	-0.654***
	(0.021)	(0.026)	(0.021)	(0.026)	(0.020)	(0.050)	(0.050)
Area*female		-0.130***		-0.144***	-0.109***	-0.074	-0.079
		(0.041)		(0.040)	(0.030)	(0.084)	(0.081)
Family labour	0.134***	0.159***	0.136***	0.160***	0.145***	0.128***	0.124***
	(0.023)	(0.023)	(0.023)	(0.023)	(0.021)	(0.031)	(0.030)
Hired labour	0.123***	0.126***	0.122***	0.124***	0.115***	0.027	0.031
	(0.016)	(0.016)	(0.016)	(0.015)	(0.015)	(0.022)	(0.021)
Organic fert	0.021***	0.020***	0.021***	0.018**	0.017**	0.003	0.003
	(0.008)	(0.008)	(0.008)	(0.007)	(0.007)	(0.013)	(0.013)
Inorganic fert	0.140***	0.133***	0.134***	0.127***	0.116***	0.049**	0.050**
	(0.012)	(0.011)	(0.011)	(0.011)	(0.010)	(0.020)	(0.020)
Rainfall	-0.022	0.008	-0.065	-0.042	0.007	-0.115	-0.090
	(0.077)	(0.075)	(0.079)	(0.077)	(0.074)	(0.100)	(0.101)

Female head		-0.067		-0.064	-0.058	0.200	0.239
		(0.051)		(0.049)	(0.049)	(0.320)	(0.310)
Farm size		0.123***		0.125***	0.182***	0.068	0.154***
		(0.028)		(0.028)	(0.023)	(0.053)	(0.045)
Saving group		0.061		0.084	0.092	0.092	0.094
		(0.077)		(0.074)	(0.074)	(0.107)	(0.112)
Head educ		0.015		0.007	0.012	0.056	0.052
		(0.033)		(0.032)	(0.031)	(0.053)	(0.053)
Age of head		-0.312***		-0.298***	-0.312***	-0.038	-0.074
		(0.065)		(0.063)	(0.060)	(0.490)	(0.476)
Transport		0.143***		0.147***	0.135***	0.097	0.087
		(0.039)		(0.038)	(0.036)	(0.074)	(0.074)
Plots with crop		-0.019		-0.073	-0.060	-0.165**	-0.201**
		(0.044)		(0.044)	(0.041)	(0.084)	(0.082)
Crops on farm		-0.023***		-0.017**	-0.026***	0.014	0.006
		(0.008)		(0.008)	(0.007)	(0.016)	(0.016)
Cooperative		0.072*		0.073**	0.090***	0.116**	0.114**
		(0.037)		(0.036)	(0.035)	(0.051)	(0.052)
Improved seeds		-0.063*		-0.061*	-0.055	0.031	0.033
		(0.036)		(0.035)	(0.034)	(0.049)	(0.049)
Erosion			-0.005	0.007	-0.010	0.138	0.140
			(0.052)	(0.052)	(0.052)	(0.086)	(0.088)
Irrigation			0.077	0.041	0.014	0.184	0.189
			(0.135)	(0.131)	(0.125)	(0.186)	(0.177)
Steepness			0.039**	0.034*	0.030*		
			(0.020)	(0.019)	(0.018)		
Elevation			0.057	0.079**	0.063*		
			(0.037)	(0.038)	(0.035)		
Intercrop			-0.121***	-0.084**	-0.088**	-0.103*	-0.087*
			(0.036)	(0.036)	(0.034)	(0.053)	(0.052)
Maincrop			0.296***	0.303***	0.328***	0.208**	0.234**
			(0.049)	(0.047)	(0.045)	(0.093)	(0.095)
Trees per plot			-0.000	-0.000	0.000	0.000	0.000
			(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Soil quality			0.130***	0.133***	0.137***	0.072*	0.079**
			(0.027)	(0.026)	(0.024)	(0.038)	(0.038)
soil_type==SANDY			-0.206***	-0.218***	-0.188***		
			(0.044)	(0.043)	(0.043)		
soil_type==CLAY			0.025	0.015	0.037		
			(0.045)	(0.045)	(0.043)		
soil_type==OTHER			0.132	0.094	0.126		
			(0.099)	(0.097)	(0.090)		
time=2	0.054	0.064	0.058	0.070	0.068	0.092	0.110
	(0.063)	(0.062)	(0.078)	(0.077)	(0.076)	(0.112)	(0.111)
time=3	-0.042	-0.027	-0.059	-0.044	0.000	0.037	0.057
	(0.064)	(0.064)	(0.064)	(0.064)	(0.062)	(0.087)	(0.086)
Constant	4.512***	5.313***	3.848***	4.463***	4.344***	4.791**	4.693**
	(0.470)	(0.502)	(0.533)	(0.572)	(0.545)	(1.992)	(1.940)

Observations	3407	3407	3407	3407	3407	3407	3407
R^2	0.25	0.28	0.28	0.31	0.40	0.28	0.32
Regions	Yes	Yes	Yes	Yes	Yes	-	-
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	SR	SR	SR	GPS	SR	GPS

Standard errors clustered at household level for models 1-5, and at household/plot level for models 6-7
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B.3: Yield functions for rice (full output)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Benchmark	P1	P2	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.242***	-0.368***	-0.271***	-0.374***	-0.431***	-0.813***	-0.775***
	(0.050)	(0.065)	(0.049)	(0.064)	(0.053)	(0.147)	(0.098)
Area*female		-0.023		-0.038	-0.056	-0.293	-0.206
		(0.089)		(0.090)	(0.072)	(0.220)	(0.204)
Family labour	0.205***	0.217***	0.170***	0.175***	0.171***	0.108*	0.097
	(0.038)	(0.045)	(0.039)	(0.045)	(0.042)	(0.063)	(0.068)
Hired labour	0.184***	0.185***	0.161***	0.163***	0.155***	0.116**	0.127**
	(0.022)	(0.021)	(0.022)	(0.021)	(0.019)	(0.052)	(0.057)
Organic fert	0.046*	0.048**	0.058**	0.058**	0.054**	-0.012	-0.018
	(0.026)	(0.024)	(0.026)	(0.025)	(0.025)	(0.042)	(0.045)
Inorganic fert	0.111***	0.095***	0.114***	0.096***	0.084***	-0.016	-0.034
	(0.033)	(0.030)	(0.031)	(0.028)	(0.026)	(0.056)	(0.058)
Rainfall	0.137	0.169	0.075	0.093	0.112	-0.317	-0.333
	(0.114)	(0.116)	(0.107)	(0.110)	(0.105)	(0.218)	(0.223)
Female head		0.093		0.089	0.038	1.307***	1.458***
		(0.094)		(0.094)	(0.093)	(0.452)	(0.403)
Farm size		0.225***		0.171***	0.238***	0.215*	0.199
		(0.065)		(0.063)	(0.054)	(0.126)	(0.126)
Saving group		0.038		0.037	0.126	-0.387	-0.387
		(0.115)		(0.119)	(0.117)	(0.272)	(0.280)
Head educ		0.015		0.017	0.023	-0.119	-0.133
		(0.053)		(0.052)	(0.050)	(0.124)	(0.124)
Age of head		-0.376***		-0.325***	-0.411***	0.464	0.554
		(0.124)		(0.119)	(0.117)	(0.614)	(0.586)
Transport		0.107		0.160**	0.081	0.310	0.317
		(0.087)		(0.081)	(0.078)	(0.297)	(0.295)
Plots with crop		-0.072		-0.083	-0.107	-0.110	-0.077
		(0.099)		(0.097)	(0.094)	(0.241)	(0.236)
Crops on farm		-0.025		-0.006	-0.013	-0.063*	-0.067*
		(0.016)		(0.018)	(0.017)	(0.038)	(0.037)
Cooperative		0.139*		0.102	0.085	0.201	0.169
		(0.073)		(0.073)	(0.072)	(0.144)	(0.141)
Improved seeds		-0.015		0.010	0.014	-0.272*	-0.250
		(0.078)		(0.077)	(0.078)	(0.161)	(0.161)
Erosion			-0.108	-0.072	-0.024	0.356**	0.362**
			(0.102)	(0.102)	(0.098)	(0.177)	(0.177)
Irrigation			-0.009	-0.019	-0.046	-0.415	-0.376

			(0.224)	(0.210)	(0.197)	(0.334)	(0.319)
Steepness			-0.064	-0.064	-0.063		
			(0.041)	(0.040)	(0.039)		
Elevation			0.091*	0.087	0.072		
			(0.051)	(0.054)	(0.052)		
Intercrop			-0.451***	-0.419***	-0.479***	-0.218	-0.214
			(0.107)	(0.105)	(0.108)	(0.184)	(0.177)
Maincrop			0.074	0.092	0.108	0.219	0.175
			(0.101)	(0.097)	(0.095)	(0.221)	(0.218)
Trees per plot			0.000	0.000	0.000**	-0.000	-0.000
			(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Soil quality			0.090	0.102*	0.115**	-0.054	-0.070
			(0.057)	(0.055)	(0.053)	(0.123)	(0.119)
soil_type==SANDY			-0.153	-0.140	-0.117		
			(0.096)	(0.098)	(0.097)		
soil_type==CLAY			0.013	0.030	0.083		
			(0.074)	(0.072)	(0.069)		
soil_type==OTHER			0.237	0.145	0.033		
			(0.266)	(0.284)	(0.268)		
time=2	-0.118	-0.126	-0.190	-0.251	-0.236	0.517*	0.474
	(0.142)	(0.144)	(0.167)	(0.168)	(0.162)	(0.282)	(0.288)
time=3	-0.224	-0.234	-0.271*	-0.274*	-0.201	0.081	0.067
	(0.143)	(0.144)	(0.147)	(0.149)	(0.145)	(0.242)	(0.234)
Constant	4.450***	5.304***	4.195***	4.904***	5.185***	4.848*	4.761*
	(0.750)	(0.884)	(0.851)	(0.988)	(0.964)	(2.643)	(2.786)
Observations	630	630	630	630	630	630	630
R^2	0.41	0.44	0.45	0.48	0.57	0.54	0.54
Regions	Yes	Yes	Yes	Yes	Yes	-	-
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	SR	SR	SR	GPS	SR	GPS

Standard errors clustered at household level for models 1-5, and at household/plot level for models 6-7
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B.4: Yield functions for beans (full output)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Benchmark	P1	P2	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.357***	-0.468***	-0.370***	-0.464***	-0.515***	-0.569***	-0.610***
	(0.041)	(0.052)	(0.039)	(0.051)	(0.040)	(0.092)	(0.090)
Area*female		-0.188**		-0.176**	-0.105	-0.048	-0.320
		(0.086)		(0.082)	(0.065)	(0.127)	(0.209)
Family labour	0.061	0.108***	0.081**	0.117***	0.088***	0.080	0.132**
	(0.038)	(0.037)	(0.037)	(0.035)	(0.032)	(0.054)	(0.055)
Hired labour	0.074***	0.083***	0.078***	0.086***	0.064***	0.093**	0.077**
	(0.026)	(0.024)	(0.024)	(0.023)	(0.024)	(0.037)	(0.036)
Organic fert	0.003	0.005	0.015	0.015	0.014	0.032	0.029
	(0.013)	(0.013)	(0.014)	(0.013)	(0.013)	(0.029)	(0.028)
Inorganic fert	0.005	-0.005	0.020	0.011	0.014	-0.010	0.003
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.035)	(0.033)

Rainfall	-0.232	-0.212	-0.182	-0.174	-0.121	0.669**	0.716***
	(0.157)	(0.160)	(0.148)	(0.150)	(0.141)	(0.267)	(0.277)
Female head		-0.098		-0.089	-0.064	-0.038	-0.185
		(0.095)		(0.092)	(0.089)	(0.319)	(0.333)
Farm size		0.254***		0.224***	0.259***	-0.118	0.027
		(0.053)		(0.053)	(0.044)	(0.107)	(0.092)
Saving group		0.044		0.008	-0.001	0.074	-0.068
		(0.121)		(0.122)	(0.120)	(0.306)	(0.393)
Head educ		-0.102*		-0.099*	-0.085	-0.223**	-0.196*
		(0.060)		(0.059)	(0.058)	(0.098)	(0.101)
Age of head		-0.119		-0.078	-0.076	0.799	0.147
		(0.117)		(0.111)	(0.105)	(1.831)	(1.838)
Transport		0.159**		0.145**	0.130*	0.206	0.233
		(0.073)		(0.072)	(0.070)	(0.152)	(0.153)
Plots with crop		-0.145*		-0.159*	-0.103	0.192	0.211
		(0.083)		(0.083)	(0.083)	(0.136)	(0.139)
Crops on farm		-0.029**		-0.016	-0.025*	0.016	-0.009
		(0.014)		(0.014)	(0.014)	(0.027)	(0.026)
Cooperative		0.004		0.024	0.065	0.216*	0.179
		(0.072)		(0.071)	(0.067)	(0.116)	(0.115)
Improved seeds		0.044		0.028	0.014	-0.012	0.006
		(0.073)		(0.070)	(0.068)	(0.115)	(0.118)
Erosion			-0.221**	-0.213**	-0.197**	-0.151	-0.123
			(0.087)	(0.084)	(0.084)	(0.134)	(0.134)
Irrigation			-0.124	-0.045	-0.032	-0.548	-0.359
			(0.311)	(0.338)	(0.322)	(0.464)	(0.521)
Steepness			0.061*	0.053*	0.037		
			(0.032)	(0.031)	(0.029)		
Elevation			-0.404**	-0.279	-0.168		
			(0.192)	(0.179)	(0.174)		
Intercrop			-0.297***	-0.241**	-0.248***	0.026	-0.040
			(0.103)	(0.101)	(0.095)	(0.152)	(0.148)
Maincrop			0.380***	0.391***	0.417***	0.234*	0.239
			(0.089)	(0.092)	(0.088)	(0.135)	(0.146)
Trees per plot			-0.000	-0.000	-0.000	0.000	0.000
			(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Soil quality			0.098*	0.089*	0.097**	0.067	0.057
			(0.050)	(0.049)	(0.048)	(0.082)	(0.080)
soil_type==SANDY			0.046	0.072	0.054		
			(0.105)	(0.106)	(0.105)		
soil_type==CLAY			0.036	0.031	0.025		
			(0.077)	(0.075)	(0.072)		
soil_type==OTHER			-0.002	-0.045	0.107		
			(0.189)	(0.193)	(0.166)		
time=2	0.034	0.041	0.062	0.067	0.054	-0.102	-0.076
	(0.096)	(0.094)	(0.138)	(0.137)	(0.130)	(0.201)	(0.212)
time=3	0.035	-0.001	-0.043	-0.069	-0.050	-0.271	-0.225
	(0.096)	(0.097)	(0.097)	(0.099)	(0.098)	(0.210)	(0.210)

Constant	6.164***	5.668***	8.046***	6.651***	5.719***	-3.875	-1.830
	(0.931)	(1.037)	(1.524)	(1.563)	(1.542)	(6.888)	(6.887)
Observations	936	936	936	936	936	936	936
R^2	0.24	0.28	0.30	0.33	0.44	0.50	0.50
Regions	Yes	Yes	Yes	Yes	Yes	-	-
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	SR	SR	SR	GPS	SR	GPS

Standard errors clustered at household level for models 1-5, and at household/plot level for models 6-7
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B.5: Yield functions for groundnut (full output)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Benchmark	P1	P2	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.358***	-0.449***	-0.354***	-0.431***	-0.473***	-0.988***	-0.925***
	(0.058)	(0.076)	(0.058)	(0.078)	(0.062)	(0.190)	(0.191)
Area*female		-0.041		-0.043	-0.073	0.008	-0.220
		(0.090)		(0.091)	(0.078)	(0.302)	(0.207)
Family labour	0.138**	0.189***	0.119*	0.159***	0.185***	0.148	0.107
	(0.061)	(0.059)	(0.061)	(0.058)	(0.055)	(0.156)	(0.147)
Hired labour	0.072*	0.078*	0.058	0.067*	0.056	0.126	0.126
	(0.038)	(0.040)	(0.039)	(0.040)	(0.039)	(0.095)	(0.087)
Organic fert	0.015	0.023	0.022	0.031	0.025	0.026	0.019
	(0.019)	(0.018)	(0.020)	(0.020)	(0.020)	(0.044)	(0.043)
Inorganic fert	0.006	-0.005	0.018	0.009	0.004	-0.016	-0.045
	(0.037)	(0.038)	(0.037)	(0.038)	(0.039)	(0.093)	(0.085)
Rainfall	-0.247	-0.145	-0.164	-0.049	-0.036	0.357	0.223
	(0.248)	(0.258)	(0.253)	(0.265)	(0.270)	(0.469)	(0.466)
Female head		-0.119		-0.116	-0.056	-3.923***	-4.261***
		(0.114)		(0.113)	(0.111)	(0.801)	(0.689)
Farm size		0.160**		0.139*	0.206***	-0.153	-0.237
		(0.081)		(0.081)	(0.064)	(0.203)	(0.183)
Saving group		0.128		0.060	0.177	-1.051**	-1.070**
		(0.168)		(0.167)	(0.173)	(0.509)	(0.516)
Head educ		0.048		0.035	0.061	0.071	0.075
		(0.094)		(0.092)	(0.092)	(0.288)	(0.270)
Age of head		-0.137		-0.094	-0.093	-3.751	-3.805
		(0.161)		(0.158)	(0.161)	(4.901)	(4.941)
Transport		0.163		0.153	0.183*	0.269	0.195
		(0.106)		(0.106)	(0.105)	(0.341)	(0.358)
Plots with crop		-0.206		-0.283*	-0.266*	-0.770**	-0.735**
		(0.153)		(0.153)	(0.160)	(0.321)	(0.356)
Crops on farm		-0.044**		-0.044**	-0.053***	-0.057	-0.052
		(0.022)		(0.022)	(0.021)	(0.069)	(0.068)
Cooperative		-0.137		-0.133	-0.154	0.059	0.068
		(0.094)		(0.096)	(0.095)	(0.172)	(0.166)
Improved seeds		-0.164		-0.127	-0.139	-0.252	-0.264
		(0.102)		(0.105)	(0.105)	(0.265)	(0.266)
Erosion			0.012	-0.009	-0.024	-0.164	-0.195

			(0.178)	(0.174)	(0.172)	(0.391)	(0.384)
Irrigation			0.548***	0.254	0.273	1.965***	1.973***
			(0.204)	(0.226)	(0.226)	(0.436)	(0.420)
Steepness			0.027	0.019	0.018		
			(0.056)	(0.055)	(0.054)		
Elevation			0.152	0.166	0.169		
			(0.112)	(0.110)	(0.106)		
Intercrop			-0.095	-0.036	0.018	0.204	0.192
			(0.112)	(0.110)	(0.107)	(0.303)	(0.296)
Maincrop			0.364***	0.359***	0.363***	0.412	0.369
			(0.119)	(0.125)	(0.124)	(0.301)	(0.259)
Trees per plot			-0.000	-0.000	-0.000	-0.000*	-0.000**
			(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Soil quality			-0.092	-0.111	-0.093	0.240	0.227
			(0.073)	(0.073)	(0.074)	(0.175)	(0.177)
soil_type==SANDY			-0.232**	-0.207*	-0.194*		
			(0.110)	(0.109)	(0.108)		
soil_type==CLAY			0.054	-0.036	-0.061		
			(0.180)	(0.182)	(0.183)		
soil_type==OTHER			-0.139	-0.180	-0.215		
			(0.228)	(0.230)	(0.245)		
time=2	-0.098	-0.157	-0.061	-0.085	0.010	0.779*	0.781*
	(0.158)	(0.142)	(0.204)	(0.191)	(0.188)	(0.404)	(0.397)
time=3	-0.076	-0.130	-0.101	-0.155	-0.074	0.547	0.538
	(0.159)	(0.144)	(0.163)	(0.147)	(0.145)	(0.470)	(0.462)
Constant	5.625***	5.863***	4.368**	4.306**	3.976*	16.834	18.347
	(1.520)	(1.778)	(1.786)	(2.090)	(2.111)	(19.421)	(19.462)
Observations	460	460	460	460	460	460	460
R^2	0.25	0.29	0.29	0.33	0.40	0.66	0.66
Regions	Yes	Yes	Yes	Yes	Yes	-	-
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	SR	SR	SR	GPS	SR	GPS

Standard errors clustered at household level for models 1-5, and at household/plot level for models 6-7
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

B.0.2 Controlling for P4: full output tables

Table B.6: Testing P4 for maize (full output)

	(1)	(2)	(3)	(4)
	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.180***	-0.302***	-0.571***	-0.622***
	(0.036)	(0.025)	(0.059)	(0.056)
Area*Intercrop	-0.118***	-0.088***	-0.100**	-0.049
	(0.035)	(0.025)	(0.050)	(0.042)
Area*female	-0.137***	-0.104***	-0.070	-0.073
	(0.040)	(0.030)	(0.084)	(0.081)

Family labour	0.160***	0.145***	0.125***	0.124***
	(0.023)	(0.021)	(0.031)	(0.030)
Hired labour	0.122***	0.115***	0.024	0.029
	(0.015)	(0.015)	(0.022)	(0.021)
Organic fert	0.018**	0.018**	0.001	0.003
	(0.007)	(0.007)	(0.013)	(0.013)
Inorganic fert	0.128***	0.116***	0.049**	0.050**
	(0.011)	(0.010)	(0.021)	(0.020)
Rainfall	-0.037	0.009	-0.108	-0.090
	(0.077)	(0.074)	(0.100)	(0.101)
Female head	-0.066	-0.061	0.221	0.245
	(0.050)	(0.049)	(0.322)	(0.311)
Farm size	0.126***	0.184***	0.070	0.155***
	(0.028)	(0.023)	(0.052)	(0.045)
Saving group	0.085	0.094	0.086	0.096
	(0.074)	(0.074)	(0.107)	(0.112)
Head educ	0.008	0.009	0.054	0.051
	(0.032)	(0.031)	(0.053)	(0.053)
Age of head	-0.298***	-0.313***	-0.079	-0.113
	(0.063)	(0.060)	(0.483)	(0.474)
Transport	0.146***	0.132***	0.094	0.083
	(0.038)	(0.036)	(0.074)	(0.074)
Plots with crop	-0.074*	-0.061	-0.172**	-0.203**
	(0.044)	(0.041)	(0.084)	(0.082)
Crops on farm	-0.017**	-0.027***	0.014	0.006
	(0.008)	(0.007)	(0.016)	(0.016)
Cooperative	0.071**	0.089**	0.113**	0.112**
	(0.036)	(0.035)	(0.050)	(0.051)
Improved seeds	-0.064*	-0.057*	0.031	0.036
	(0.035)	(0.034)	(0.049)	(0.049)
Erosion	0.009	-0.007	0.144*	0.143
	(0.051)	(0.052)	(0.086)	(0.088)
Irrigation	0.040	0.011	0.194	0.195
	(0.133)	(0.127)	(0.189)	(0.179)
Steepness	0.034*	0.031*		
	(0.019)	(0.018)		
Elevation	0.081**	0.065*		

	(0.038)	(0.035)		
Intercrop	-0.082**	-0.094***	-0.103*	-0.091*
	(0.036)	(0.034)	(0.054)	(0.052)
Maincrop	0.298***	0.323***	0.210**	0.232**
	(0.047)	(0.045)	(0.093)	(0.095)
Trees per plot	-0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Soil quality	0.134***	0.138***	0.073*	0.081**
	(0.026)	(0.024)	(0.038)	(0.038)
soil_type==SANDY	-0.216***	-0.188***		
	(0.043)	(0.042)		
soil_type==CLAY	0.016	0.036		
	(0.045)	(0.043)		
soil_type==OTHER	0.105	0.132		
	(0.098)	(0.090)		
time=2	0.073	0.067	0.107	0.117
	(0.077)	(0.076)	(0.112)	(0.111)
time=3	-0.045	-0.002	0.043	0.059
	(0.064)	(0.062)	(0.087)	(0.086)
Constant	4.426***	4.324***	4.913**	4.841**
	(0.572)	(0.545)	(1.967)	(1.933)
Observations	3407	3407	3407	3407
R^2	0.31	0.40	0.29	0.32
Regions	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	GPS	SR	GPS

Standard errors clustered at household level for models 1-5, and at household/plot level for models 6-7

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B.7: Testing P4 for rice (full output)

	(1)	(2)	(3)	(4)
	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.287***	-0.374***	-0.643***	-0.699***
	(0.067)	(0.053)	(0.172)	(0.102)
Area*Intercrop	-0.301***	-0.226***	-0.430**	-0.326**
	(0.109)	(0.078)	(0.186)	(0.152)
Area*female	0.011	-0.055	-0.165	-0.184

	(0.088)	(0.069)	(0.218)	(0.175)
Family labour	0.174***	0.168***	0.148**	0.118*
	(0.041)	(0.040)	(0.059)	(0.064)
Hired labour	0.163***	0.157***	0.114**	0.109*
	(0.021)	(0.019)	(0.051)	(0.057)
Organic fert	0.056**	0.058**	-0.005	-0.009
	(0.025)	(0.025)	(0.034)	(0.039)
Inorganic fert	0.090***	0.076***	-0.031	-0.048
	(0.028)	(0.025)	(0.053)	(0.057)
Rainfall	0.085	0.096	-0.418*	-0.421*
	(0.110)	(0.103)	(0.235)	(0.223)
Female head	0.095	0.032	1.594***	1.715***
	(0.093)	(0.093)	(0.450)	(0.410)
Farm size	0.156**	0.233***	0.228**	0.222*
	(0.062)	(0.054)	(0.107)	(0.122)
Saving group	0.021	0.109	-0.381	-0.339
	(0.119)	(0.114)	(0.306)	(0.296)
Head educ	0.021	0.022	-0.083	-0.102
	(0.052)	(0.050)	(0.122)	(0.122)
Age of head	-0.344***	-0.440***	0.751	0.729
	(0.118)	(0.116)	(0.541)	(0.584)
Transport	0.154*	0.077	0.333	0.334
	(0.081)	(0.077)	(0.291)	(0.293)
Plots with crop	-0.078	-0.104	-0.165	-0.132
	(0.096)	(0.092)	(0.248)	(0.239)
Crops on farm	-0.001	-0.009	-0.073**	-0.081**
	(0.018)	(0.017)	(0.036)	(0.036)
Cooperative	0.099	0.080	0.234*	0.202
	(0.071)	(0.070)	(0.139)	(0.142)
Improved seeds	0.007	0.020	-0.297*	-0.230
	(0.075)	(0.077)	(0.161)	(0.160)
Erosion	-0.073	-0.028	0.335**	0.327**
	(0.100)	(0.098)	(0.155)	(0.158)
Irrigation	-0.040	-0.064	-0.407	-0.403
	(0.214)	(0.200)	(0.369)	(0.362)
Steepness	-0.053	-0.051		

	(0.040)	(0.040)		
Elevation	0.079	0.069		
	(0.054)	(0.052)		
Intercrop	-0.429***	-0.462***	-0.226	-0.214
	(0.104)	(0.108)	(0.183)	(0.183)
Maincrop	0.080	0.117	0.229	0.192
	(0.096)	(0.095)	(0.216)	(0.215)
Trees per plot	0.000	0.000**	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Soil quality	0.103*	0.122**	-0.052	-0.036
	(0.054)	(0.052)	(0.124)	(0.118)
soil_type==SANDY	-0.137	-0.119		
	(0.097)	(0.097)		
soil_type==CLAY	0.009	0.072		
	(0.071)	(0.068)		
soil_type==OTHER	0.143	0.009		
	(0.289)	(0.282)		
time=2	-0.204	-0.231	0.555*	0.448
	(0.162)	(0.158)	(0.284)	(0.290)
time=3	-0.236	-0.183	0.127	0.095
	(0.144)	(0.142)	(0.245)	(0.241)
Constant	5.059***	5.369***	4.064*	4.328
	(0.989)	(0.955)	(2.254)	(2.793)
Observations	630	630	630	630
R^2	0.49	0.57	0.57	0.56
Regions	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	GPS	SR	GPS

Standard errors clustered at household level for models 1-5, and at household/plot level for models 6-7

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B.8: Testing P4 for beans (full output)

	(1)	(2)	(3)	(4)
	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.361***	-0.447***	-0.369***	-0.539***
	(0.096)	(0.065)	(0.129)	(0.107)
Area*Intercrop	-0.120	-0.083	-0.221**	-0.085

	(0.092)	(0.062)	(0.102)	(0.087)
Area*female	-0.189**	-0.104	-0.099	-0.329
	(0.082)	(0.066)	(0.128)	(0.205)
Family labour	0.117***	0.090***	0.078	0.136**
	(0.035)	(0.032)	(0.054)	(0.055)
Hired labour	0.086***	0.064***	0.088**	0.080**
	(0.023)	(0.024)	(0.037)	(0.036)
Organic fert	0.015	0.012	0.030	0.028
	(0.013)	(0.013)	(0.029)	(0.028)
Inorganic fert	0.012	0.013	-0.009	0.001
	(0.021)	(0.021)	(0.034)	(0.033)
Rainfall	-0.173	-0.121	0.640**	0.718***
	(0.149)	(0.141)	(0.263)	(0.273)
Female head	-0.094	-0.063	-0.090	-0.219
	(0.092)	(0.088)	(0.317)	(0.334)
Farm size	0.226***	0.263***	-0.120	0.039
	(0.053)	(0.044)	(0.106)	(0.095)
Saving group	-0.001	0.000	0.042	-0.061
	(0.124)	(0.120)	(0.310)	(0.387)
Head educ	-0.101*	-0.086	-0.239**	-0.207**
	(0.059)	(0.058)	(0.098)	(0.103)
Age of head	-0.070	-0.072	0.486	-0.136
	(0.111)	(0.105)	(1.740)	(1.824)
Transport	0.143**	0.127*	0.220	0.235
	(0.072)	(0.069)	(0.151)	(0.153)
Plots with crop	-0.157*	-0.101	0.149	0.198
	(0.083)	(0.083)	(0.138)	(0.139)
Crops on farm	-0.017	-0.025*	0.022	-0.009
	(0.015)	(0.014)	(0.026)	(0.026)
Cooperative	0.018	0.063	0.208*	0.173
	(0.071)	(0.067)	(0.114)	(0.114)
Improved seeds	0.027	0.013	-0.012	0.003
	(0.070)	(0.068)	(0.114)	(0.118)
Erosion	-0.202**	-0.186**	-0.131	-0.108
	(0.084)	(0.084)	(0.131)	(0.134)
Irrigation	-0.029	-0.031	-0.512	-0.350

	(0.339)	(0.323)	(0.464)	(0.517)
Steepness	0.052*	0.038		
	(0.031)	(0.029)		
Elevation	-0.277	-0.173		
	(0.179)	(0.174)		
Intercrop	-0.272***	-0.276***	0.014	-0.058
	(0.102)	(0.098)	(0.147)	(0.149)
Maincrop	0.394***	0.425***	0.240*	0.251*
	(0.093)	(0.089)	(0.133)	(0.146)
Trees per plot	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Soil quality	0.087*	0.096**	0.069	0.056
	(0.049)	(0.048)	(0.083)	(0.081)
soil_type==SANDY	0.070	0.050		
	(0.105)	(0.104)		
soil_type==CLAY	0.038	0.030		
	(0.076)	(0.072)		
soil_type==OTHER	-0.029	0.113		
	(0.193)	(0.165)		
time=2	0.069	0.045	-0.031	-0.050
	(0.137)	(0.129)	(0.206)	(0.212)
time=3	-0.067	-0.052	-0.250	-0.209
	(0.100)	(0.098)	(0.205)	(0.208)
Constant	6.625***	5.782***	-2.482	-0.751
	(1.561)	(1.540)	(6.559)	(6.860)
Observations	936	936	936	936
R^2	0.33	0.44	0.50	0.50
Regions	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	GPS	SR	GPS

Standard errors clustered at household level for models 1-5, and at household/plot level for models 6-7

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B.9: Testing P4 for groundnut (full output)

	(1)	(2)	(3)	(4)
	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.332***	-0.420***	-1.179***	-0.985***

	(0.114)	(0.081)	(0.254)	(0.259)
Area*Intercrop	-0.132	-0.073	0.285	0.097
	(0.106)	(0.081)	(0.283)	(0.239)
Area*female	-0.033	-0.068	-0.053	-0.252
	(0.089)	(0.078)	(0.302)	(0.210)
Family labour	0.162***	0.187***	0.162	0.112
	(0.058)	(0.055)	(0.157)	(0.147)
Hired labour	0.069*	0.057	0.098	0.120
	(0.040)	(0.039)	(0.096)	(0.089)
Organic fert	0.032	0.025	0.021	0.018
	(0.020)	(0.020)	(0.043)	(0.043)
Inorganic fert	0.012	0.005	-0.004	-0.037
	(0.038)	(0.039)	(0.091)	(0.088)
Rainfall	-0.043	-0.033	0.345	0.230
	(0.266)	(0.272)	(0.455)	(0.455)
Female head	-0.119	-0.059	-3.996***	-4.267***
	(0.113)	(0.111)	(0.780)	(0.689)
Farm size	0.144*	0.210***	-0.204	-0.251
	(0.081)	(0.064)	(0.192)	(0.185)
Saving group	0.045	0.162	-0.885*	-0.978*
	(0.169)	(0.175)	(0.528)	(0.550)
Head educ	0.041	0.064	0.028	0.057
	(0.091)	(0.092)	(0.314)	(0.284)
Age of head	-0.099	-0.093	-4.787	-4.176
	(0.158)	(0.161)	(5.137)	(5.068)
Transport	0.144	0.175*	0.135	0.199
	(0.106)	(0.105)	(0.339)	(0.361)
Plots with crop	-0.282*	-0.267*	-0.770**	-0.737**
	(0.153)	(0.161)	(0.308)	(0.354)
Crops on farm	-0.044**	-0.054***	-0.048	-0.053
	(0.022)	(0.021)	(0.068)	(0.068)
Cooperative	-0.140	-0.157	0.048	0.069
	(0.097)	(0.096)	(0.161)	(0.165)
Improved seeds	-0.122	-0.136	-0.251	-0.296
	(0.105)	(0.105)	(0.269)	(0.289)
Erosion	-0.012	-0.020	-0.129	-0.190

	(0.173)	(0.171)	(0.406)	(0.386)
Irrigation	0.254	0.267	2.094***	2.015***
	(0.230)	(0.230)	(0.425)	(0.417)
Steepness	0.021	0.020		
	(0.055)	(0.055)		
Elevation	0.156	0.160		
	(0.110)	(0.107)		
Intercrop	-0.033	0.027	0.043	0.129
	(0.109)	(0.107)	(0.370)	(0.364)
Maincrop	0.367***	0.371***	0.380	0.350
	(0.124)	(0.124)	(0.300)	(0.267)
Trees per plot	-0.000	-0.000	-0.000*	-0.000*
	(0.000)	(0.000)	(0.000)	(0.000)
Soil quality	-0.112	-0.092	0.225	0.225
	(0.073)	(0.074)	(0.163)	(0.172)
soil_type==SANDY	-0.202*	-0.193*		
	(0.110)	(0.108)		
soil_type==CLAY	-0.037	-0.057		
	(0.182)	(0.183)		
soil_type==OTHER	-0.155	-0.201		
	(0.233)	(0.246)		
time=2	-0.083	0.012	0.788**	0.747*
	(0.191)	(0.188)	(0.394)	(0.415)
time=3	-0.148	-0.074	0.656	0.557
	(0.147)	(0.145)	(0.482)	(0.462)
Constant	4.358**	4.000*	21.139	19.846
	(2.098)	(2.119)	(20.591)	(20.093)
Observations	460	460	460	460
R^2	0.33	0.40	0.66	0.66
Regions	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	GPS	SR	GPS

Standard errors clustered at household level for models 1-5, and at household/plot level for models 6-7

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

B.0.3 Controlling for P5: full output tables

Table B.10: Testing P5 for maize (full output)

	(1)	(2)	(3)	(4)
	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.421***	-0.479***	-0.851***	-0.868***
	(0.042)	(0.037)	(0.089)	(0.081)
Area*Maincrop	0.196***	0.141***	0.253***	0.244***
	(0.041)	(0.037)	(0.087)	(0.077)
Area*female	-0.145***	-0.113***	-0.083	-0.074
	(0.039)	(0.030)	(0.084)	(0.081)
Family labour	0.160***	0.146***	0.127***	0.122***
	(0.023)	(0.021)	(0.030)	(0.030)
Hired labour	0.124***	0.116***	0.029	0.029
	(0.015)	(0.015)	(0.022)	(0.021)
Organic fert	0.017**	0.017**	0.004	0.004
	(0.007)	(0.007)	(0.013)	(0.013)
Inorganic fert	0.127***	0.116***	0.050**	0.050**
	(0.011)	(0.010)	(0.020)	(0.020)
Rainfall	-0.043	0.003	-0.104	-0.084
	(0.077)	(0.074)	(0.099)	(0.099)
Female head	-0.064	-0.058	0.209	0.240
	(0.049)	(0.048)	(0.316)	(0.305)
Farm size	0.127***	0.186***	0.067	0.152***
	(0.028)	(0.023)	(0.052)	(0.045)
Saving group	0.083	0.088	0.098	0.114
	(0.074)	(0.074)	(0.107)	(0.111)
Head educ	0.009	0.012	0.062	0.057
	(0.032)	(0.031)	(0.053)	(0.053)
Age of head	-0.301***	-0.314***	0.019	0.002
	(0.063)	(0.060)	(0.496)	(0.472)
Transport	0.143***	0.135***	0.091	0.087
	(0.038)	(0.036)	(0.074)	(0.073)
Plots with crop	-0.070	-0.062	-0.161*	-0.192**
	(0.044)	(0.041)	(0.084)	(0.082)
Crops on farm	-0.017**	-0.026***	0.015	0.005
	(0.008)	(0.007)	(0.016)	(0.016)
Cooperative	0.070*	0.087**	0.116**	0.121**
	(0.036)	(0.035)	(0.050)	(0.051)

Improved seeds	-0.057	-0.054	0.034	0.041
	(0.035)	(0.034)	(0.049)	(0.048)
Erosion	0.006	-0.008	0.127	0.133
	(0.051)	(0.052)	(0.085)	(0.087)
Irrigation	0.034	0.006	0.175	0.182
	(0.133)	(0.127)	(0.191)	(0.183)
Steepness	0.033*	0.030		
	(0.019)	(0.018)		
Elevation	0.075**	0.060*		
	(0.038)	(0.035)		
Intercrop	-0.082**	-0.087**	-0.100*	-0.079
	(0.036)	(0.034)	(0.053)	(0.052)
Maincrop	0.297***	0.328***	0.227**	0.245***
	(0.047)	(0.045)	(0.092)	(0.093)
Trees per plot	-0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Soil quality	0.135***	0.139***	0.075**	0.083**
	(0.026)	(0.024)	(0.038)	(0.037)
soil_type==SANDY	-0.210***	-0.186***		
	(0.043)	(0.043)		
soil_type==CLAY	0.017	0.037		
	(0.045)	(0.043)		
soil_type==OTHER	0.110	0.133		
	(0.099)	(0.092)		
time=2	0.072	0.068	0.097	0.122
	(0.076)	(0.075)	(0.111)	(0.110)
time=3	-0.045	-0.005	0.045	0.062
	(0.063)	(0.062)	(0.087)	(0.084)
Constant	4.495***	4.378***	4.457**	4.317**
	(0.570)	(0.543)	(2.014)	(1.925)
Observations	3407	3407	3407	3407
R^2	0.32	0.40	0.29	0.33
Regions	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	GPS	SR	GPS

Standard errors clustered at household level for models 1-5, and at household/plot level for models 6-7

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B.11: Testing P5 for rice (full output)

	(1)	(2)	(3)	(4)
	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.504***	-0.587***	-0.480**	-0.681***
	(0.097)	(0.079)	(0.230)	(0.149)
Area*Maincrop	0.155*	0.182**	-0.385	-0.116
	(0.091)	(0.072)	(0.245)	(0.164)
Area*female	-0.032	-0.066	-0.330	-0.191
	(0.091)	(0.074)	(0.208)	(0.207)
Family labour	0.171***	0.166***	0.091	0.093
	(0.044)	(0.041)	(0.064)	(0.069)
Hired labour	0.161***	0.155***	0.117**	0.126**
	(0.021)	(0.019)	(0.053)	(0.058)
Organic fert	0.057**	0.054**	-0.012	-0.017
	(0.025)	(0.025)	(0.042)	(0.045)
Inorganic fert	0.098***	0.086***	-0.021	-0.040
	(0.028)	(0.025)	(0.055)	(0.059)
Rainfall	0.084	0.108	-0.331	-0.352
	(0.110)	(0.105)	(0.217)	(0.229)
Female head	0.091	0.040	1.253***	1.467***
	(0.094)	(0.093)	(0.479)	(0.411)
Farm size	0.171***	0.246***	0.231*	0.195
	(0.063)	(0.054)	(0.128)	(0.127)
Saving group	0.047	0.145	-0.457	-0.438
	(0.120)	(0.117)	(0.282)	(0.313)
Head educ	0.018	0.027	-0.117	-0.132
	(0.052)	(0.050)	(0.123)	(0.124)
Age of head	-0.326***	-0.416***	0.407	0.540
	(0.118)	(0.117)	(0.664)	(0.608)
Transport	0.157*	0.071	0.307	0.324
	(0.081)	(0.078)	(0.293)	(0.299)
Plots with crop	-0.076	-0.095	-0.130	-0.098
	(0.097)	(0.093)	(0.231)	(0.242)
Crops on farm	-0.005	-0.013	-0.061	-0.066*
	(0.018)	(0.017)	(0.037)	(0.037)
Cooperative	0.093	0.071	0.198	0.174

	(0.073)	(0.071)	(0.143)	(0.140)
Improved seeds	0.016	0.022	-0.276*	-0.255
	(0.076)	(0.077)	(0.158)	(0.159)
Erosion	-0.074	-0.033	0.379**	0.374**
	(0.102)	(0.098)	(0.178)	(0.180)
Irrigation	-0.047	-0.079	-0.359	-0.353
	(0.210)	(0.195)	(0.320)	(0.315)
Steepness	-0.063	-0.066*		
	(0.040)	(0.039)		
Elevation	0.089*	0.074		
	(0.054)	(0.052)		
Intercrop	-0.422***	-0.484***	-0.195	-0.225
	(0.105)	(0.108)	(0.182)	(0.179)
Maincrop	0.080	0.072	0.117	0.138
	(0.097)	(0.096)	(0.249)	(0.242)
Trees per plot	0.000	0.000**	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Soil quality	0.103*	0.111**	-0.054	-0.070
	(0.055)	(0.053)	(0.121)	(0.119)
soil_type==SANDY	-0.136	-0.120		
	(0.099)	(0.097)		
soil_type==CLAY	0.023	0.075		
	(0.071)	(0.068)		
soil_type==OTHER	0.131	0.026		
	(0.288)	(0.275)		
time=2	-0.253	-0.247	0.532*	0.483*
	(0.167)	(0.160)	(0.288)	(0.290)
time=3	-0.268*	-0.190	0.065	0.063
	(0.148)	(0.144)	(0.247)	(0.236)
Constant	4.972***	5.276***	5.317*	4.981*
	(0.992)	(0.972)	(2.868)	(2.925)
Observations	630	630	630	630
R^2	0.48	0.57	0.55	0.54
Regions	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	GPS	SR	GPS

Standard errors clustered at household level for models 1-5, and at household/plot level for models 6-7

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B.12: Testing P5 for beans (full output)

	(1)	(2)	(3)	(4)
	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.504***	-0.558***	-0.567***	-0.615***
	(0.052)	(0.042)	(0.093)	(0.092)
Area*Maincrop	0.231***	0.204***	-0.009	0.028
	(0.081)	(0.063)	(0.130)	(0.101)
Area*female	-0.184**	-0.092	-0.047	-0.324
	(0.080)	(0.065)	(0.128)	(0.208)
Family labour	0.108***	0.086***	0.080	0.132**
	(0.035)	(0.032)	(0.054)	(0.056)
Hired labour	0.083***	0.061***	0.093**	0.078**
	(0.023)	(0.023)	(0.037)	(0.036)
Organic fert	0.016	0.014	0.032	0.029
	(0.013)	(0.013)	(0.029)	(0.028)
Inorganic fert	0.011	0.012	-0.010	0.002
	(0.021)	(0.022)	(0.035)	(0.034)
Rainfall	-0.163	-0.127	0.671**	0.718***
	(0.148)	(0.138)	(0.272)	(0.277)
Female head	-0.096	-0.066	-0.033	-0.202
	(0.092)	(0.088)	(0.321)	(0.345)
Farm size	0.223***	0.266***	-0.118	0.029
	(0.052)	(0.043)	(0.107)	(0.092)
Saving group	0.003	0.003	0.075	-0.067
	(0.122)	(0.120)	(0.307)	(0.391)
Head educ	-0.104*	-0.090	-0.222**	-0.198*
	(0.059)	(0.058)	(0.100)	(0.103)
Age of head	-0.078	-0.076	0.837	0.007
	(0.111)	(0.105)	(1.830)	(1.857)
Transport	0.138*	0.119*	0.206	0.234
	(0.072)	(0.069)	(0.152)	(0.153)
Plots with crop	-0.151*	-0.095	0.192	0.211
	(0.083)	(0.083)	(0.136)	(0.138)
Crops on farm	-0.016	-0.026*	0.017	-0.010
	(0.014)	(0.014)	(0.026)	(0.027)

Cooperative	0.018	0.064	0.217*	0.175
	(0.071)	(0.067)	(0.116)	(0.115)
Improved seeds	0.023	0.006	-0.012	0.004
	(0.070)	(0.067)	(0.115)	(0.119)
Erosion	-0.194**	-0.178**	-0.152	-0.120
	(0.083)	(0.083)	(0.133)	(0.132)
Irrigation	0.004	0.004	-0.548	-0.361
	(0.345)	(0.331)	(0.465)	(0.520)
Steepness	0.046	0.030		
	(0.031)	(0.029)		
Elevation	-0.292	-0.171		
	(0.179)	(0.173)		
Intercrop	-0.237**	-0.257***	0.025	-0.040
	(0.101)	(0.094)	(0.152)	(0.148)
Maincrop	0.469***	0.514***	0.232	0.248*
	(0.095)	(0.091)	(0.141)	(0.150)
Trees per plot	-0.000	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Soil quality	0.092*	0.102**	0.067	0.055
	(0.049)	(0.047)	(0.082)	(0.081)
soil_type==SANDY	0.080	0.059		
	(0.106)	(0.105)		
soil_type==CLAY	0.029	0.020		
	(0.076)	(0.072)		
soil_type==OTHER	-0.028	0.104		
	(0.196)	(0.169)		
time=2	0.070	0.028	-0.105	-0.070
	(0.136)	(0.127)	(0.210)	(0.212)
time=3	-0.061	-0.051	-0.274	-0.218
	(0.099)	(0.097)	(0.210)	(0.208)
Constant	6.693***	5.849***	-4.034	-1.285
	(1.550)	(1.535)	(7.017)	(6.949)
Observations	936	936	936	936
R^2	0.34	0.44	0.50	0.50
Regions	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	GPS	SR	GPS

Standard errors clustered at household level for models 1-5, and at household/plot level for models 6-7

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B.13: Testing P5 for groundnut (full output)

	(1)	(2)	(3)	(4)
	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.456***	-0.482***	-1.023***	-1.006***
	(0.082)	(0.067)	(0.208)	(0.214)
Area*Maincrop	0.137	0.047	0.187	0.228
	(0.113)	(0.092)	(0.301)	(0.263)
Area*female	-0.043	-0.071	-0.050	-0.180
	(0.090)	(0.078)	(0.304)	(0.206)
Family labour	0.162***	0.186***	0.142	0.100
	(0.057)	(0.055)	(0.158)	(0.148)
Hired labour	0.069*	0.055	0.134	0.125
	(0.041)	(0.040)	(0.095)	(0.086)
Organic fert	0.032*	0.025	0.024	0.016
	(0.020)	(0.020)	(0.043)	(0.040)
Inorganic fert	0.011	0.005	-0.021	-0.054
	(0.038)	(0.039)	(0.093)	(0.084)
Rainfall	-0.062	-0.040	0.324	0.167
	(0.268)	(0.272)	(0.471)	(0.481)
Female head	-0.122	-0.060	-4.171***	-4.359***
	(0.113)	(0.111)	(0.914)	(0.712)
Farm size	0.143*	0.209***	-0.152	-0.205
	(0.081)	(0.064)	(0.201)	(0.183)
Saving group	0.071	0.181	-1.035**	-1.145**
	(0.168)	(0.175)	(0.525)	(0.531)
Head educ	0.040	0.062	0.036	0.062
	(0.092)	(0.093)	(0.313)	(0.274)
Age of head	-0.098	-0.093	-4.777	-4.668
	(0.158)	(0.161)	(5.406)	(5.268)
Transport	0.146	0.179*	0.280	0.136
	(0.106)	(0.105)	(0.335)	(0.371)
Plots with crop	-0.274*	-0.262	-0.731**	-0.701*
	(0.152)	(0.161)	(0.330)	(0.358)
Crops on farm	-0.044**	-0.054***	-0.063	-0.053

	(0.022)	(0.021)	(0.070)	(0.068)
Cooperative	-0.135	-0.156	0.040	0.032
	(0.096)	(0.095)	(0.174)	(0.167)
Improved seeds	-0.123	-0.139	-0.289	-0.235
	(0.105)	(0.105)	(0.266)	(0.280)
Erosion	-0.022	-0.029	-0.180	-0.206
	(0.174)	(0.172)	(0.388)	(0.386)
Irrigation	0.237	0.263	1.972***	1.947***
	(0.225)	(0.227)	(0.445)	(0.429)
Steepness	0.021	0.018		
	(0.055)	(0.055)		
Elevation	0.164	0.168		
	(0.111)	(0.106)		
Intercrop	-0.044	0.016	0.206	0.205
	(0.111)	(0.108)	(0.296)	(0.288)
Maincrop	0.363***	0.364***	0.371	0.307
	(0.124)	(0.124)	(0.308)	(0.255)
Trees per plot	-0.000	-0.000	-0.000*	-0.000*
	(0.000)	(0.000)	(0.000)	(0.000)
Soil quality	-0.108	-0.092	0.245	0.239
	(0.073)	(0.074)	(0.176)	(0.173)
soil_type==SANDY	-0.218**	-0.200*		
	(0.110)	(0.110)		
soil_type==CLAY	-0.023	-0.062		
	(0.183)	(0.183)		
soil_type==OTHER	-0.156	-0.211		
	(0.230)	(0.246)		
time=2	-0.102	0.005	0.754*	0.816**
	(0.191)	(0.187)	(0.411)	(0.412)
time=3	-0.153	-0.074	0.585	0.631
	(0.147)	(0.145)	(0.486)	(0.502)
Constant	4.397**	4.011*	21.242	22.059
	(2.114)	(2.124)	(21.560)	(20.726)
Observations	460	460	460	460
R^2	0.33	0.40	0.66	0.66
Regions	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Panel FE	Panel FE

Area	SR	GPS	SR	GPS

Standard errors clustered at household level for models 1-5, and at household/plot level for models 6-7

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

B.0.4 Jointly controlling for P4 and P5: full output tables

Table B.14: Testing P4 and P5 for maize (full output)

	(1)	(2)	(3)	(4)
	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.343***	-0.419***	-0.785***	-0.842***
	(0.053)	(0.043)	(0.103)	(0.091)
Area*Intercrop	-0.091***	-0.069***	-0.075	-0.031
	(0.035)	(0.026)	(0.051)	(0.043)
Area*Maincrop	0.175***	0.121***	0.234***	0.237***
	(0.041)	(0.037)	(0.090)	(0.078)
Area*female	-0.139***	-0.108***	-0.079	-0.071
	(0.039)	(0.030)	(0.084)	(0.081)
Family labour	0.160***	0.146***	0.126***	0.122***
	(0.023)	(0.021)	(0.030)	(0.030)
Hired labour	0.123***	0.116***	0.027	0.028
	(0.015)	(0.015)	(0.022)	(0.021)
Organic fert	0.017**	0.017**	0.002	0.003
	(0.007)	(0.007)	(0.013)	(0.013)
Inorganic fert	0.128***	0.116***	0.050**	0.050**
	(0.011)	(0.010)	(0.020)	(0.020)
Rainfall	-0.039	0.005	-0.099	-0.084
	(0.077)	(0.074)	(0.099)	(0.099)
Female head	-0.065	-0.060	0.224	0.243
	(0.049)	(0.049)	(0.317)	(0.305)
Farm size	0.128***	0.187***	0.069	0.152***
	(0.028)	(0.023)	(0.052)	(0.045)
Saving group	0.084	0.090	0.093	0.116
	(0.074)	(0.074)	(0.106)	(0.111)
Head educ	0.010	0.010	0.060	0.056
	(0.032)	(0.031)	(0.052)	(0.053)
Age of head	-0.300***	-0.314***	-0.017	-0.024
	(0.063)	(0.060)	(0.490)	(0.472)
Transport	0.143***	0.133***	0.089	0.084

	(0.038)	(0.036)	(0.074)	(0.073)
Plots with crop	-0.072	-0.062	-0.167**	-0.193**
	(0.044)	(0.041)	(0.084)	(0.082)
Crops on farm	-0.017**	-0.027***	0.015	0.005
	(0.008)	(0.007)	(0.016)	(0.016)
Cooperative	0.069*	0.087**	0.114**	0.119**
	(0.036)	(0.035)	(0.050)	(0.051)
Improved seeds	-0.060*	-0.056*	0.034	0.042
	(0.035)	(0.034)	(0.049)	(0.049)
Erosion	0.008	-0.006	0.132	0.135
	(0.051)	(0.052)	(0.086)	(0.087)
Irrigation	0.034	0.004	0.184	0.186
	(0.134)	(0.128)	(0.192)	(0.184)
Steepness	0.033*	0.031*		
	(0.019)	(0.018)		
Elevation	0.077**	0.063*		
	(0.038)	(0.035)		
Intercrop	-0.080**	-0.093***	-0.100*	-0.081
	(0.035)	(0.034)	(0.053)	(0.052)
Maincrop	0.294***	0.325***	0.227**	0.243***
	(0.047)	(0.045)	(0.092)	(0.093)
Trees per plot	-0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Soil quality	0.136***	0.140***	0.076**	0.084**
	(0.026)	(0.024)	(0.038)	(0.037)
soil_type==SANDY	-0.210***	-0.186***		
	(0.043)	(0.042)		
soil_type==CLAY	0.017	0.036		
	(0.045)	(0.043)		
soil_type==OTHER	0.117	0.137		
	(0.099)	(0.092)		
time=2	0.073	0.068	0.109	0.127
	(0.076)	(0.075)	(0.111)	(0.109)
time=3	-0.046	-0.006	0.048	0.064
	(0.063)	(0.062)	(0.087)	(0.084)
Constant	4.462***	4.357***	4.574**	4.423**

	(0.571)	(0.543)	(1.993)	(1.926)
Observations	3407	3407	3407	3407
R^2	0.32	0.40	0.29	0.33
Regions	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	GPS	SR	GPS

Standard errors clustered at household level for models 1-5, and at household/plot level for models 6-7

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B.15: TestingP4 and P5 for rice (full output)

	(1)	(2)	(3)	(4)
	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.349***	-0.488***	-0.226	-0.563***
	(0.107)	(0.087)	(0.253)	(0.180)
Area*Intercrop	-0.283**	-0.193**	-0.462**	-0.339**
	(0.117)	(0.084)	(0.186)	(0.150)
Area*Maincrop	0.067	0.123*	-0.467**	-0.164
	(0.093)	(0.074)	(0.235)	(0.189)
Area*female	0.011	-0.062	-0.200	-0.162
	(0.089)	(0.070)	(0.205)	(0.176)
Family labour	0.172***	0.165***	0.130**	0.114*
	(0.041)	(0.039)	(0.059)	(0.064)
Hired labour	0.162***	0.157***	0.115**	0.106*
	(0.021)	(0.019)	(0.052)	(0.057)
Organic fert	0.056**	0.057**	-0.004	-0.008
	(0.025)	(0.025)	(0.034)	(0.039)
Inorganic fert	0.091***	0.079***	-0.038	-0.057
	(0.028)	(0.025)	(0.053)	(0.056)
Rainfall	0.081	0.095	-0.443*	-0.451*
	(0.110)	(0.103)	(0.233)	(0.230)
Female head	0.095	0.034	1.550***	1.737***
	(0.093)	(0.093)	(0.472)	(0.420)
Farm size	0.157**	0.240***	0.248**	0.218*
	(0.062)	(0.054)	(0.110)	(0.122)
Saving group	0.026	0.125	-0.465	-0.408
	(0.121)	(0.116)	(0.306)	(0.327)
Head educ	0.021	0.025	-0.078	-0.099

	(0.052)	(0.050)	(0.120)	(0.122)
Age of head	-0.343***	-0.439***	0.704	0.716
	(0.118)	(0.117)	(0.592)	(0.619)
Transport	0.153*	0.071	0.331	0.345
	(0.081)	(0.077)	(0.281)	(0.296)
Plots with crop	-0.076	-0.096	-0.193	-0.164
	(0.095)	(0.092)	(0.239)	(0.242)
Crops on farm	-0.001	-0.009	-0.071**	-0.080**
	(0.018)	(0.017)	(0.035)	(0.036)
Cooperative	0.095	0.071	0.232*	0.210
	(0.072)	(0.070)	(0.137)	(0.141)
Improved seeds	0.009	0.025	-0.303*	-0.238
	(0.075)	(0.076)	(0.156)	(0.157)
Erosion	-0.074	-0.033	0.362**	0.343**
	(0.100)	(0.098)	(0.153)	(0.161)
Irrigation	-0.051	-0.083	-0.338	-0.371
	(0.215)	(0.198)	(0.345)	(0.348)
Steepness	-0.053	-0.055		
	(0.040)	(0.040)		
Elevation	0.081	0.071		
	(0.054)	(0.052)		
Intercrop	-0.430***	-0.468***	-0.198	-0.231
	(0.104)	(0.108)	(0.182)	(0.184)
Maincrop	0.076	0.091	0.107	0.140
	(0.096)	(0.096)	(0.239)	(0.234)
Trees per plot	0.000	0.000**	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Soil quality	0.104*	0.118**	-0.053	-0.033
	(0.054)	(0.053)	(0.122)	(0.118)
soil_type==SANDY	-0.135	-0.121		
	(0.097)	(0.097)		
soil_type==CLAY	0.008	0.068		
	(0.070)	(0.068)		
soil_type==OTHER	0.137	0.007		
	(0.292)	(0.285)		
time=2	-0.208	-0.239	0.576**	0.461

	(0.162)	(0.158)	(0.290)	(0.292)
time=3	-0.236	-0.178	0.110	0.091
	(0.144)	(0.142)	(0.251)	(0.244)
Constant	5.080***	5.404***	4.573*	4.621
	(0.989)	(0.963)	(2.474)	(2.980)
Observations	630	630	630	630
R^2	0.49	0.57	0.58	0.56
Regions	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	GPS	SR	GPS

Standard errors clustered at household level for models 1-5, and at household/plot level for models 6-7

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B.16: TestingP4 and P5 for beans (full output)

	(1)	(2)	(3)	(4)
	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.492***	-0.590***	-0.312**	-0.523***
	(0.109)	(0.083)	(0.145)	(0.135)
Area*Intercrop	-0.013	0.034	-0.260**	-0.099
	(0.100)	(0.075)	(0.113)	(0.111)
Area*Maincrop	0.226**	0.221***	-0.107	-0.030
	(0.094)	(0.081)	(0.138)	(0.131)
Area*female	-0.186**	-0.092	-0.094	-0.327
	(0.080)	(0.065)	(0.126)	(0.206)
Family labour	0.109***	0.085***	0.081	0.136**
	(0.035)	(0.032)	(0.053)	(0.055)
Hired labour	0.083***	0.061***	0.089**	0.081**
	(0.023)	(0.023)	(0.037)	(0.036)
Organic fert	0.016	0.014	0.029	0.028
	(0.013)	(0.013)	(0.029)	(0.028)
Inorganic fert	0.011	0.012	-0.009	0.001
	(0.021)	(0.022)	(0.034)	(0.033)
Rainfall	-0.163	-0.127	0.652**	0.717***
	(0.148)	(0.139)	(0.267)	(0.274)
Female head	-0.097	-0.067	-0.044	-0.205
	(0.092)	(0.088)	(0.318)	(0.346)
Farm size	0.223***	0.265***	-0.117	0.039

	(0.052)	(0.044)	(0.107)	(0.095)
Saving group	0.002	0.003	0.042	-0.061
	(0.122)	(0.120)	(0.313)	(0.388)
Head educ	-0.104*	-0.090	-0.236**	-0.206**
	(0.059)	(0.058)	(0.098)	(0.104)
Age of head	-0.077	-0.078	0.879	-0.027
	(0.112)	(0.105)	(1.792)	(1.892)
Transport	0.138*	0.119*	0.220	0.235
	(0.072)	(0.069)	(0.150)	(0.152)
Plots with crop	-0.151*	-0.095	0.141	0.196
	(0.083)	(0.083)	(0.139)	(0.140)
Crops on farm	-0.016	-0.026*	0.027	-0.007
	(0.015)	(0.014)	(0.026)	(0.027)
Cooperative	0.017	0.065	0.219*	0.176
	(0.071)	(0.067)	(0.115)	(0.114)
Improved seeds	0.023	0.005	-0.011	0.005
	(0.070)	(0.067)	(0.114)	(0.119)
Erosion	-0.194**	-0.181**	-0.133	-0.109
	(0.083)	(0.082)	(0.131)	(0.134)
Irrigation	0.004	0.006	-0.500	-0.347
	(0.345)	(0.331)	(0.467)	(0.518)
Steepness	0.046	0.029		
	(0.031)	(0.029)		
Elevation	-0.292	-0.169		
	(0.179)	(0.173)		
Intercrop	-0.240**	-0.247***	0.002	-0.061
	(0.100)	(0.095)	(0.147)	(0.150)
Maincrop	0.467***	0.519***	0.217	0.242
	(0.093)	(0.091)	(0.142)	(0.151)
Trees per plot	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Soil quality	0.092*	0.102**	0.072	0.058
	(0.049)	(0.047)	(0.083)	(0.082)
soil_type==SANDY	0.079	0.061		
	(0.106)	(0.106)		
soil_type==CLAY	0.030	0.018		

	(0.076)	(0.072)		
soil_type==OTHER	-0.026	0.102		
	(0.196)	(0.169)		
time=2	0.070	0.030	-0.058	-0.052
	(0.136)	(0.127)	(0.213)	(0.212)
time=3	-0.061	-0.050	-0.284	-0.214
	(0.099)	(0.097)	(0.207)	(0.209)
Constant	6.689***	5.834***	-4.117	-1.181
	(1.550)	(1.533)	(6.903)	(7.120)
Observations	936	936	936	936
R^2	0.34	0.44	0.51	0.50
Regions	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	GPS	SR	GPS

Standard errors clustered at household level for models 1-5, and at household/plot level for models 6-7

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table B.17: TestingP4 and P5 for groundnut (full output)

	(1)	(2)	(3)	(4)
	P1+P2	P1+P2+P3	P1+P2	P1+P2+P3
Area	-0.367***	-0.429***	-1.248***	-1.131***
	(0.125)	(0.098)	(0.270)	(0.293)
Area*Intercrop	-0.112	-0.067	0.318	0.166
	(0.110)	(0.091)	(0.291)	(0.258)
Area*Maincrop	0.109	0.021	0.253	0.289
	(0.117)	(0.105)	(0.295)	(0.271)
Area*female	-0.035	-0.067	-0.138	-0.223
	(0.089)	(0.078)	(0.298)	(0.207)
Family labour	0.163***	0.187***	0.155	0.107
	(0.058)	(0.055)	(0.158)	(0.147)
Hired labour	0.071*	0.057	0.105	0.114
	(0.041)	(0.040)	(0.094)	(0.086)
Organic fert	0.033*	0.025	0.018	0.013
	(0.020)	(0.020)	(0.042)	(0.041)
Inorganic fert	0.013	0.006	-0.010	-0.042
	(0.038)	(0.039)	(0.091)	(0.086)
Rainfall	-0.055	-0.034	0.298	0.165

	(0.269)	(0.273)	(0.465)	(0.474)
Female head	-0.124	-0.060	-4.339***	-4.395***
	(0.113)	(0.111)	(0.907)	(0.714)
Farm size	0.146*	0.211***	-0.208	-0.220
	(0.081)	(0.065)	(0.189)	(0.181)
Saving group	0.056	0.165	-0.845	-1.008*
	(0.170)	(0.179)	(0.545)	(0.554)
Head educ	0.044	0.064	-0.023	0.028
	(0.092)	(0.093)	(0.353)	(0.297)
Age of head	-0.102	-0.093	-6.297	-5.535
	(0.158)	(0.161)	(5.724)	(5.532)
Transport	0.140	0.174	0.133	0.127
	(0.107)	(0.106)	(0.329)	(0.367)
Plots with crop	-0.275*	-0.265	-0.718**	-0.697*
	(0.152)	(0.161)	(0.319)	(0.355)
Crops on farm	-0.044**	-0.054***	-0.055	-0.055
	(0.022)	(0.021)	(0.069)	(0.067)
Cooperative	-0.140	-0.158*	0.021	0.025
	(0.097)	(0.096)	(0.161)	(0.161)
Improved seeds	-0.120	-0.136	-0.301	-0.283
	(0.105)	(0.105)	(0.273)	(0.294)
Erosion	-0.023	-0.023	-0.146	-0.201
	(0.173)	(0.171)	(0.405)	(0.388)
Irrigation	0.241	0.263	2.118***	2.012***
	(0.229)	(0.230)	(0.439)	(0.423)
Steepness	0.022	0.020		
	(0.055)	(0.055)		
Elevation	0.156	0.160		
	(0.110)	(0.107)		
Intercrop	-0.040	0.025	0.027	0.100
	(0.109)	(0.108)	(0.361)	(0.353)
Maincrop	0.369***	0.371***	0.320	0.259
	(0.124)	(0.124)	(0.314)	(0.273)
Trees per plot	-0.000	-0.000	-0.000*	-0.000*
	(0.000)	(0.000)	(0.000)	(0.000)
Soil quality	-0.110	-0.092	0.229	0.238

	(0.073)	(0.074)	(0.164)	(0.167)
soil_type==SANDY	-0.211*	-0.195*		
	(0.110)	(0.110)		
soil_type==CLAY	-0.027	-0.058		
	(0.183)	(0.183)		
soil_type==OTHER	-0.140	-0.200		
	(0.234)	(0.247)		
time=2	-0.097	0.010	0.755*	0.768*
	(0.191)	(0.188)	(0.397)	(0.419)
time=3	-0.147	-0.074	0.721	0.689
	(0.147)	(0.145)	(0.499)	(0.507)
Constant	4.423**	4.013*	27.611	25.622
	(2.116)	(2.129)	(23.147)	(21.980)
Observations	460	460	460	460
R^2	0.33	0.40	0.67	0.67
Regions	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Estimation	Pooled OLS	Pooled OLS	Panel FE	Panel FE
Area	SR	GPS	SR	GPS

Standard errors clustered at household level for models 1-5, and at household/plot level for models 6-7

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Appendix C

Appendix to Chapter 3

C.0.1 Summary statistics for food and export crops

Table C.1: Summary statistics for food crops

	Sweet pot.		Irish pot.		Beans		Cowpeas		Pigeon pea		Bambara		Sunflower		Groundnut		Sugarcane	
	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
Contribution to diet (%)	7.6	10	9.5	11	8.2	8	6.6	7	7.3	9	6.8	7	6.3	7	7.4	7	7.6	9
Harvest (kg)	387	446	540	685	121	157	71	145	137	209	111	119	248	369	195	272	367	644
Price (Tshs/kg)	262	231	249	141	745	277	684	401	574	276	578	411	411	272	719	438	410	710
Sales (kg)	80	261	407	670	43	104	28	123	66	147	32	65	153	312	81	183	202	513
Sales (Tshs 1000s)	19	69	85	158	30	81	197	109	37	85	15	33	60	137	50	130	49	299
N	569		101		1358		360		455		130		371		825		262	

Table C.2: Summary statistics for export crops

	Simsim		Cashews		Cotton		Sisal		Coffee		Tea		Cocoa		Cardamom		Cloves	
	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
Harvest (kg)	182	291	308	764	913	1082	89	97	204	563	2179	1607	414	558	19	19	153	211
Price (Tshs/kg)	1230	937	930	587	631	292	1185	1457	1645	3300	235	297	1682	801	6546	4334	5851	4969
Sales (kg)	166	251	220	713	893	1074	39	69	154	503	1381	1260	375	539	14	16	116	194
Sales (Tshs 1000s)	218	417	213	832	520	530	15	22	142	362	255	203	702	1164	69	81	548	829
N	210		609		211		16		389		15		30		26		54	

C.0.2 Two-part models with lagged prices

Table C.3: Maize: two-part models

	Participation equation					Supply equation				
	Wave 1	Wave 2	Wave 2 lags	Wave 3	Wave 3 lags	Wave 1	Wave 2	Wave 2 lags	Wave 3	Wave 3 lags
Price	-0.046	-0.128**	-0.164***	-0.187***	-0.207***	0.025	0.065	-0.001	-0.039	-0.041
	(0.033)	(0.050)	(0.057)	(0.036)	(0.039)	(0.145)	(0.106)	(0.125)	(0.101)	(0.114)
Lagged prics			0.003		-0.041*			-0.134		-0.092
			(0.036)		(0.021)			(0.123)		(0.100)
Harvest	0.135***	0.139***	0.129***	0.138***	0.136***	0.554***	0.469***	0.407***	0.597***	0.572***
	(0.012)	(0.012)	(0.014)	(0.009)	(0.010)	(0.061)	(0.052)	(0.056)	(0.052)	(0.053)
Farm size	-0.019	0.028*	0.019	0.018	0.028**	0.199***	0.301***	0.345***	0.180***	0.211***
	(0.015)	(0.016)	(0.020)	(0.012)	(0.012)	(0.065)	(0.063)	(0.074)	(0.056)	(0.059)
Dependency ratio	-0.001	-0.001	-0.001	-0.001**	-0.001**	-0.003	-0.003*	-0.001	-0.003	-0.002
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Female head	-0.017	0.078**	0.090**	-0.001	-0.013	-0.423***	-0.132	-0.113	-0.339***	-0.361***
	(0.032)	(0.033)	(0.039)	(0.024)	(0.026)	(0.161)	(0.121)	(0.134)	(0.113)	(0.118)
Age head	-0.091**	-0.033	-0.052	-0.110***	-0.115***	-0.134	0.166	0.371**	0.197	0.236*
	(0.041)	(0.045)	(0.053)	(0.030)	(0.032)	(0.190)	(0.169)	(0.176)	(0.121)	(0.129)
Distance	0.000	0.003	0.006	0.006	0.005	-0.095	0.026	0.014	0.003	-0.008
	(0.013)	(0.012)	(0.015)	(0.009)	(0.010)	(0.058)	(0.044)	(0.049)	(0.039)	(0.040)

Transport	-0.046*	-0.035	-0.021	-0.062***	-0.074***	0.090	0.129	0.130	0.153*	0.156*
	(0.028)	(0.028)	(0.033)	(0.021)	(0.022)	(0.111)	(0.104)	(0.118)	(0.086)	(0.090)
Nutrition district	-0.001	-0.001	-0.002	-0.002	-0.000	0.005	0.008**	0.006	0.006*	0.009**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
HDDS district	-0.014	-0.033*	-0.022	-0.002	-0.002	0.040	-0.033	-0.103	-0.084*	-0.093*
	(0.013)	(0.017)	(0.021)	(0.013)	(0.014)	(0.059)	(0.061)	(0.072)	(0.050)	(0.051)
Radio	0.046	-0.052*	-0.043	-0.001	-0.010					
	(0.028)	(0.030)	(0.035)	(0.020)	(0.022)					
Primary educ	0.017	0.018	0.007	-0.006	0.004					
	(0.030)	(0.030)	(0.036)	(0.020)	(0.022)					
Secondary educ	0.038	0.032	0.036	0.047	0.086**					
	(0.064)	(0.065)	(0.085)	(0.039)	(0.042)					
N	1087	1105	842	1627	1448	304	369	302	467	428
R^2						0.46	0.39	0.40	0.47	0.46
Zone dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mix	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table C.4: Cassava: two-part models

	Participation equation					Supply equation				
	Wave 1	Wave 2	Wave 2 lags	Wave 3	Wave 3 lags	Wave 1	Wave 2	Wave 2 lags	Wave 3	Wave 3 lags
Price	-0.041	-0.121***	-0.148***	0.039	0.042	-0.244**	-0.353**	-0.419**	-0.201**	-0.245**
	(0.032)	(0.019)	(0.022)	(0.031)	(0.036)	(0.102)	(0.143)	(0.180)	(0.081)	(0.100)
Lagged prices			0.006		-0.024*			-0.044		-0.023
			(0.032)		(0.014)			(0.212)		(0.062)
Harvest	0.100***	0.079***	0.048**	0.128***	0.116***	1.036***	0.758***	0.738***	0.813***	0.823***
	(0.014)	(0.016)	(0.020)	(0.012)	(0.014)	(0.059)	(0.120)	(0.173)	(0.078)	(0.095)
Farm size	0.034*	0.005	0.036	0.007	0.040**	-0.059	0.315**	0.330*	0.109	0.122
	(0.019)	(0.023)	(0.031)	(0.015)	(0.019)	(0.073)	(0.142)	(0.176)	(0.070)	(0.083)
Dependency ratio	-0.001*	-0.001	-0.001	-0.001	-0.002**	0.007*	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.004)	(0.003)	(0.005)	(0.003)	(0.003)
Female head	0.059	0.004	-0.055	0.056	0.019	-0.306	0.185	0.149	-0.075	0.070
	(0.046)	(0.047)	(0.062)	(0.036)	(0.044)	(0.197)	(0.228)	(0.354)	(0.135)	(0.183)
Age head	-0.065	-0.047	-0.054	-0.097**	-0.091*	0.012	-0.073	0.139	-0.257	-0.306
	(0.059)	(0.065)	(0.083)	(0.045)	(0.054)	(0.206)	(0.309)	(0.505)	(0.201)	(0.258)
Distance	0.029	-0.024	-0.040*	0.014	0.024	0.058	0.058	-0.012	-0.015	0.029
	(0.018)	(0.017)	(0.022)	(0.014)	(0.018)	(0.063)	(0.095)	(0.136)	(0.063)	(0.079)
Transport	-0.015	0.060	-0.003	-0.001	-0.012	-0.047	0.363*	0.479	-0.230*	-0.128
	(0.036)	(0.040)	(0.052)	(0.031)	(0.038)	(0.160)	(0.215)	(0.311)	(0.129)	(0.161)

Nutrition district	-0.002	0.002	0.004*	-0.003**	-0.003**	-0.022***	-0.027***	-0.023*	-0.002	-0.006
	(0.002)	(0.002)	(0.002)	(0.001)	(0.002)	(0.005)	(0.007)	(0.012)	(0.006)	(0.007)
HDDS district	0.023	0.079**	0.073	0.029	0.015	-0.077	-0.302	-0.404	0.134	0.091
	(0.022)	(0.039)	(0.057)	(0.023)	(0.032)	(0.059)	(0.210)	(0.337)	(0.098)	(0.118)
Radio	-0.009	-0.063	-0.071	-0.030	-0.020					
	(0.038)	(0.040)	(0.053)	(0.030)	(0.036)					
Primary educ	0.012	-0.100**	-0.073	-0.001	-0.041					
	(0.040)	(0.044)	(0.057)	(0.031)	(0.038)					
Secondary educ	0.033	-0.105	-0.089	0.049	0.037					
	(0.056)	(0.071)	(0.087)	(0.046)	(0.055)					
N	501	430	255	714	510	106	102	67	158	113
R^2						0.77	0.69	0.66	0.63	0.63
Zone dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mix	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table C.5: Food crops: two-part models

	Participation equation					Supply equation				
	Wave 1	Wave 2	Wave 2 lags	Wave 3	Wave 3 lags	Wave 1	Wave 2	Wave 2 lags	Wave 3	Wave 3 lags
Value	0.132***	0.140***	0.110***	0.141***	0.146***	0.704***	0.659***	0.550***	0.690***	0.708***
	(0.010)	(0.011)	(0.021)	(0.008)	(0.012)	(0.041)	(0.052)	(0.071)	(0.035)	(0.044)
Lag value			0.062***		-0.006			0.162***		-0.005
			(0.020)		(0.012)			(0.048)		(0.037)
Farm size	0.027*	0.035**	0.065**	0.005	0.013	0.150***	0.110	-0.016	0.064	0.072
	(0.016)	(0.017)	(0.027)	(0.012)	(0.017)	(0.052)	(0.069)	(0.078)	(0.044)	(0.053)
Dependency ratio	-0.000	-0.001	0.000	-0.001***	-0.002**	0.004**	0.002	0.001	-0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)
Female head	-0.021	-0.014	0.053	-0.006	-0.014	-0.035	-0.048	-0.178	-0.238***	-0.297***
	(0.034)	(0.036)	(0.058)	(0.026)	(0.036)	(0.123)	(0.132)	(0.144)	(0.088)	(0.107)
Age head	-0.173***	-0.183***	-0.211***	-0.119***	-0.103**	-0.153	0.193	0.119	0.073	0.068
	(0.043)	(0.046)	(0.069)	(0.033)	(0.047)	(0.143)	(0.172)	(0.196)	(0.111)	(0.133)
Distance	-0.007	0.019	0.009	0.021**	0.024*	0.060	0.091**	0.131**	0.046	0.042
	(0.014)	(0.013)	(0.021)	(0.010)	(0.013)	(0.048)	(0.046)	(0.052)	(0.036)	(0.043)
Transport	-0.050*	-0.065**	-0.104**	-0.065***	-0.105***	0.107	0.141	0.155	0.053	0.092
	(0.030)	(0.030)	(0.046)	(0.023)	(0.031)	(0.090)	(0.101)	(0.123)	(0.077)	(0.087)
Nutrition district	-0.006	-0.002	-0.005	0.005	0.005	-0.015	-0.033**	-0.028	-0.017	-0.003
	(0.004)	(0.004)	(0.006)	(0.004)	(0.005)	(0.018)	(0.016)	(0.021)	(0.013)	(0.014)

HDDS district	-0.012	-0.030*	-0.031	-0.034**	-0.050**	0.129**	0.023	0.173**	-0.044	-0.087
	(0.015)	(0.018)	(0.029)	(0.015)	(0.020)	(0.051)	(0.069)	(0.079)	(0.057)	(0.068)
Radio	-0.046	-0.021	-0.006	-0.050**	-0.030					
	(0.029)	(0.032)	(0.049)	(0.022)	(0.030)					
Primary educ	0.019	-0.031	-0.078	0.042*	0.070**					
	(0.032)	(0.033)	(0.049)	(0.022)	(0.030)					
Secondary educ	-0.073	-0.091	-0.151	0.016	0.081					
	(0.069)	(0.063)	(0.102)	(0.044)	(0.056)					
N	1250	1089	464	1848	1030	522	441	229	707	455
R^2						0.50	0.44	0.49	0.47	0.52
Zone dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mix	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table C.6: Export crops: two-part models

	Participation equation					Supply equation				
	Wave 1	Wave 2	Wave 2 lags	Wave 3	Wave 3 lags	Wave 1	Wave 2	Wave 2 lags	Wave 3	Wave 3 lags
Value	0.054***	0.049***	0.032	0.072***	0.058***	0.723***	0.745***	0.612***	0.711***	0.617***
	(0.010)	(0.017)	(0.027)	(0.008)	(0.009)	(0.044)	(0.066)	(0.128)	(0.042)	(0.057)
Lag value			0.039		0.004			0.224***		0.141***
			(0.025)		(0.009)			(0.084)		(0.048)
Farm size	-0.030*	-0.042	-0.093**	-0.005	0.002	0.205***	0.237**	0.272**	0.462***	0.398***
	(0.018)	(0.032)	(0.041)	(0.013)	(0.016)	(0.051)	(0.094)	(0.109)	(0.054)	(0.066)
Dependency ratio	0.001	0.001	0.000	0.002***	0.002***	0.002	0.006	0.006	0.000	0.003
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.002)	(0.004)	(0.005)	(0.002)	(0.002)
Female head	-0.069**	-0.034	-0.066	0.024	0.033	0.055	0.112	0.191	0.105	-0.067
	(0.035)	(0.062)	(0.082)	(0.027)	(0.031)	(0.107)	(0.160)	(0.211)	(0.097)	(0.110)
Age head	-0.053	-0.035	-0.124	-0.099***	-0.064	-0.124	-0.088	-0.201	-0.384***	-0.249
	(0.057)	(0.088)	(0.111)	(0.035)	(0.041)	(0.151)	(0.239)	(0.299)	(0.124)	(0.165)
Distance	-0.002	0.001	-0.003	0.026**	0.015	-0.028	-0.010	-0.073	0.075*	0.083*
	(0.014)	(0.022)	(0.030)	(0.011)	(0.013)	(0.042)	(0.051)	(0.079)	(0.040)	(0.048)
Transport	-0.007	-0.025	-0.070	-0.007	-0.011	0.198**	0.235	0.202	0.022	0.019
	(0.034)	(0.055)	(0.076)	(0.026)	(0.028)	(0.092)	(0.153)	(0.219)	(0.088)	(0.103)
HDDS district	-0.009	0.014	0.046	-0.025*	-0.003	-0.283***	-0.302***	-0.157	-0.434***	-0.541***
	(0.015)	(0.036)	(0.050)	(0.015)	(0.017)	(0.053)	(0.110)	(0.167)	(0.064)	(0.076)

Radio	-0.003	-0.111**	-0.126*	-0.006	0.016					
	(0.034)	(0.055)	(0.073)	(0.024)	(0.023)					
Primary educ	-0.054	0.042	-0.055	0.035	0.035					
	(0.037)	(0.061)	(0.083)	(0.023)	(0.026)					
Secondary educ	-0.127**	0.042	-0.075	0.039	-0.002					
	(0.061)	(0.115)	(0.151)	(0.051)	(0.045)					
N	396	389	221	692	463	344	235	130	599	416
R^2						0.73	0.65	0.70	0.66	0.65
Zone dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mix	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

C.0.3 Heckman selection models

Table A7: Maize: Heckman models

	Wave 1	Wave 2	Wave 2 lags	Wave 3	Wave 3 lags
Supply equation					
Price	0.044	-0.019	-0.106	-0.172	-0.177
	(0.197)	(0.115)	(0.136)	(0.117)	(0.125)
Lag price			-0.131		-0.113
			(0.120)		(0.099)
Harvest	0.488	0.564***	0.493***	0.693***	0.657***
	(0.518)	(0.065)	(0.064)	(0.062)	(0.059)
Farm size	0.209**	0.318***	0.355***	0.194***	0.228***
	(0.097)	(0.062)	(0.073)	(0.057)	(0.060)
Dependency ratio	-0.003	-0.004**	-0.001	-0.003*	-0.003
	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)
Female head	-0.408**	-0.076	-0.050	-0.336***	-0.366***
	(0.196)	(0.121)	(0.133)	(0.110)	(0.116)
Age head	-0.089	0.139	0.336*	0.121	0.167
	(0.395)	(0.169)	(0.175)	(0.123)	(0.129)
Distance	-0.096*	0.032	0.022	0.007	-0.004
	(0.057)	(0.044)	(0.049)	(0.039)	(0.040)
Transport	0.107	0.098	0.111	0.111	0.110
	(0.181)	(0.105)	(0.117)	(0.089)	(0.093)
Nutrition district	0.005	0.007**	0.005	0.005	0.009**
	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)
HDDS district	0.045	-0.055	-0.118	-0.081	-0.088*
	(0.071)	(0.061)	(0.072)	(0.049)	(0.051)
Selection equation					
Price	-0.166	-0.427**	-0.518***	-0.732***	-0.796***
	(0.120)	(0.167)	(0.183)	(0.146)	(0.157)
Lag price			0.006		-0.157**
			(0.113)		(0.080)
Harvest	0.477***	0.462***	0.416***	0.549***	0.531***
	(0.072)	(0.048)	(0.052)	(0.042)	(0.045)
Farm size	-0.066	0.091*	0.057	0.064	0.103**
	(0.059)	(0.054)	(0.063)	(0.046)	(0.049)
Dependency ratio	-0.002	-0.003	-0.002	-0.005**	-0.005***

	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Female head	-0.058	0.255**	0.281**	-0.002	-0.050
	(0.124)	(0.107)	(0.122)	(0.095)	(0.101)
Age head	-0.326**	-0.111	-0.163	-0.432***	-0.444***
	(0.150)	(0.147)	(0.166)	(0.120)	(0.125)
Distance	0.002	0.007	0.018	0.025	0.021
	(0.046)	(0.041)	(0.046)	(0.036)	(0.038)
Transport	-0.168	-0.120	-0.073	-0.238***	-0.282***
	(0.103)	(0.094)	(0.105)	(0.081)	(0.086)
Nutrition district	-0.002	-0.004	-0.005	-0.006	-0.002
	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)
HDDS district	-0.053	-0.113**	-0.074	-0.011	-0.012
	(0.051)	(0.056)	(0.066)	(0.050)	(0.054)
Radio	0.190	-0.160	-0.134	-0.023	-0.055
	(0.252)	(0.098)	(0.109)	(0.082)	(0.086)
Primary educ	0.061	0.027	-0.001	-0.001	0.033
	(0.107)	(0.104)	(0.112)	(0.082)	(0.085)
Secondary educ	0.148	0.136	0.174	0.178	0.311*
	(0.239)	(0.215)	(0.285)	(0.149)	(0.162)
N	1087	1105	842	1627	1448
Selection (p-value)	0.90	0.01	0.01	0.02	0.03
Regions	Yes	Yes	Yes	Yes	Yes
Mix	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A8: Cassava: Heckman models

	Wave 1	Wave 2	Wave 2 lags	Wave 3	Wave 3 lags
Supply equation					
Price	-0.341**	-0.410**	-0.692**	-0.172*	-0.241***
	(0.146)	(0.181)	(0.289)	(0.092)	(0.092)
Lag price			-0.006		-0.026
			(0.180)		(0.058)
Harvest	1.202***	0.795***	0.838***	0.940***	0.838***
	(0.136)	(0.127)	(0.145)	(0.232)	(0.118)
Farm size	-0.008	0.310**	0.371**	0.112	0.126

	(0.078)	(0.132)	(0.180)	(0.069)	(0.081)
Dependency ratio	0.004	-0.002	-0.003	-0.002	-0.001
	(0.004)	(0.003)	(0.006)	(0.003)	(0.004)
Female head	-0.213	0.200	0.121	-0.017	0.072
	(0.192)	(0.216)	(0.321)	(0.186)	(0.169)
Age head	-0.122	-0.081	0.052	-0.348	-0.314
	(0.236)	(0.278)	(0.430)	(0.270)	(0.241)
Distance	0.117	0.042	-0.100	0.001	0.033
	(0.088)	(0.095)	(0.150)	(0.067)	(0.077)
Transport	-0.091	0.382*	0.507*	-0.242*	-0.129
	(0.170)	(0.200)	(0.273)	(0.135)	(0.148)
Nutrition district	-0.025***	-0.026***	-0.015	-0.005	-0.006
	(0.006)	(0.006)	(0.012)	(0.007)	(0.007)
HDDS district	-0.028	-0.272	-0.227	0.163	0.094
	(0.071)	(0.193)	(0.340)	(0.112)	(0.108)
Selection equation					
Price	-0.145	-0.502***	-0.682***	0.161	0.173
	(0.133)	(0.089)	(0.105)	(0.126)	(0.149)
Lag price			-0.035		-0.100*
			(0.155)		(0.058)
Harvest	0.425***	0.328***	0.189**	0.531***	0.476***
	(0.063)	(0.070)	(0.092)	(0.061)	(0.065)
Farm size	0.146*	0.020	0.180	0.023	0.161**
	(0.082)	(0.095)	(0.131)	(0.066)	(0.080)
Dependency ratio	-0.006*	-0.002	-0.004	-0.003	-0.008**
	(0.003)	(0.004)	(0.006)	(0.003)	(0.003)
Female head	0.239	0.015	-0.192	0.218	0.078
	(0.187)	(0.196)	(0.283)	(0.153)	(0.179)
Age head	-0.253	-0.194	-0.242	-0.402**	-0.372*
	(0.241)	(0.268)	(0.343)	(0.190)	(0.224)
Distance	0.109	-0.101	-0.198**	0.057	0.099
	(0.075)	(0.069)	(0.099)	(0.060)	(0.072)
Transport	-0.020	0.248	-0.066	0.019	-0.046
	(0.156)	(0.167)	(0.231)	(0.138)	(0.159)
Nutrition district	-0.009	0.008	0.017**	-0.012**	-0.013**
	(0.006)	(0.007)	(0.009)	(0.006)	(0.007)
HDDS district	0.101	0.324**	0.295	0.117	0.063

	(0.088)	(0.159)	(0.224)	(0.098)	(0.130)
Radio	-0.159	-0.260	-0.235	-0.167	-0.088
	(0.193)	(0.168)	(0.225)	(0.144)	(0.169)
Primary educ	0.067	-0.412**	-0.284	0.041	-0.163
	(0.160)	(0.185)	(0.243)	(0.173)	(0.178)
Secondary educ	0.156	-0.428	-0.297	0.136	0.151
	(0.213)	(0.295)	(0.391)	(0.279)	(0.227)
N	501	430	255	714	510
Selection (p-value)	0.22	0.63	0.28	0.59	0.87
Regions	Yes	Yes	Yes	Yes	Yes
Mix	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A9: Food crops: Heckman models

	(1)	(2)	(3)	(4)	(5)
	Wave 1	Wave 2	Wave 2 lags	Wave 3	Wave 3 lags
Supply equation					
Value	0.871***	0.351***	0.701***	0.775***	0.803***
	(0.081)	(0.054)	(0.090)	(0.044)	(0.071)
Lag value			0.247***		-0.008
			(0.060)		(0.037)
Farm size	0.178***	0.079	0.048	0.068	0.082
	(0.056)	(0.070)	(0.082)	(0.044)	(0.053)
Dependency ratio	0.004*	0.002	0.001	-0.002	-0.001
	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)
Female head	-0.073	0.002	-0.095	-0.235***	-0.299***
	(0.131)	(0.145)	(0.156)	(0.088)	(0.108)
Age head	-0.378**	0.440**	-0.165	0.003	0.003
	(0.174)	(0.181)	(0.221)	(0.113)	(0.141)
Distance	0.057	0.045	0.141**	0.059	0.057
	(0.050)	(0.046)	(0.062)	(0.037)	(0.045)
Transport	0.034	0.260**	0.001	0.011	0.027
	(0.101)	(0.110)	(0.133)	(0.078)	(0.094)
Nutrition district	-0.023	-0.026	-0.034	-0.014	-0.000
	(0.019)	(0.016)	(0.024)	(0.013)	(0.014)

HDDS district	0.106*	0.055	0.107	-0.067	-0.122*
	(0.054)	(0.072)	(0.087)	(0.058)	(0.072)
Selection equation					
Value	0.390***	-0.140**	0.346***	0.444***	0.444***
	(0.037)	(0.056)	(0.071)	(0.031)	(0.045)
Lag value			0.204***		-0.015
			(0.063)		(0.036)
Farm size	0.087*	0.066	0.214***	0.014	0.036
	(0.046)	(0.052)	(0.080)	(0.036)	(0.050)
Dependency ratio	-0.001	-0.003	-0.000	-0.004**	-0.005**
	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)
Female head	-0.045	-0.048	0.116	-0.030	-0.051
	(0.101)	(0.115)	(0.167)	(0.082)	(0.111)
Age head	-0.510***	-0.421***	-0.553**	-0.372***	-0.300**
	(0.128)	(0.138)	(0.218)	(0.106)	(0.146)
Distance	-0.027	0.016	0.021	0.064**	0.072*
	(0.040)	(0.037)	(0.064)	(0.030)	(0.041)
Transport	-0.160*	-0.243***	-0.291**	-0.210***	-0.327***
	(0.087)	(0.088)	(0.136)	(0.071)	(0.096)
Nutrition district	-0.017	-0.008	-0.020	0.015	0.015
	(0.013)	(0.012)	(0.020)	(0.012)	(0.015)
HDDS district	-0.033	-0.053	-0.085	-0.108**	-0.154**
	(0.044)	(0.053)	(0.083)	(0.047)	(0.063)
Radio	-0.147*	-0.046	-0.081	-0.156**	-0.090
	(0.080)	(0.074)	(0.123)	(0.068)	(0.090)
Primary educ	0.037	0.007	-0.224*	0.144**	0.245***
	(0.088)	(0.075)	(0.123)	(0.067)	(0.090)
Secondary educ	-0.130	-0.044	-0.398	0.081	0.255
	(0.199)	(0.148)	(0.246)	(0.138)	(0.165)
N	1250	1089	464	1848	1030
Selection (p-value)	0.02	0.00	0.00	0.00	0.12
Regions	Yes	Yes	Yes	Yes	Yes
Mix	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A10: Export crops: Heckman models

	(1)	(2)	(3)	(4)	(5)
	Wave 1	Wave 2	Wave 2 lags	Wave 3	Wave 3 lags
Supply equation					
Value	0.722***	0.762***	0.552***	0.727***	0.628***
	(0.044)	(0.069)	(0.131)	(0.044)	(0.064)
Lag value			0.160**		0.142***
			(0.081)		(0.047)
Farm size	0.206***	0.222**	0.448***	0.462***	0.399***
	(0.051)	(0.094)	(0.136)	(0.054)	(0.065)
Dependency ratio	0.002	0.007*	0.006	0.001	0.003
	(0.002)	(0.004)	(0.005)	(0.002)	(0.002)
Female head	0.056	0.109	0.289	0.111	-0.061
	(0.106)	(0.157)	(0.244)	(0.097)	(0.108)
Age head	-0.124	-0.106	0.048	-0.404***	-0.260
	(0.147)	(0.231)	(0.303)	(0.124)	(0.165)
Distance	-0.028	-0.009	-0.060	0.080**	0.086*
	(0.042)	(0.050)	(0.096)	(0.040)	(0.048)
Transport	0.198**	0.224	0.342	0.019	0.017
	(0.090)	(0.153)	(0.259)	(0.087)	(0.102)
HDDS district	-0.282***	-0.299***	-0.237	-0.439***	-0.543***
	(0.052)	(0.105)	(0.160)	(0.063)	(0.074)
Selection equation					
Value	0.303***	0.136***	0.074	0.457***	0.446***
	(0.063)	(0.049)	(0.082)	(0.057)	(0.074)
Lag value			0.108		0.041
			(0.066)		(0.077)
Farm size	-0.171*	-0.122	-0.300***	-0.034	0.020
	(0.099)	(0.095)	(0.107)	(0.085)	(0.126)
Dependency ratio	0.005	0.003	0.000	0.012***	0.013***
	(0.004)	(0.003)	(0.004)	(0.003)	(0.004)
Female head	-0.393*	-0.099	-0.116	0.133	0.237
	(0.204)	(0.173)	(0.219)	(0.171)	(0.237)
Age head	-0.297	-0.077	-0.224	-0.616***	-0.495
	(0.324)	(0.258)	(0.292)	(0.217)	(0.309)
Distance	-0.011	0.004	-0.006	0.159**	0.115
	(0.080)	(0.062)	(0.092)	(0.067)	(0.099)

Transport	-0.041	-0.083	-0.224	-0.045	-0.100
	(0.195)	(0.158)	(0.211)	(0.163)	(0.224)
HDDS district	-0.050	0.037	0.004	-0.150	-0.005
	(0.087)	(0.101)	(0.169)	(0.097)	(0.138)
Radio	-0.015	-0.306**	-0.360**	-0.046	0.112
	(0.194)	(0.154)	(0.171)	(0.149)	(0.183)
Primary educ	-0.307	0.147	-0.058	0.217	0.268
	(0.206)	(0.185)	(0.266)	(0.141)	(0.193)
Secondary educ	-0.729**	0.167	-0.100	0.296	0.048
	(0.359)	(0.350)	(0.424)	(0.342)	(0.424)
N	396	389	221	692	463
Selection (p-value)	0.83	0.42	0.02	0.19	0.63
Regions	Yes	Yes	Yes	Yes	Yes
Mix	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Appendix D

Appendix to Chapter 4

D.0.1 Quantitative Appendix

Table D.1: Definition of variables

Variable	Definition
Household variables	
Dependency ratio	Ratio of persons between 0-16 and above 65 to the number of persons of working age (16-65)
No of household members	Number of persons normally resident in the household
Age of head	Age of the head of household
Gender of head	Gender of the head of household (0=male, 1=female)
Primary education	Whether the head of household has completed primary education (0=no, 1=yes)
Phone	Whether anyone in the household holds a phone (0=no, 1=yes)
Transport	Whether anyone in the household holds a means of transport: bike and/or motorbike (0=no, 1=yes)
Farm variables	
Farm size	Farm size in acres, understood as total area farmed in the 2014/2015 season
Rented plot(s)	Whether the household has rented any plot in the 2014/2015 season
Family workers	Number of family workers who worked on the farm in the 2014/2015 season
Hired workers	Number of hired workers who worked on the farm in the 2014/2015 season
Seasonal work	Whether anyone in the household has worked on someone else's farm in the 2014/2015 season (0=no, 1=yes)
Number of crops	Total number of crops grown on the farm in the 2014/2015 season
Farm training	Whether anyone in the household received farming training (0=no, 1=yes)
Chemical use	Whether the household uses chemicals to farm (0=no, 1=yes)
Cashew grower	Whether the household is a cashew grower (0=no, 1=yes)
Village variables	
Market	Whether there is a physical marketplace in the village (0=no, 1=yes)

Table D.2: Assets Summary Statistics

	Non-growers			Growers			Diff in means
	mean	min	max	mean	min	max	P-value
Transport ownership (1=yes)	0.65	0	1	0.61	0	1	0.51
Oxen ownership (1=yes)	0.02	0	1	0.01	0	1	0.66
Phone ownership (1=yes)	0.68	0	1	0.66	0	1	0.81
Observations	99			157			

Table D.3: Goodness of fit statistics of probit models

	Pseudo R^2	Sensitivity	Specificity	Correct predictions	LROC
Pooled sample	0.14	67	65	66	0.74
Pooled sample with fixed effects	0.18	72	67	70	0.77
BG	0.36	63	83	76	0.87
BG with fixed effects	0.44	77	86	83	0.90
Cassava	0.23	42	90	75	0.81
Cassava with fixed effects	0.38	62	87	79	0.89
Other legumes	0.38	88	68	80	0.89
other legumes with fixed effects	0.51	85	77	82	0.93

Note: Sensitivity refers to the percentage of correctly specified ones, while specificity refers to the percentage of correctly specified zeros. The LROC statistics refers to the area (between zero and one) comprised under the receiver operating characteristic curve. The higher the area is to one, the greater the fit of the probit model. Note that the sensitivity, specificity and percentage of correct predictions are based on a 0.5 cut-off. Hence, it is logical to find a much higher specificity than sensitivity for crops such as cassava which are largely retained, while the opposite happens for crops which are very often sold. The cut-off value can be increased or decreased depending on the crop one is looking at, thus affecting the sensitivity, specificity and correct prediction rates.

D.0.2 Qualitative Appendix

Focus groups 1: Nangumi village (Mayanga ward). Date: 28/10/16

6 farmers participated, 1 woman and 5 men. In addition, the village extension officer (woman) and ward agricultural extension officer (man) also participated. Focus group was conducted in the village office.

Introductory questions (introduce yourself, and tell us about the main issues you face in the village as farmers. Then tell us your general opinion about bambara)

One of the main issue farmers mentioned is the problem of pests and diseases for many crops. For example, simsim is often eaten by insects (also a problem of leaf obstruction), cassava suffers from batobato disease, for Bambara there are insects that cause wilting of pods, or the crop can be destructed during flowering stage. There are also droughts problems that have recently been experienced for maize and Bambara. Regarding Bambara, the village extension officer mentioned the problem of taboos in the village that complicate growing. She is the only person who talked about taboo in these introductory questions, and the fact she is an official may be a reason (all other farmers initially did not mention these, although it's clear they are stringent concerns in this village). The ward extension officer also expressed a general concern for the lack of availability of improved seeds, and the fact that agriculture uses very little fertiliser.

Regarding opinions about Bambara, farmers expressed the following:
'Bambara is a good crop, but we do not have access to improved seed varieties' (Yusufu Musa)
'We are still using local traditional varieties, but Bambara helps us on food consumption and income generation' (Stavao King)
'Bambara is a good crop, but we need to know if we can use fertiliser for it. It helps for food consumption and income' (Pius Likutwete)
'Farmers get good harvest for Bambara. There is need for formal farming training though. Many farmers also suffer from the taboos' (Salma Mataka, village EO)
'Bambara is a good crop, but we do not have a good market for it, and some farmers stop growing because of that' (Salum Hamis)
'It's a good crop for food consumption, sometimes a good source of income too, but there

is no permanent market for it, which is a problem' (Rachid Abdulahman)

'Here we get very little information about Bambara from Naliendele research centre, but we get a lot of information for other crops' (WAEO)

Core questions

Why do you grow or don't grow BG?

Stavao King explains that Bambara is mainly grown for food consumption, but that another reason for growing is that it can be a source of income when needed too. According to Salma Makata, it involves a lot of activities to farm. Salum Hamis only grows for food consumption. He explains that although Bambara is an important crop, it is not a priority crop like other crops such as groundnuts, cashew and simsim. The latter, especially cashew and simsim are full cash crops. He also explains that Bambara is not grown that much because of the absence of market to sell. And taboos are strong. The main taboo is that if a woman on her periods walks past a plot of Bambara, the pods will dry up and there will be no harvest. Therefore, farmers have to buy a special medecine for 1,000 schillings to a witch. The medicine is a liquid in which you soak seeds before planting to immunise them against drying up. He explains that even if they get seminars explaining the farming of Bambara etc., farmers will listen but will still behave according to the taboo. However, the taboo is not exclusive to Bambara in this village, but also applies to groundnuts and simsim, for which farmers also buy the medicine.

In what ways is Bambara an important crop?

For Rukia Musa and Pius Likutwete, Bambara helps for food consumption within the household. Pius explains that you can eat Bambara in the morning and then don't eat to eat until the evening (it fills you a lot). For Yusuf Musa, it is also a source of income whenever there are unexpected problems arising.

It is also a popular food during Ramadhan, when people like to eat soft food (hard food is not good for the stomach during fasting).

How does Bambara compare to other crops (maize, paddy, sweet potatoes, cow pea, pigeon peas, cassava and groundnut) in terms of...

Growing: For Salum Hamis, Bambara is a tedious crop to grow because you have to do earthing up (cover the pods in small mud piles). But for Rashid Abdulahman, it is an easy crop to grow compared to the above. For Rukia Musa, the easiest crops to grow are cowpeas, maize and cassava. Therefore, there seems to be no clear consensus on this

matter.

Selling: For Pius Likutwete, Bambara is harder to sell than the above crops, but Stavao King stresses that Bambara and groundnuts have the advantage that they can be sold fresh from the farm during harvesting season.

Storing: For the WAEO, Rukia Musa and Salma Makata, Bambara is very easy to store (and groundnuts, which is similar), while other crops are harder to store.

Cooking: For Rukia Musa, cassava, sweet potatoes and groundnuts are the easiest to cook. Salma Makata stresses that Bambara and pigeon peas consume a lot of charcoal for cooking, which is a problem.

How do you buy/sell Bambara? (under which forms)

For Stavao King, fresh Bambara is easier to sell (fresh from farm). It can also be boiled and sold in town, which is pretty popular. When selling boiled Bambara, any variety can easily be sold, but when selling dried, there is a strong preference for the creamy variety. In the village people seem to prefer fresh Bambara over boiled. But boiled Bambara can be sold like boiled groundnut.

When is Bambara most available or popular?

Salum Hamis says time of harvesting is between May and June, where it's available without any scarcity. Scarcity arises during sowing season, in January-February, where price for seeds can reach 2,500 or 3,000 schillings per kilogram. Stavao King says price is about 10,000 for a plastic bag of approximately 20 kilograms during harvesting season, which is 500 schillings per kilogram. This is the usual selling price when they sell to town buyers. Sometimes there are also price increases during Ramadhan, as it's a popular food during fasting period.

Focus groups 2: Mtama village (Lipwidi ward). Date: 29/10/16

6 farmers participated, 3 woman and 3 men. In addition, the ward agricultural extension officer (man) also participated. Focus group was conducted under a tree.

Introductory questions (introduce yourself, and tell us about the main issues you face in the village as farmers. Then tell us your general opinion about bambara)

Farmers expressed several concerns regarding farming: problems of wilting of Bambara, for cassava there are problems of pigs eating the plants and the fact that it often dries

before harvest. For groundnut, there is an issue of pests and insects, and for cowpeas farmers say they cannot afford chemicals they would like to use for that crop. For Bambara, there is also an insect problem which affects pod formation.

Regarding opinions about Bambara, farmers expressed the following:
'Bambara is a very good crop, because if you plant 1 kg of seeds you can get 50 kg harvest' (Said Ally)
'Bambara production is very good, sometimes if you plant 1 kg you can harvest 2 bags of 100 kg each' (Hadija Mohamed)
The rest of farmers agreed with the above opinion about Bambara being a good crop with good yield. They also said it depends on the weather and it can easily be destructed by insects.

Core questions

Why do you grow or don't grow BG?

Said Ally said that they grow Bambara because it has a good price compared to other legumes, especially during the Ramadhan period. During that period, price is 1,500 per kilogram, while cowpeas sell only for about 700 per kilogram. Before and during Ramadhan, traders from Zanzibar sometimes come to buy Bambara in the villages. Mohamed Chikambo said that Bambara is good for food consumption especially in the morning. Further, it has a good market and it is very easy to sell fresh Bambara.

Ally Hussein says that Bambara involves a lot of work and he fails to grow it sometimes for this reason, because you have to do ploughing which requires lots of work and he cannot afford to hire labour for that work. Mohamed Chikambo agrees that ploughing is a problem, and he also explains that Bambara is not an easy crop for intercropping because it needs dense planting and does not leave space for other crops. Regarding taboos, he says there are no taboo in this village, but they used to exist long ago (in a village nearby, they say farmers do not plant Bambara because they fear it will attract lions to the village). However, we found that there are issues of this sort, but they are not considered as taboos by farmers because everyone follows them and it's common practice and knowledge, as explained in the following description. Ally Hussein says that farmers use a local medicine called male that stops magic power from disturbing the production of Bambara. But this

medicine is also used for many other crops, and is not unique to Bambara. It costs 3,000 schillings. If a farmers cannot pay for it when needed, he can take some from a friend and repay later in crop. Said Ally explains that the medicine is like a paste, prepared with plant extracts and water that the witch doctor has previously used to wash her intimate body parts. Regarding the origins of this practice, Mohamed Chikambo says it started because some people were jealous of others' success in agriculture and wanted to slow their success by putting spell on them. This medicine is thus like an antidote to the spell, and this is how it all started. It can only be prepared by local female leaders (it must be made by a woman who no longer has her periods).

In what ways is Bambara an important crop?

For Asha Mohamed, it is both a source of income and food, neither of which has a bigger weight (fifty fifty). For Hadija Mohamed, it is also the case, with equal importance of selling and eating. But Mohamed Chikambo adds that selling is often prioritised because it is easy to sell as seeds. Said Ally says you can sell as grain for 1,200 per kilogram, but seeds often sell at around 2,000 per kilogram (or even more). This man says that he had been to Dar Es Salaam last year and saw Bambara being sold for 2,800 per kg as grain, and there were many customers. He would like to go there and sell there before Ramadhan at a higher price than here, maybe he could also take with him some of his fellow farmers' harvests to sell.

How does Bambara compare to other crops (maize, paddy, sweet potatoes, cow pea, pigeon peas, cassava and groundnut) in terms of...

Growing: For one woman, groundnut, cassava and cowpeas are the easiest to grow on that list, they are easier than Bambara which requires lots of ploughing. For another woman, maize, pigeon pea and cowpeas are the easiest, while Bambara requires too much work.

Selling: For Ally Hussein, Bambara is very easy to sell, no matter whether it's sold fresh or dry. Said Ally emphasizes that selling fresh Bambara is easy.

Storing: For Said Ally, maize is the easiest to store because you can leave the leaves on it, and dry it outside your house on a wooden structure (hanging on it). Stealing is not a problem (and apparently the threat of a spell is part of the reason). For Hadija Mohamed, cassava is the easiest to store because you can simply smoke it in the kitchen (*dari*).

Cooking: For Hadija Mohamed, sweet potatoes are very easy to cook, they just need to be boiled. For Asha Mohamed, pigeon peas is the easiest. Ally Hussein says the easy

crops to grow in our list are: sweet potatoes, cassava, maize and groundnut. So there is no agreement as to which crop is the easiest to cook, but there is clear agreement it's not Bambara.

How do you buy/sell Bambara? (under which forms)

Zaituni Chombo says she sells fresh Bambara for 7,000 per plastic bag, but sometimes she also sells dry. She adds that when selling fresh, any variety can be sold, while for selling dry there is a clear preference for the cream colour ones.

When is Bambara most available or popular?

Mohamed Chikambo says that the period of high availability is June-August, where price lies between 1,000 and 1,500 per kilogram. Scarcity period is during January-February where it reaches between 2,000 and 2,500 per kilogram when farmers need seeds for planting. Bambara is also very popular during Ramadhan when it's eaten with *tambi* (sort of noodles), *andazi* (doughnuts) and chapatis.

Focus groups 3: Mwindi village (Mbawala ward). Date: 30/10/16

6 farmers participated, 3 woman and 3 men. In addition, 2 village officials participated (one man and one woman). Focus group was conducted in the village office.

Introductory questions (introduce yourself, and tell us about the main issues you face in the village as farmers. Then tell us your general opinion about bambara)

Regarding problems faced by villagers, Musa Hamis said there is an issue of diseases on cassava which they do not know how to control (don't know what chemicals to use). For cashew there was a problem of availability: fertilisers arrived late which caused problems. Cassava does not have a big market. Zainab Mpiku also says getting inputs is a problem, and fertilisers don't come on time. For cashew there is a disease, there is also a problem of insects for Bambara, and the market for cassava is too small. Ester Mrope says there are rats and diseases on fields. For cassava, they have the batobato desease, and for Bambara the major issue is that it has no market. Cashew has the problem of disease mentioned by previous farmers, and paddy often gets eaten by birds.

Regarding opinions about Bambara, farmers expressed the following:

'Bambara is a good crop, it is good for health, and it helps for food consumption and also

as a source of income' (Rukia Sallum)

'Bambara is a good crop, but the main problems with it are the absence of market and the diseases that can arise' (Adam Fwahili)

'Bambara is a good crop; but the problem is it has no market' (Hassan Ally)

Core questions

Why do you grow or don't grow BG?

Zainab Mpiku says it is a good source of food consumption and it serves to satisfy needs. It is good food as futari. Halima Munga (village official) says it's good for food and income but market is the main issue. She says they are asking the government to provide a reliable price as for cashew. It is a crop with a good and sweet taste. For Rukia Salum, it can be sold to buy other crops like paddy, and also to cover medical bills for children.

Regarding non-growers, Musa Hamis says he does not grow because there's no market, even if growing Bambara is very easy. Hassan Ally insists on the same problem.

Regarding taboos or traditions, Musa Hamis says traditions are not very stringent anymore, but they used to be more important. Hassan Ally says there used to be the belief that if you planted Bambara too early, lions would come to your house. Zainab Mpiku explains that the taboos about witchcraft and women on their periods causing pods to dry still exist though, and you can use a medicine called numbati to prevent those issues. Ester Mrope says it's produced by old people, and it is sold between 500 and 2,500 schillings depending on the amount bought. However, it is specific to Bambara (unlike in village for previous focus group). But not all farmers follow this tradition and grow it without the medicine. A farmer insists that what matters is rainfall, and not numbati.

In what ways is Bambara an important crop?

Adam Fwahili says it's important for food consumption, especially as futari, and mboga (side dish). Rukia Salum says you can have it in the morning and work on your farm all day after that, and she says it's also very good for Ramadhan. Hassan Ally says they'd like a reliable price (following government intervention). Ester Mrope says it's good food and there is no need to go to the market if you have Bambara.

How does Bambara compare to other crops (maize, paddy, sweet potatoes, cow pea, pigeon peas, cassava and groundnut) in terms of...

Growing: For Musa Hamis Bambara is very easy to grow because you don't need to do weeding more than three times per year. For Zainab Mpiku, Bambara is also easy to grow for the same reason, and because you don't need to use fertiliser. For Hamis Sadiki (village official), Bambara is easy to grow, but it needs ploughing, weeding and earthing up. With 1 kilogram of seeds he says you can harvest about 50 kilograms.

Selling: For Ester Mrope, the easiest to sell are cowpeas and groundnut because of the high demand existing for these crops (for fresh product). For Zainab Mpiku, Bambara and cassava are easy to sell but market is quite small. Bambara can also be sold pretty easily when fresh. Hassan Ally says the easiest crop to sell is groundnut. Musa Hamis says Bambara, groundnut, pigeon peas and sweet potatoes are the easiest to sell in our list, but that as soon as you want to sell big amounts, things get complicated due to absence of markets.

Storing: For Rukia Salum, Bambara and groundnuts are very easy to store in clay pots, and you don't need to shell before selling. Adam Fwahili agrees with this.

Cooking: For Ester Mrope, groundnut, pigeon peas and cowpeas are the easiest to cook. Bambara takes a long time to cook, and requires lots of charcoal.

How do you buy/sell Bambara? (under which forms)

Zainab Mpiku says fresh Bambara is more popular during harvesting season. After that, dried Bambara is the main form under which you can consume it. During harvesting, you can sell a plastic bag (20 litres bag) of fresh Bambara for about 5,000 schillings. Outside harvesting periods, Bambara sells for about 2,000 per kilogram (dry). Regarding varieties, people want the white Bambara to eat fresh and for selling dried. The red variety is only retained for home consumption (not sold). She says you can sell dried Bambara for about 1,500 per kilogram in the villages (at the shop). It sells higher in town (about 2,000) but there is a search cost in terms of finding market and buyers. Hamis Musa insists that price varies with demand. For Hassan Ally, dried Bambara are more marketable. People sell fresh Bambara to satisfy short term immediate needs, while dried Bambara is sold with a more medium/long term commercial logic.

When is Bambara most available or popular?

Musa Hamis says May-September is the period of high availability, while the period of scarcity stars in December. Price during high availability ranges between 1,000 and 1,500 schillings per kilogram when selling, while it ranges between 2,000 and 2,500 in December, when many farmers want to buy seeds for planting. Adam Fwahili says that the price

also increases to about 2,000 per kilogram during Ramadhan when it's a very popular food.

At the end of the meeting, Musa Hamis asks for feedback and tell us we should get back to them to tell them about the importance of our discussion.

Focus groups 4: Mnazi village (Nalingu ward). Date: 02/11/16

Many more farmers than we had asked for participated today. At some point we had 11 villagers participating, which was clearly too much but we could not reduce numbers. After explaining several times that we just needed 6 and no one being willing to leave, we started. Some people came and went away during the meeting etc. so it was not the best setup. 3 farmers were non-growers. Focus group was conducted in village office. This village is on the beach, so fishing is very important for people here.

Introductory questions (introduce yourself, and tell us about the main issues you face in the village as farmers. Then tell us your general opinion about bambara)

Ally Said says a big problem is goats, because they eat the leaves of many crops, and destroy an important part of harvest. Masudi Musa says Bambara is affected by diseases, especially one which leaves spots on the leaves. Mohamed Said said that in addition to goat, there are also issues with baboons and monkeys which eat crops. For cashew, Said Abdallah says there is a disease during flowering stage which affects harvest. But he also mentions diseases for groundnut and Bambara: spots on leaves, plant wilting, as well as the goat/baboon problem already mentioned. He also complains that cassava harvests are very small here.

Regarding opinions about Bambara, farmers expressed the following:
'Bambara suffers from diseases' (Ashura Hashimu)
'We grow Bambara here, but we have low yields and we get pests and diseases' (Adija Abdallah)
'Bambara tastes good' (Rashid Mohamed)
'Although we have the problem of goats and monkeys and diseases, Bambara is still a good crop to grow' (Ally Said)
'Last year I planted 1,5 acres of Bambara but only harvested 10 kg because of diseases,

especially leaf spots' (VO)

Core questions

Why do you grow or don't grow BG?

Sharifa Abdallah started growing Bambara because her parents were growing it. For Ashura Hashimu it is a source of food and income. In terms of food, it's eaten both on its own (futari) and as a side dish (mboga). The village official says he started growing it because he heard in a radio program that traders from the Comoros islands had come to town to buy big amounts of Bambara due to a very high demand in their country at that time. He thought he would try to sell his harvest, and his friends', but he was not successful.

Regarding why non-growers are not planting Bambara, Rashid Mohamed says it is not worth it due to the baboon problem: if almost everything gets eaten up, then you face a big loss. Mohamed Saidi has the same opinion. Ally Said says it is the goats issue that prevents him from growing. Said Abdallah says they need support in terms of chemicals usage, although the main problem is baboons, because they eat/destroy the plant during pod formation.

Regarding taboos or traditional beliefs, the village official says the belief that if you plant too early will delay rainfall still persists. This is why they only plant in February (doing so before would cause drought). Said Abdallah says that in this village, people believe that if farmers plant Bambara too early, they will only see thunderstorm but the rain will fail to come.

In what ways is Bambara an important crop?

This question was omitted due to lack of time and complications because of the high number of farmers.

How does Bambara compare to other crops (maize, paddy, sweet potatoes, cow pea, pigeon peas, cassava and groundnut) in terms of...

Growing: For Ashura Hasimu, the easiest crops to grow are: groundnut, cassava and Bambara because you only need to weed a couple of times, which is not the case with other crops. For Mohamed Saidi, these are also the easiest crops to grown because they are drought resistant. The village official says that pigeon pea is also very popular to grow

here (on small areas, mostly around houses).

Selling: For Adija Abdallah, groundnut is the easiest to sell because it's sold fresh. For Mohamed Saidi, Bambara is the easiest because you can sell dried.

Storing: For Masudi Musa, Bambara and groundnuts are very easy to store unshelled. Fatuma Yusufu (arrived late in meeting) agrees with this.

Cooking: For Fatuma Yusufu, cassava is the easiest to cook as it does not require a long cooking time. The village official says sweet potatoes are also very easy to cook, and several villagers agree while he says that.

How do you buy/sell Bambara? (under which forms)

Fatuma Yusufu says fresh Bambara is the preferred form, but Said Abdallah says dried Bambara is also popular. The village official says fresh Bambara can either be sold on the plots or at home, for a price of between 5,000 and 7,000 schillings for a plastic bag of 20 litres. Dried Bambara sells at higher price, between 1,300 (farmers' price) and 1,500 (shop price) schillings per kilogram. Boiled Bambara is also sold, for about 200 schillings per cup. He says that fresh Bambara is sold to satisfy immediate needs (as opposed to dried Bambara).

When is Bambara most available or popular?

Masudi Musa says the scarcity period is December-January, where price can reach up to 2,500 schillings per kg when farmers want seeds. During harvest time, when Bambara is abundant, it sells are around 1,000 to 1,200 per kg. During Ramadhan, the price usually goes up as it is a popular food at that time of the year. In the past years there have been boats coming to buy Bambara from Zanzibar for Ramadhan. However, because it roughly coincided with harvest time in the past 2 years, there was no major effect on price due to abundance of the crop. Fatuma Yusufu says it's a good and soft food during Ramadhan.

Traders' interview: Mtwara Central Market. Date: 03/11/16

The three traders interviewed are:

-Shahibu Ngombo : aged 53, with primary level of education, from Lindi region

-Mhamed Naheka: aged 54, with primary level of education, from Mtwara region

-Ramadhani Mtumba: aged 48, with secondary level of education, from Mtwara region

All of them are traders, but in addition, Ramadhani is also the chairman of the traders' association. We had planned for an interview with one trader only, but another one asked

us at the last minute if he could join. Further, we were joined by the chairman since the interview took place in the traders' office.

Why and when did you become an agricultural trader?

Shahibu started working in business in 1974, he was selling fruits in Mtwara market. He started being an agricultural trader as such in 1982, because at that time, being in this business paid more than other forms of employment. In 1994 they formed the traders' association and he was secretary.

Mhamed started selling fruits in 1985. He also worked as a labourer which was not enough to live, and was influenced by other traders who were already established. This is how he became a trader himself in 1994/1995. He started working with Shahibu who influenced his decision to become a trader.

Ramadhani started in 1986 by selling fish in his village, right after he completed primary school. But in 1989 he arrived in Mtwara where he stayed at his uncle's place and he became a trader due to other traders' influence. Between 2004 and 2006 he went back to school to follow secondary education; he was doing trading business in the morning, and went to school in the afternoon.

What crops do you sell here?

Basically all of them sell cereals and leguminous crops. What they are selling exactly at one point in time depends on seasonal availability and customers' demand. Among crops sold are: groundnut, paddy, Bambara, green gams, maize, cowpeas, sorghum, millet etc.

What are the positive and negative aspects of selling Bambara from a trader's perspective?

Ramadhani said that a positive aspect is that it is easy to sell to many small restaurants around who cook Bambara. A negative aspect is that there used to be traders coming

to town from Pemba/Zanzibar to buy large amounts of Bambara but they do not come as regularly anymore, because the price of Bambara has increased in Mtwara region. He says that in that sense, the market is not reliable. A corollary problem is that sometimes they buy big amounts of Bambara when they think traders from Pemba will come, but if they don't, they end up with huge amounts to store. Further, if they cannot sell readily to Pemba traders, they need to use chemicals to store the crop so it doesn't go bad after a few months.

Mhamed said that in the past years, yields of Bambara have been low in the villages around, especially in Nambare village in Tandahimba district where they used to get large supply. Now they rely more in villages in Newala district. This means that the price is now higher than it used to be. A good point is that Bambara is a good crop for food consumption and is popular because it can be eaten on its own or as a side dish.

Shahibu said that a good aspect of trading Bambara is that it keeps a very good appearance, after months after harvest. The nut stays nice even 12 months after harvesting, while it is much shorter for cowpeas (about 3 months before it changes colour and appearance). But on the bad side, yields have been too low recently, partially due to eroded soil fertility, so that farmers are switching to other crops (some of them cash crops like simsim).

In which months is there high demand/supply of Bambara? When do you buy? In what amount? At what price?

Shahibu said that supply is abundant in June and July, when the price ranges between 700 and 800 schillings per kg for wholesale price (large amounts), and 900 to 1000 for retail price (small amounts). Between November and May, when availability goes down, wholesale price increases to between 1,200 and 1,400 per kg, and retail price between 1,800 and 2,000.

Regarding buying, there are often trucks coming from the villages to sell Bambara to traders at the market. He explains that he does 'his research'. This means that he tells the first truck coming 'Yes- I will buy from you in a few days but I don't have the money now'. In fact, he waits for other trucks to come in the days after and checks their price,

and he then selects the seller with the most advantageous price. The quantities they buy are very big: each trader can buy up to 20 tons of Bambara (and 20 of groundnut, 30 of cowpeas etc.). However, the amount bought varies according the capital that each trader has. Mhamed agreed with this last point.

Tell us about Bambara collection. Who is collecting the crop? And where do you buy it from?

Shahibu said that during high availability season, right after harvest, there is no need to go to the villages, because farmers are coming to town by themselves to sell Bambara (or trucks come, as explained above). But from September onwards, traders need to send agents to the villages to get Bambara.

Mhamed said he used to go himself to the villages and collect the crop, but now he is too old for that. He also explained that woman traders get more quantity than men because they do not incur the same costs than men (because in a household, a man is supposed to cover expenditures for the family, so that the wife does not have to pay for the bus fare to go collect Bambara to a village etc.).

Do you have any links with markets outside Mtwara, like in Dar Es Salaam, Zanzibar or nearby countries such as Comoros Islands?

Ramadhani said that in terms of foreign markets, they often sell to traders in Mozambique, who send money to an agent here, who then dispatches the crop (i.e., traders from Mozambique don't physically come here). There is no trade from other countries, because such trade goes via Zanzibar, which is much closer to Comoros Islands and big coastal cities such as Mombasa in Kenya, so the only foreign trade here is with Mozambique, which is very close from Mtwara. There is also national trade with other regions like Lindi, which is quite close. Here too, trade usually operates via an agent who receives the money and makes sure that crop is dispatched. They also have customers in Dar Es Salaam.

In terms of trading, how does Bambara compare with other important crops like groundnut, cowpeas and pigeon peas?

Shahibu explained that Bambara is a 'secondary' crop, that it is less important than cowpeas. Cowpeas usually have a higher selling price. For example, cowpeas sells for 1,300 to 1,400 schillings per kg now, as oppose to 1,200 to 1,300 for Bambara.

Mhamed said that pigeon peas also became a very important crop because of a very high export demand to India, which pushes its price. It used to be a crop with a very low price but things have changed after trade with India started, the price is now about 2,000 per kg.

How and where do you store your crops?

Mhamed explained there are different storage places. One is inside the market, the other is outside. In the latter they store crops on which chemicals have just been applied, because of the strong smell it gives for some time. Once sprayed with chemicals, Bambara needs to be put away and not consumed for some months before it can be sold. It is then stored in big jute bags.

Are you aware of any processing of Bambara in the region?

They all agreed that there is no processing in the region. They do not know of any factory that would process Bambara into flour for instance. Everything seems to be used for home/restaurant consumption, and not for processing.

After the interview, we went back into the market place to take pictures of crops stored in jute bags, piled up right in the middle of the market place. So there is no separate storage facility, rather all crops are stored in the same place where they are sold.

Chapter 6

Bibliography

Bibliography

Adzawla, W., Donkoh, S., Nyarko, G., O'Reilly, P., and Mayes, S. (2016a). Use patterns and perceptions about the attributes of Bambara groundnut (Vigna subterranea (L.) Verdc.) in Northern Ghana. *Ghana Journal of Science, Technology and Development*, 4(2):56–71.

Adzawla, W., George, N., O'Reilly Patrick, J., Sean, M., Aryo, F., and Halimi, A. (2016b). Adoption of Bambara groundnut production and its effects on farmers welfare in Northern Ghana. *African Journal of Agricultural Research*, 11(7):583–594.

Akram-Lodhi, A. H. (2000). A bitter pill? Peasants and sugarcane markets in northern Pakistan. *The European Journal of Development Research*, 12(1):206–228.

Akram-Lodhi, A. H. and Kay, C. (2010). Surveying the agrarian question (part 1): Unearthing foundations, exploring diversity. *The Journal of Peasant Studies*, 37(1):177–202.

Alene, A. D., Manyong, V., Omanya, G., Mignouna, H., Bokanga, M., and Odhiambo, G. (2008). Smallholder market participation under transactions costs: Maize supply and fertilizer demand in Kenya. *Food Policy*, 33(4):318–328.

Ani, D., Umeh, J., and Ekwe, K. (2013). Bambara groundnut as panacea for food security: Profitability and production efficiency in Benue state, Nigeria. In *Proc. 2nd Int. Symp. on Underutilized Plants Species "Crops for the Future – Beyond Food Security"*.

Arndt, C., Farmer, W., Strzepek, K., and Thurlow, J. (2012). Climate Change, Agriculture and Food Security in Tanzania. *Review of Development Economics*, 16(3):378–393.

Assunção, J. J. and Braido, L. H. B. (2007). Testing Household-Specific Explanations for the Inverse Productivity Relationship. *American Journal of Agricultural Economics*, 89(4):980–990.

Azam-Ali, S. N., Sesay, A., Karikari, S. K., Massawe, F. J., Aguilar-Manjarrez, J., Bannayan, M., and Hampson, K. J. (2001). Assessing the potential of an underutilized crop – a case study using bambara groundnut. *Experimental Agriculture*, 37(04).

Barrett, C. B. (1996). On price risk and the inverse farm size-productivity relationship. *Journal of Development Economics*, 51(2):193–215.

Barrett, C. B. (2008). Smallholder market participation: Concepts and evidence from eastern and southern Africa. *Food Policy*, 33(4):299–317.

Barrett, C. B., Bellemare, M. F., and Hou, J. Y. (2010). Reconsidering Conventional Explanations of the Inverse Productivity–Size Relationship. *World Development*, 38(1):88–97.

Bartus, T. (2005). Estimation of marginal effects using margeff. *Stata journal*, 5(3):309–329.

Bellon, M. R., Gotor, E., and Caracciolo, F. (2015). Assessing the Effectiveness of Projects Supporting On-Farm Conservation of Native Crops: Evidence From the High Andes of South America. *World Development*, 70:162–176.

Bernstein, H. (2010). *Class Dynamics of Agrarian Change*. Fernwood Publishing, Black Point, Nova Scotia.

Bhaduri, A. (1986). Forced commerce and agrarian growth. *World Development*, 14(2):267–272.

Biodiversity International (2016). Mainstreaming Agrobiodiversity in Sustainable Food Systems: Scientific Foundations for an Agrobiodiversity Index – Summary. Technical report, Biodiversity International, Rome.

Bloor, M. (2001). *Focus Groups in Social Research*. Sage.

Bogaert, P., Delincé, J., and Kay, S. (2005). Assessing the error of polygonal area measurements: A general formulation with applications to agriculture. *Measurement Science and Technology*, 16(5):1170.

Bryceson, D. F. (2010). Agrarian fundamentalism or foresight? revisiting Nyerere's vision for rural Tanzania. In Havnevik, Kjell and Isinika, Aida, editor, *Tanzania in Transition: From Nyerere to Mkapa*, pages 71–98. Mkuki na Nyota, Dar es Salaam.

Carletto, C., Gourlay, S., and Winters, P. (2015). From guesstimates to GPStimates: Land area measurement and implications for agricultural analysis. *Journal of African Economies*, 24(5):593–628.

Carletto, C., Savastano, S., and Zezza, A. (2013). Fact or artifact: The impact of measurement errors on the farm size–productivity relationship. *Journal of Development Economics*, 103:254–261.

Chayanov, A. V. (1986). *The Theory of Peasant Economy*. Manchester University Press, Manchester.

Cloete, P. C. and Idsardi, E. F. (2013). Consumption of Indigenous and Traditional Food Crops: Perceptions and Realities from South Africa. *Agroecology and Sustainable Food Systems*, 37(8):902–914.

De Groote, H. and Traoré, O. (2005). The cost of accuracy in crop area estimation. *Agricultural Systems*, 84(1):21–38.

de Janvry, A., Fafchamps, M., and Sadoulet, E. (1991). Peasant Household Behaviour with Missing Markets: Some Paradoxes Explained. *The Economic Journal*, 101(409):1400.

Deere, C. D. and de Janvry, A. (1979). A Conceptual Framework for the Empirical Analysis of Peasants. *American Journal of Agricultural Economics*, 61(4):601.

Di Falco, S. and Perrings, C. (2005). Crop biodiversity, risk management and the implications of agricultural assistance. *Ecological Economics*, 55(4):459–466.

Doss, C. R. (2002). Men's crops? Women's crops? The gender patterns of cropping in Ghana. *World Development*, 30(11):1987–2000.

Dyer, G. (2004). Redistributive land reform: No April rose. The poverty of Berry and Cline and GKI on the inverse relationship. *Journal of Agrarian Change*, 4(1-2):45–72.

Ebert, A. (2014). Potential of Underutilized Traditional Vegetables and Legume Crops to Contribute to Food and Nutritional Security, Income and More Sustainable Production Systems. *Sustainability*, 6(1):319–335.

Forsythe, L., Nyamanda, M., Mbachi Mwangwela, A., and Bennett, B. (2015). Beliefs, taboos and minor crop value chains: The case of Bambara Groundnut in Malawi. *Food, Culture & Society*, 18(3):501–517.

Fouéré, M.-A. (2015). *Remembering Julius Nyerere in Tanzania: History, Memory, Legacy*. Mkuki na Nyota Publishers, Dar es Salaam,Tanzania.

Friedline, T., Masa, R. D., and Chowa, G. A. (2015). Transforming wealth: Using the inverse hyperbolic sine (IHS) and splines to predict youth's math achievement. *Social Science Research*, 49:264–287.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M., and Toulmin, C. (2010). Food security: The challenge of feeding 9 billion people. *Science*, 327(5967):812–818.

Gourlay, S., Kilic, T., and Lobell, D. (2017). Could the debate be over? errors in farmer-reported production and their implications for the inverse scale-productivity relationship in Uganda. In *CSAE Conference 2017*, University of Oxford.

Greenhalgh, P. (2000). The market potential for Bambara groundnut. Technical report, University of Greenwhich.

Griffin, K., Khan, A. R., and Ickowitz, A. (2002). Poverty and the Distribution of Land. *Journal of Agrarian Change*, 2(3):279–330.

Handschuch, C. and Wollni, M. (2016). Traditional Food Crop Marketing in Sub-Saharan Africa: Does Gender Matter? *The Journal of Development Studies*, 52(3):343–359.

Haug, R. and Hella, J. (2013). The art of balancing food security: Securing availability and affordability of food in Tanzania. *Food Security*, 5(3):415–426.

Havnevik, K. (2010). A historical framework for analysing current Tanzanian transitions: The post-independence model, Nyerere's ideas and some interpretations. In Havnevik, Kjell and Isinika, Aida, editor, *Tanzania in Transition. From Nyerere to Mkapa*, pages 19–56. Mkuki na Nyota, Dar es Salaam.

Heltberg, R. (1998). Rural market imperfections and the farm size—productivity relationship: Evidence from Pakistan. *World Development*, 26(10):1807–1826.

Heltberg, R. and Tarp, F. (2002). Agricultural supply response and poverty in Mozambique. *Food policy*, 27(2):103–124.

Hillocks, R. J., Bennett, C., and Mponda, O. M. (2012). Bambara nut: A review of utilisation, market potential and crop improvement. *African Crop Science Journal*, 20(1).

Hoddinott, J. and Yohannes, Y. (2002). Dietary diversity as a food security indicator. *Food consumption and nutrition division discussion paper*, 136(136):2002.

Holden, S. T. and Fisher, M. (2013). Can area measurement error explain the inverse farm size productivity relationship? *Centre for Land Tenure Studies Working Paper, Norwegian University of Life Sciences*, 12(13):18–29.

IFRC (2011). Emergency appeal Tanzania: Drought and Food Insecurity. Technical report, IFRC, Geneva, Switzerland.

Jan, M. A. and Harriss-White, B. (2012). The Three Roles of Agricultural Markets. *Economic & Political Weekly*, 47(52):39–52.

Jayne, T., Mather, D., and Mghenyi, E. (2010). Principal Challenges Confronting Smallholder Agriculture in Sub-Saharan Africa. *World Development*, 38(10):1384–1398.

Jones, A. D., Shrinivas, A., and Bezner-Kerr, R. (2014). Farm production diversity is associated with greater household dietary diversity in Malawi: Findings from nationally representative data. *Food Policy*, 46:1–12.

Kagin, J., Taylor, J. E., and Yúnez-Naude, A. (2016). Inverse Productivity or Inverse Efficiency? Evidence from Mexico. *The Journal of Development Studies*, 52(3):396–411.

Kennedy, G., Ballard, T., and Dop, M. C. (2011). *Guidelines for Measuring Household and Individual Dietary Diversity*. Food and Agriculture Organization of the United Nations, Rome. OCLC: 764422748.

Key, N., Sadoulet, E., and Janvry, A. D. (2000). Transactions costs and agricultural household supply response. *American journal of agricultural economics*, 82(2):245–259.

Kimhi, A. (2006). Plot size and maize productivity in Zambia: Is there an inverse relationship? *Agricultural Economics*, 35(1):1–9.

Lamb, R. L. (2003). Inverse productivity: Land quality, labor markets, and measurement error. *Journal of Development Economics*, 71(1):71–95.

Layton, D. F. (2001). Alternative approaches for modeling concave willingness to pay functions in conjoint valuation. *American Journal of Agricultural Economics*, 83(5):1314–1320.

Leung, S. F. and Yu, S. (1996). On the choice between sample selection and two-part models. *Journal of econometrics*, 72(1):197–229.

Leyaro, V., Boulay, B., and Morrissey, O. (2014). Food crop production in Tanzania. IGC Working Paper F-40110-TZA-1.

Lokina, R., Nerman, M., and Sandefur, J. (2011). Poverty and Productivity: Small-Scale Farming in Tanzania, 1991-2007. ICG Working paper 11/0896.

Mabhaudhi, T., O'Reilly, P., Walker, S., and Mwale, S. (2016). Opportunities for Underutilised Crops in Southern Africa's Post–2015 Development Agenda. *Sustainability*, 8(4):302.

Madden, D. (2008). Sample selection versus two-part models revisited: The case of female smoking and drinking. *Journal of Health Economics*, 27(2):300–307.

Malhotra, K. (2013). National Agricultural Input Voucher Scheme (NAIVS 2009-2012), Tanzania: Opportunities for improvement. Technical Report 40, Repoa, Dar es Salaam, Tanzania.

Marenya, P. P., Kassie, M. B., Jaleta, M. D., and Rahut, D. B. (2017). Maize Market Participation among Female- and Male-Headed Households in Ethiopia. *The Journal of Development Studies*, 53(4):481–494.

McKay, A., Morrissey, O., and Vaillant, C. (1999). Aggregate supply response in Tanzanian agriculture. *Journal of International Trade & Economic Development*, 8(1):107–123.

McMichael, P. (2013). *Food Regimes and Agrarian Questions*. Fernwood Publishing, Black Point, Nova Scotia.

Michler, J. D. and Josephson, A. L. (2017). To Specialize or Diversify: Agricultural Diversity and Poverty Dynamics in Ethiopia. *World Development*, 89:214–226.

Mihalopoulos, V. G. and Demoussis, M. P. (2001). Greek household consumption of food away from home: A microeconometric approach. *European Review of Agricultural Economics*, 28(4):421–432.

Minot, N. (2009). Fertilizer policy and use in Tanzania. In *Fertilizer Policy Symposium of the COMESA African Agricultural Markets Programme (AAMP)*, volume 15, Livingstone, Zambia.

Mkandawire, C. H. (2007). Review of bambara groundnut (Vigna subterranea (L.) Verdc.) production in Sub-Sahara Africa. *Agricultural Journal*, 2(4):464–470.

Mueller, B. E. (2011). The agrarian question in Tanzania: Using new evidence to reconcile an old debate. *Review of African Political Economy*, 38(127):23–42.

National Bureau of Statistics (2006). Tanzania population census 2002 Analytical report Volume X. Technical report, Dar es Salaam,Tanzania.

National Bureau of Statistics Tanzania (2014). Panel Survey Report (NPS) - Wave 3, 2012 - 2013. Technical report, NBS, Dar es Salaam,Tanzania.

Olwande, J., Smale, M., Mathenge, M. K., Place, F., and Mithöfer, D. (2015). Agricultural marketing by smallholders in Kenya: A comparison of maize, kale and dairy. *Food Policy*, 52:22–32.

Ozanne, A. (1999). Perverse supply response in peasant agriculture: A review. *Oxford Development Studies*, 27(2):251–270.

Pence, K. M. (2006). The role of wealth transformations: An application to estimating the effect of tax incentives on saving. *The BE Journal of Economic Analysis & Policy*, 5(1).

Puhani, P. (2000). The Heckman correction for sample selection and its critique. *Journal of Economic Surveys*, 14(1):53–68.

Putterman, L. (1995). Economic reform and smallholder agriculture in Tanzania: A discussion of recent market liberalization, road rehabilitation, and technology dissemination efforts. *World Development*, 23(2):311–326.

Renkow, M., Hallstrom, D. G., and Karanja, D. D. (2004). Rural infrastructure, transactions costs and market participation in Kenya. *Journal of Development Economics*, 73(1):349–367.

Sen, A. K. (1962). An aspect of Indian agriculture. *Economic Weekly*, 14(4-6):243–246.

Sen, A. K. (1966). Peasants and dualism with or without surplus labor. *Journal of political Economy*, 74(5):425–450.

Sender, J. and Johnston, D. (2004). Searching for a weapon of mass production in rural

Africa: Unconvincing arguments for land reform. *Journal of Agrarian Change*, 4(1-2):142–164.

Sheahan, M. and Barrett, C. B. (2017). Ten striking facts about agricultural input use in Sub-Saharan Africa. *Food Policy*, 67:12–25.

Singh, I., Squire, L., and Strauss, J. (1986). *Agricultural Household Models: Extensions, Applications, and Policy*. The World Bank.

Skarstein, R. (2005). Economic liberalization and smallholder productivity in Tanzania. From promised success to real failure, 1985–1998. *Journal of Agrarian Change*, 5(3):334–362.

Skarstein, R. (2010). Smallholder Agriculture in Tanzania: Can Economic Liberalisation Keep its Promises? In Havnevik, Kjell and Isinika, Aida, editor, *Tanzania in Transition. From Nyerere to Mkapa*, pages 99–131. Mkuki na Nyota, Dar es Salaam.

van der Merwe, J. D., Cloete, P. C., and van der Hoeven, M. (2016). Promoting food security through indigenous and traditional food crops. *Agroecology and Sustainable Food Systems*, 40(8):830–847.

Van der Ploeg, J. D. (2013). *Peasants and the Art of Farming: A Chayanovian Manifesto*. Practical Action Publishing, Rugby.

White, G. (1993). Towards a political analysis of markets. *IDS bulletin*, 24(3):4–11.

World Bank (2008). Agriculture for Development. World Development Report 2008. Technical report, World Bank, Washington, D.C.

Yen, S. T. and Jones, A. M. (1997). Household consumption of cheese: An inverse hyperbolic sine double-hurdle model with dependent errors. *American journal of agricultural economics*, 79(1):246–251.