Drivers of and Barriers to Adoption of Improved Sunflower Varieties amongst Smallholder Farmers in Singida, Tanzania: the Double-Hurdle Approach

by Felister Y. Tibamanya, Arne Henningsen, and Mursali A. Milanzi

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Abstract
Yield-enhancing agricultural technologies, like improved crop varieties, are widely promoted in developing countries to improve the food security, income and welfare of farm households. Nonetheless, farm households show low adoption rates of these technologies. To gain more insight into the drivers of and the barriers to the adoption of improved crop varieties, we study the adoption of improved sunflower varieties by smallholder farmers in Tanzania. Unlike most earlier studies, we distinguish between the initial adoption and the extent of adoption. Additionally, we investigate the roles of market constraints, liquidity constraints and contract farming, which are largely ignored in previous adoption studies. We find that risk aversion and liquidity constraints are barriers to adoption, whilst radios, extension service and farmers' groups are important information channels for new technologies. Our results can help to improve policies, development programmes and business decisions and finally to enhance agricultural productivity and farm household welfare.

Keywords: improved crop varieties, sunflower, smallholder farmers, market and liquidity constraints, double-hurdle model, Tanzania

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1. Introduction

Yield-enhancing technologies such as improved crop varieties are essential in agricultural and rural development, because they improve agricultural productivity (Suri, 2011; Kyle et al., 2016; Kinuthia and Mabaya, 2017), technical efficiency (Asante et al., 2014), income from crop production (Kassie et al., 2011; Simtowe et al., 2012; Afolami et al., 2015), household welfare (e.g. Mathenge et al., 2014; Zeng et al., 2015; Abate et al., 2017; Manda et al., 2017; Alwang et al., 2019) and food security (e.g. Nata et al., 2014; Shiferaw et al., 2014; Khonje et al., 2015; Jaleta et al., 2018). Increasing adoption of improved technologies is thus important for achieving the said positive outcomes, particularly in developing countries. Efforts have been done by public and private agencies as well as policy makers to widely promote the use of yield-enhancing technologies such as improved crop varieties. However, the adoption of improved crop varieties among smallholder farmers in sub-Saharan Africa (SSA) remains low (e.g. Asfaw et al., 2012b; Schroeder et al., 2013; Wineman et al., 2020). Fostering the adoption of improved crop varieties requires knowledge of barriers to and drivers of the adoption.

To obtain this knowledge, our study analyses barriers to and drivers of the adoption of improved sunflower varieties by smallholder sunflower farmers in Singida region, Tanzania. We distinguish two dimensions of the adoption: (a) whether or not a farm household adopts the improved sunflower varieties and (b) the extent of the adoption. This paper shows to which extent various factors are related to these two dimensions of the adoption of improved sunflower varieties.

Existing studies on adoption of improved crop varieties in SSA reveal that adoption is related to numerous factors and barriers. The factors include household size, education, age, gender and farming experience (Ghimire and Huang, 2015; Jaleta et al., 2015; Villano et al., 2015; Seymour et al., 2016; Alwang et al., 2019) as well as price of seeds, price of fertilisers, off-farm employment and household income (Bezu et al., 2014; Verkaart et al., 2017). The barriers include lack of awareness of or information about the availability of improved crop varieties (Simtowe et al., 2011); inadequate supply of seeds of improved crop varieties in the market, liquidity constraints and limited access to credit (e.g. Shiferaw et al., 2015; Wineman et al., 2020); high prices of hybrid seeds (Schroeder et al., 2013); negative perceptions about the cultivation of improved varieties (Asfaw et al., 2012a); misidentification of seed type (Floro et al., 2017; Kosmowski et al., 2018; Wineman et al., 2020) and poor development of market infrastructure and limited access to agricultural extension (Kassie et al., 2011; Shiferaw et al., 2008).

Most of the factors and barriers were studied in the context of cereals such as maize (e.g. Kijima et al., 2008; Becerril and Abdulai, 2010; Suri, 2011; Amare et al., 2012; Bezu et al., 2014; Jaleta et al., 2015; Alwang et al., 2019), rice (e.g. Wang et al., 2012; Mariano et al., 2012; Villano et al., 2015), and legumes such as chickpea and pigeonpea (e.g. Shiferaw et al., 2008; Simtowe et al., 2011; Amare et al., 2012; Asfaw et al., 2012b; Verkaart et al., 2017; Jaleta et al., 2015). The adoption of improved oilseed crop varieties has been analysed in only a few studies such as the adoption of improved groundnut varieties in Malawi (Simtowe et al., 2010, 2011) and Uganda (Kassie et al., 2011)[1], and improved oil palm varieties in Cameroon (Assoumou Mezui et al., 2013). In developing countries, the value chains of oilseeds such as sunflower usually largely differ from the value chains of cereals and grain legumes. Most oilseeds are processed by companies or cooperatives before they are sold to households, whereas most cereals and grain legumes are frequently sold to consumers without prior processing as households usually process them at home or do not process them at all. As oil mills have different requirements regarding the purchased oilseeds (e.g. homogenous product, varieties with high oil content) than consumers have regarding the purchase of cereals and grain legumes (e.g. taste, smell, look in terms of colour and size, preference for traditional varieties), adoption decisions regarding

[1] Biologically, groundnuts are legumes but as they have a high oil content and are frequently used to produce groundnut oil, groundnuts are also considered as an oil crop.

improved oilseed varieties likely differ from adoption decisions regarding improved varieties of other crops such as cereals and grain legumes.

The cultivation of improved sunflower varieties is widely promoted by the government of Tanzania and the private sector through contract farming and through stockists. Stockists sell seeds of improved sunflower varieties to smallholder farmers, sometimes at subsidised prices. The promotion of improved sunflower varieties is partly induced by a growing demand for sunflower edible oil in local, domestic and international markets. For example, the expansion of the processing capacity and the awareness of health advantages of sunflower oil (Adam Smith International, 2014; MITI, 2016) have contributed to the increased demand for sunflower oilseeds in Tanzania. There is also a growing demand for oilseeds and its by-products in foreign markets (Food and Agriculture Organization, 2016; MITI, 2016). The growing demand for sunflower oil and its by-products (e.g. sunflower seed cake) provide opportunities to sunflower farmers to expand production without lowering prices. Thus, the cultivation of improved sunflower varieties is an opportunity for smallholder sunflower farmers to gain income from the growing demand for sunflower oil and by-products on the domestic and foreign markets.

In spite of a plethora of studies that analyse adoption of improved crop varieties, to the best of our knowledge our study is one of only a few studies of adoption of improved oilseed varieties and the first study on the adoption of improved sunflower varieties among smallholder farmers in Africa. Besides this empirical contribution, our study contributes to the literature in four conceptional aspects. Firstly, we advance literature on the relationship between contract farming and the adoption of improved sunflower varieties, which to the best of our knowledge has not been studied before. Secondly, we analyse the relationship between farmers' adoption decisions and their liquidity constraints as well as the availability of seeds of improved varieties, which was largely ignored in previous studies. Thirdly, we study the association between risk attitudes and the adoption of improved sunflower varieties, which is largely overlooked in existing studies. Fourthly, we suggest a microeconomic model for adoption decisions, where households can choose between different extents of adoption, i.e. adoption is not a binary variable but a continuous variable that is left-censored at zero. The results of this analysis have implications for policy and practice in the public and private sector as they can be used to improve policies, programmes, and business decisions that increase the adoption of improved varieties and ultimately improve agricultural productivity and household welfare.

The remainder of this paper is organised as follows. Section 2 presents an overview of sunflower farming and sunflower varieties in Tanzania, the microeconomic background of our analysis, and an overview of existing studies on the adoption of improved crop varieties. Section 3 presents data and methods. Section 4 presents results and discussion. Finally, section 5 concludes and presents policy implication.

2. Empirical and Theoretical Contexts

2.1. Sunflower farming and sunflower varieties in Tanzania

Sunflower was introduced in Tanzania during the colonial era (Food and Agriculture Organization, 2012; MITI, 2016) and it is mostly grown in the Eastern, Central, Northern and Southern Highlands of Tanzania (Ministry of Agriculture, Food Security and Cooperatives, 2012; MITI, 2016). About 61% of the sunflower production in Tanzania is located in the highlands of the central corridor of Tanzania, which is located in the administration regions Dodoma and Singida (Salisali, 2012).[2]

Sunflower is grown by farm households individually or in farmer groups using both monoculture and mixed cropping systems that include cassava, maize, sorghum and cowpeas (MITI, 2016; RLDC, 2008). All sunflower varieties available in Tanzania are bred for oil production,

[2]A brief summary of sunflower production and trade in Tanzania is given in Section A of the Appendix.

while varieties that are specifically bred for direct consumption of so-called “confectionary seeds” are not yet available in Tanzania (MITI, 2016). Hence in Tanzania smallholder sunflower farmers use only a very small proportion of the produced sunflower seeds for direct household consumption, while selling the vast majority of their produce to oil mills or to traders who sell it to oil mills. About 95% of sunflower farmers in Tanzania are smallholders who cultivate less than 2 ha of land with sunflower (MITI, 2016). Due to their small size of production, smallholder farmers often encounter a multitude of internal and external constraints including limited access to input and output markets, credit and technologies such as improved sunflower varieties (e.g. Adam Smith International, 2014).

There have been ubiquitous efforts by various organisations, both public and private, to address these constraints, e.g. through breeding, certifying, promoting and distributing improved sunflower varieties. In Tanzania, seed production and certification are regulated under the Seed Act of 2003 as amended in 2007 (BOT, 2017) and in 2014 (Westengen et al., 2019). The Seed Act in Tanzania stipulates the formation of a National Seeds Committee to advise the government on the development of the seed industry in Tanzania (MITI, 2016). It also states the minimum standards for seeds and requires proper labelling of seeds in order to curb counterfeit seeds in the market (MITI, 2016; BOT, 2017). Moreover, seed quality control and certification in Tanzania is done by the Tanzania Official Seed Certification Institute (TOSCI). Since the 1950s, TOSCI has been collaborating with the Agricultural Research Institute (ARI) and private seed companies within and outside the country in developing and marketing sunflower seeds of both open-pollinated varieties (OPVs) and hybrid varieties. However, only 8 of the 1058 seed companies that are registered with TOSCI breed new sunflower varieties and certify them with TOSCI (Tanzania Official Seed Certification Institute, 2020). According to the Tanzania Official Seed Certification Institute (2017, 2020), only 17 sunflower varieties have been approved, released and disseminated in Tanzania (Table 1).

Table 1: Certified Sunflower Varieties in Tanzania

Variety	Type	Year	Company	Yield (t/ha)
RECORD	OPV	1950	ARI-Ilonga	1 – 2
CRN 1435	Hybrid	1999	Monsanto South Africa	2 - 2.5
PAN 7352	Hybrid	2002	Panna Seed Co.	1.5 - 2.5
KENYA FEDHA	OPV	2006	Kenya Seed Co. Ltd	3 - 3.5
NSFH 36	Hybrid	2016	Sunflower development Co.	3.4
NSFH 145	Hybrid	2016	Sunflower development Co.	3.6
AGUARA 4	Hybrid	2016	Advanta Seed Co. Ltd	2 - 2.5
HYSUN 33	Hybrid	2016	UPL-INDIA	2 - 4
ANCILLA	Hybrid	2019	East African Seeds (T) Co. Ltd	2.5
MICHEL	Hybrid	2019	East African Seeds (T) Co. Ltd	2.5
SOLEADO	Hybrid	2019	East African Seeds (T) Co. Ltd	2.5
ARCHEO	Hybrid	2019	East African Seeds (T) Co. Ltd	2
SUPERSUN64	Hybrid	2019	Silverlands Ndolela Ltd	2 - 3
SUPERSUN66	Hybrid	2019	Silverlands Ndolela Ltd	2 - 3
NALSUN 1-2018	OPV	2020	TARI	1.5 - 2
NALSUN 2-2018	OPV	2020	TARI	1.5 - 2
AGUARA 6	Hybrid	2020	Advanta seed co. Ltd	1.5 - 2

Note: OPV = open-pollinated variety, TARI = Tanzania Agriculture Research Institute
Source: own compilation based on Tanzania Official Seed Certification Institute (2017, 2020)

Between 1950 and 2015, only four sunflower varieties, two open-pollinated varieties (OPV) and two hybrid varieties were certified and made available in the market for sale to farmers

(Table 1). During this period, seeds of the OPV "RECORD" and later on also the OPV "KENYA FEDHA" were most widely available in the central corridor of Tanzania. However, most smallholder farmers very rarely buy certified seeds but usually sow seeds that they retained from the seeds that they harvested in the previous growing season (e.g. Kosmowski et al., 2018; Maredia et al., 2019). These seeds are usually called recycled seeds, local seeds, or traditional seeds and they usually give lower yields than certified seeds, because they are of low-yielding varieties, crossbred with lower-yielding varieties, or affected by genetic deterioration (see, e.g. Morris et al., 1999), particularly in case of continued recycling over many years or decades. For example, due to the use of recycled seeds and other yield-limiting farming practices, the average sunflower yield in Tanzania is 0.69 t/ha, which is much lower than the average potential yield of 3 t/ha (e.g. Adam Smith International, 2014; MITI, 2016; BOT, 2017).

In order to encourage farmers to reduce seed recycling and thus to achieve higher yields, so-called "quality declared seeds" (QDS) were introduced. The production of sunflower QDS is conducted by farmers who sow foundation seeds[3] of an OPV (usually the "RECORD" variety), follow certain production rules and are monitored by TOSCI in order to guarantee a high quality and purity of the harvested seeds (for details see Table 8 in Section B of the Appendix). The harvested seeds are distributed to other farmers for a much lower price than the certified seeds. As QDS are direct descendants of foundation seeds and are produced under regulated conditions, yields obtained from QDS are expected to be almost as high as yields obtained from certified seeds and much higher than yields obtained from recycled seeds. In the Central sunflower corridor of Tanzania, QDS production started with two selected farmers in 2007. While QDS production initially was unrelated to sunflower processors or contract farming, in 2009 sunflower processors were given the right to be involved in QDS production and marketing. Since then, several sunflower processors have used this opportunity and purchased foundation seeds of a sunflower OPV and contracted selected farmers to produce QDS for them. In addition to "independent" sunflower farmers and sunflower farmers who are contracted by sunflower processors, QDS are sometimes also produced by Tanzania's Agricultural Seed Agency (ASA).

In order to guarantee a sufficient utilisation of their oil mills, many sunflower processors in Tanzania make contract farming arrangements with farmers' associations and individual smallholder farmers. These contracts often specify that processors provide QDS (particularly of the "RECORD" variety) or certified seeds of hybrid varieties (particularly "HYSUN 33") to contracted farmers at a price determined by the processor, either for immediate payment or on credit. This improves the access of contracted farmers to seeds that are expected to give high yields (Henningsen et al., 2015). However, although these contract farming arrangements seem to benefit farmers, participation in contract farming is still low among smallholder sunflower farmers (MITI, 2016).

In summary, sunflower farmers in Tanzania can choose among three main categories of sunflower seeds for sowing: recycled seeds, QDS (of OPV) and certified seeds (of OPV or hybrid varieties). As the demand for sunflower oil and its by-products is growing rapidly in Tanzania and in the global markets (Adam Smith International, 2014; MITI, 2016), there could be a great potential for Tanzanian sunflower farmers to gain from the increasing demand by switching to high-yielding sunflower varieties. However, private and public programmes for distributing seeds of improved sunflower varieties are challenged by low demand for QDS and certified seeds because the majority of the sunflower farmers still mostly sow recycled sunflower seeds.

2.2. Microeconomic background

Microeconomic theory provides insights into understanding decisions about the adoption of new technologies as well as into associated factors and barriers. Most of the studies on adoption of new technologies such as improved crop varieties by farm households (e.g. Asfaw et al., 2012b;

[3]Foundation seeds, sometimes also called basic seeds, are usually produced by the breeder of the variety and are usually used to produce certified seeds.

Mariano et al., 2012; Wang et al., 2012; Jaleta et al., 2015) apply the random utility framework. This framework assumes that a decision maker faces a discrete set of alternative choices and decides to adopt the technology that gives the highest expected utility. However, in many situations, a decision maker who decides to adopt an improved technology must also decide on the extent of the adoption. We present an extension of the random utility framework that does not only explain whether a new technology is adopted but also the extent of adoption. In our microeconomic model for adoption decisions, households can choose between different extents of adoption, i.e. adoption is not a binary variable but a continuous variable that is left-censored at zero.

We define a farm household's utility function $U(\cdot)$ by:

$$u = U(A, x, z, w), \tag{1}$$

where u is the obtained utility level, $A \geq 0$ indicates the extent of adoption of a new technology, $x \in \mathcal{X}$ is a vector of other decision variables, $\mathcal{X}$ indicates the set of all feasible vectors x, z is a vector of exogenous conditions, and w is a vector of the preferences of the household (e.g. risk preferences). The farm household has limited information M so that it does not exactly know how its decisions on A and x affect the utility level u. However, it can use its information M to guess how their decisions on A and x affect their utility level u, which we conceptualise as expected utility $\mathrm{E}[u|M] = \mathrm{E}[U(A, x, z, w)|M]$.

We assume that a household maximises the expected utility with respect to A and x given z, w, and M. The extent of the adoption A and the vector of other decision variables x that maximise expected utility are:

$$(A^*, x^*) = \underset{A \geq 0, x \in \mathcal{X}}{\operatorname{argmax}} \, \mathrm{E}[U(A, x, z, w)|M]. \tag{2}$$

Equation (2) indicates that the optimal extent of adoption A^* and the optimal vector of other decision variables x^* depend on exogenous conditions z, the household's preferences w, and the household's information M. As such we can estimate the reduced-form equation given as:

$$A^* = f(z, w, M) \text{ with } A^* \geq 0, \tag{3}$$

where $A^* = 0$ indicates that no adoption at all maximises expected utility given exogenous conditions z, preferences w and information M, while $A^* > 0$ indicates that an adoption of the new technology of extent A^* maximises expected utility.

2.3. Existing empirical literature

Empirical studies on adoption of improved crop varieties found that the adoption decisions are associated with various socioeconomic and institutional factors. For example, studies have found that adoption decisions are positively associated with both smaller household sizes (Villano et al., 2015; Acheampong and Acheampong, 2020) and larger household sizes (e.g. Yu et al., 2011; Khonje et al., 2015), with more education (Amare et al., 2012; Mariano et al., 2012; Abebe et al., 2013b; Bezu et al., 2014; Seymour et al., 2016; Yigezu et al., 2018; Alwang et al., 2019), younger age (Simtowe et al., 2010; Yu et al., 2011; Seymour et al., 2016; Yigezu et al., 2018; Acheampong and Acheampong, 2020), male gender (Amare et al., 2012; Abebe et al., 2013a; Ghimire and Huang, 2015; Subedi et al., 2019), and with both fewer years of farming experience (Alwang et al., 2019) and more years of farming experience (Simtowe et al., 2010). Adoption decisions are also found to be positively related to lower prices of seeds (Bezu et al., 2014), lower prices of fertiliser (Verkaart et al., 2017), less off-farm employment (Verkaart et al., 2017) and higher non-farm household income (Amare et al., 2012; Bezu et al., 2014; Armel Nonvide, 2020).

Other studies found that adoption decisions are positively related to larger land holdings (Simtowe et al., 2010; Bezu et al., 2014; Seymour et al., 2016; Verkaart et al., 2017), both to larger crop land area (Simtowe et al., 2010; Amare et al., 2012; Seymour et al., 2016; Verkaart et al., 2017; Acheampong and Acheampong, 2020) and smaller crop land area (Yu et al., 2011), ownership of radios and mobile phones (Simtowe et al., 2010; Abebe et al., 2013b), ownership of livestock (e.g. Asfaw et al., 2010; Simtowe et al., 2011), and the value of oxen and non-oxen assets holding per capita (Amare et al., 2012; Khonje et al., 2015; Alwang et al., 2019).

A number of institutional factors have also been found to be associated with the adoption of improved crop varieties. For instance, adoption decisions have been found to be positively associated with access to credit (Simtowe et al., 2010; Abebe et al., 2013b; Bezu et al., 2014), with both membership in farmers' groups (Simtowe et al., 2010; Amare et al., 2012; Ghimire and Huang, 2015; Khonje et al., 2015; Subedi et al., 2019) and non-membership in farmers' groups (Yigezu et al., 2018), with access to or use of extension service (e.g. Yu et al., 2011; Amare et al., 2012; Ghimire and Huang, 2015; Khonje et al., 2015; Seymour et al., 2016; Yigezu et al., 2018; Armel Nonvide, 2020), availability of the seeds in local stores (Ghimire and Huang, 2015), and smaller distance to the market (Simtowe et al., 2010; Ghimire and Huang, 2015; Alwang et al., 2019). Furthermore, it was found that the probability of adoption is related to the farmer's location as indicated by regional dummy variables (Asfaw et al., 2010; Simtowe et al., 2010).

While numerous empirical studies found that adoption of improved crop varieties is related to various socioeconomic and institutional factors, the relationship between contract farming and the adoption of improved crop varieties has not been examined yet. Furthermore, studies on the adoption of improved crop varieties have largely ignored the relationship between farmers' adoption decisions, and risk aversion and their liquidity constraints as well as the availability of seeds of improved varieties. These research gaps are addressed in this study.

3. Data and Methods

3.1. Data collection

The data for our empirical study were collected in Iramba and Mkalama districts in Singida region, Tanzania. Singida region was selected because the agro-climatic conditions in this region are favourable for sunflower farming (Adam Smith International, 2014; Business Care Service Limited, 2012) and because sunflower contract farming is practised in this region (RLDC, 2008). A cross-sectional data set was collected between November 2015 and January 2016.

We applied a three-stage sampling technique. First, we purposely selected two neighbouring districts, Iramba and Mkalama, because there is more sunflower production in these two districts than in other districts. Second, we purposely selected all villages in the two districts, in which sunflower contract farming was available, as the presented study is a part of a research project on contract farming. This resulted in the selection of 12 of the 78 villages in Iramba district and of 12 of the 50 villages in Mkalama district. In each of the 24 villages, we obtained lists of farmers, grouped into three strata: sunflower contract farmers, sunflower non-contract farmers, and non-sunflower farmers. Third, we used non-proportional stratified random sampling to select farmers in each stratum. The non-proportional stratified random sampling was used because it allowed us to have a sufficient number of sunflower contract farmers in our sample in spite of only a small proportion of sunflower contract farmers in each village. We randomly selected eight farmers from the list of sunflower contract farmers in villages with eight or more contract farmers and all sunflower contract farmers in villages with less than eight sunflower contract farmers. In each village, we selected nine further farmers from the combined list of the two strata of sunflower non-contract farmers and non-sunflower farmers, where we chose the proportions of these two strata in our sample to be the same as in the population.

This should have resulted in a sample of 404 smallholder farmers, consisting of 188 sunflower contract farmers (46.5%), 186 non-contract sunflower farmers (46%), and 30 non-sunflower farmers (7.5%).[4] However, 13 of the 404 farmers (3%) refused to take part in the survey. These 13 farmers were replaced by other farmers from the same stratum if possible, while some other farmers were accidentally interviewed due to unclear information. This resulted in a total sample of 416 farmers, of which eight are sunflower contract farmers (2%), 383 are non-contract sunflower farmers (92%), and 25 are non-sunflower farmers (6%).[5]

The interviews in our farm household survey were done by the main author of this paper together with six trained enumerators. Data collection was done through face-to-face interviews with the selected smallholder farmers—usually with the heads of each household—using a structured questionnaire. The questionnaire used in the survey underwent a series of reviews by experts in the field and was then pre-tested with purposely selected smallholder farmers in order to assess the relevance and clarity of the questions and thus to improve this survey instrument (Sekaran and Bougie, 2016). The survey collected data on socio-economic factors of the household agricultural production and institutional factors.

3.2. Categorisation of sunflower varieties

The collected data also include information on the use of four different types of seeds for sunflower production, i.e. certified seeds of hybrid varieties, certified seeds of OPV, QDS of OPV and recycled seeds. The majority of smallholder farmers in our data set (88.5%) used only recycled sunflower seeds (Table 2). Given the very low proportions of farmers who use certified seeds of hybrid varieties, certified seeds of OPV and QDS of OPV, we subsume these three categories under the category of "improved seeds". Hence, our empirical analysis distinguishes two types of varieties: "improved varieties" and "non-improved varieties".[6]

Table 2: Proportions of farmers using different types of sunflower seeds

Type of seed used	Frequency	Proportion (%)
Only certified seeds of hybrid varieties	12	3.1
Only certified seeds of OPV	17	4.4
Only QDS of OPV	15	3.6
Only recycled seeds	345	88.5
QDS of OPV and recycled seeds	2	0.5
Total	391	100.0

Note: the 25 farmers in our data set who do not cultivate sunflower are not included in this table.

3.3. Econometric specification

Most empirical studies that analyse the adoption of technologies estimate probit or logit models, while Tobit-type models are sometimes also applied if the analysed technology is divisible

[4] The numbers of selected farmers in the three strata in each of the 24 villages are presented in Table 7 in the Appendix.

[5] While our survey covers the 2014/15 growing season, the stratification of farmers was based on the farmers intentions for the 2015/16 growing season, because our research aimed at obtaining a two-year panel data set including both the 2014/15 growing season and the 2015/16 growing season. However, due to flooding and a drought in the 2015/16 growing season, many sunflower fields could not be harvested so that the data collection for the 2015/16 growing season was dropped.

[6] It is possible that recycled seeds are improved varieties but this cannot be known for sure given that no monitoring and labelling of recycled seeds is done. Furthermore, recycled seeds can genetically deviate from the original variety due to cross-pollination and genetic deterioration, particularly when seed recycling is repeated for multiple years. Indeed, only seven of the 345 farmers who sowed recycled seeds indicated that their recycled seeds are first-generation descendants of certified seeds or QDS. Therefore, we consider recycled seeds to not be improved varieties.

(Shiferaw et al., 2015). As an improved crop variety is a divisible technology, we could analyse its adoption with a Tobit model. However, Tobit models assume that all factors affect the decision to adopt or not adopt in the same way as they affect the decision on the extent of the adoption. As it is questionable whether this very restrictive assumption is fulfilled in our empirical application, we apply the double-hurdle model (DHM) suggested by Cragg (1971).

Cragg's DHM has been developed to analyse two stages of a sequential decision process: (i) the decision to engage (or not to engage) in an activity and (ii) in case of deciding to engage in the activity, the extent of the engagement in this activity. Cragg (1971) suggests to use a probit model for the first-stage decision:

$$D_i^* = \theta' Z_i + u_i \tag{4}$$

$$D_i = \begin{cases} 1 & \text{if } D_i^* > 0 \\ 0 & \text{if } D_i^* \leq 0 \end{cases}, \tag{5}$$

where subscript i indicates the household, variable D is an observed dummy variable that indicates whether the optimal extent of the activity (i.e. A^* as defined in Section 2.2) is zero or strictly positive:

$$D = \begin{cases} 1 & \text{if } A^* > 0 \\ 0 & \text{if } A^* \leq 0 \end{cases}, \tag{6}$$

D^* is a latent variable that indicates the tendency to engage in the activity, Z is a vector of explanatory variables that affect the tendency to engage in the activity, θ is a vector of unknown parameters and $u \sim N(0, 1)$ is a disturbance term.

The second-stage decision is estimated using a truncated normal regression model:

$$A_i^{**} = \beta' X_i + \epsilon_i \tag{7}$$

$$A_i^* = \begin{cases} A_i^{**} & \text{if } D_i^* > 0 \wedge A_i^{**} > 0 \\ 0 & \text{if } D_i^* \leq 0 \vee A_i^{**} \leq 0 \end{cases}, \tag{8}$$

where variable $A^* \geq 0$ indicates the observed extent of the activity, A^{**} is a latent variable, X is a vector of explanatory variables that affect the extent of the activity, β is a vector of unknown parameters and $\epsilon \sim N(0, \sigma^2)$ is a disturbance term. This truncated regression is only applied to those observations that engage in the activity, i.e. observations with $A^* > 0$.

The DHM defined in equations (4), (5), (7) and (8) is estimated by the maximum likelihood method based on the assumption that the error terms in equations (4) and (7) are independent i.e. $\mathrm{COV}(u, \epsilon) = 0$.

Unlike the Tobit model, the DHM allows for two different sets of explanatory variables (i.e. Z and X) and two different sets of parameters (i.e. θ and β) for the two stages of the decision process. As such, the DHM relaxes some of the restrictive assumptions of the Tobit model and thus can provide consistent parameter estimates even if the restrictive assumptions of the Tobit model are not fulfilled (Cragg, 1971; Shiferaw et al., 2008). In addition to the DHM, we conduct our analysis with the Tobit model in order to compare the results and as a robustness check.[7]

In many cases, it is reasonable to assume that the same variables affect both stages of the decision process, i.e. $Z = X = (z, w, M)$ as defined in Section 2.2, but to allow for different effects of the explanatory variables on the two stages of the decision process, i.e. $\theta \neq \beta$.

The DHM has been shown to be suitable for analysing adoption decisions as two sequential decisions, i.e. the decision to adopt or not adopt and, in case of adoption, the decision about how

[7] The sample-selection model (Heckman, 1976) could be a further suitable econometric specification for analysing the two stages of adopting a divisible technology but this specification is rarely feasible in empirical applications, because obtaining reliable estimates with this model requires at least one exclusion restriction in the empirical specification (i.e. at least one variable that significantly affects the adoption/non-adoption decision but does not affect the extent of adoption) and variables that fulfil these two conditions are rarely found in real-world applications.

much to adopt (e.g. Reyes et al., 2012; Miteva et al., 2017; Fan and Salas Garcia, 2018; Burke, 2019), including for analysing adoption of improved crop varieties (Bezu et al., 2014; Ghimire and Huang, 2015; Yigezu et al., 2018; Alwang et al., 2019).

In our empirical application, the Dummy variable D indicates whether a household has adopted improved seeds, i.e. whether the household cultivated at least a part of its sunflower area with an improved variety by sowing certified seeds of a hybrid variety, certified seeds of an OPV or QDS of an OPV (see Table 2).

The extent of adoption of improved crop varieties can be operationalised in different ways. We measure the extent of adopting improved sunflower varieties, i.e. variable A^*, as the quantity of seeds of improved sunflower varieties (in kg) divided by total land area cultivated by the household with any crop (in acres). This is a proxy for the proportion of the household's agricultural land area that is cultivated with improved varieties.

Tables 3 and 4 present the definitions of the two dependent variables as well the definitions of all variables that we use as explanatory variables $Z = X$ in our empirical analysis. We include in our analysis explanatory variables that—according to our microeconomic model—indicate exogenous conditions z, preferences w or provision of information M that could be related to the adoption of improved sunflower varieties (see equation 3).

Tables 3 and 4 also present our expectations about the direction of the association between each explanatory variable and the adoption of improved sunflower varieties. These expectations are mostly based on our theoretical microeconomic model and on the scientific literature.[8] For instance, we expect that larger farms are more likely to adopt improved sunflower varieties than smaller farms, because larger farms usually have more resources and because fixed costs of adoption are potentially less relevant for larger farms that have the opportunity to cultivate sunflower on a larger land area than for smaller farms. However, we don't expect that larger farms cultivate a larger proportion of their land with improved sunflower varieties.

Furthermore, we expect that households that participate in contract farming are more likely to adopt improved sunflower varieties and adopt improved sunflower varieties to a larger extent than households that do not participate in contract farming, because seeds of improved varieties are frequently provided through contract-farming arrangements, usually at a price lower than the market price and sometimes on credit. We also expect that households that reside in Iramba district are more likely to adopt improved sunflower varieties and adopt improved sunflower varieties to a larger extent than households that reside in Mkalama district, because Iramba district is located closer to Singida town and thus closer to shops that sell seeds of improved sunflower varieties and closer to the contractor that provides seeds of improved sunflower varieties to some of its contracted farmers than Mkalama district.

Several explanatory variables such as ownership of radio, ownership of mobile phone, off-farm income, membership in farmers' groups and participation in contract farming are not exogenously given but are endogenous decision variables. Hence, we cannot exclude that these variables are correlated with unobserved factors that affect the adoption of improved sunflower varieties (known as unobserved heterogeneity) or are even affected by reverse causality. Therefore, we cannot interpret the estimated relationships between the explanatory variables and the adoption of improved sunflower varieties as causal effects but we interpret them as associations.

[8] Our variable "extension service" indicates whether the farmer received government extension service during the twelve months prior to the survey, which is to a large extent after the sowing of the sunflower seeds. Although receiving extension service after sowing cannot affect the decision about the sunflower variety, we include this variable in our analysis, because we assume that this variable is rather persistent over time so that receiving extension service after sowing can be used as a proxy for receiving extension service before sowing.

Table 3: Variables used in the empirical analysis (part 1)

Variable name	Type	Definition	Direction
Dependent variables			
Adoption	binary	1 = cultivated improved sunflower varieties, 0 = Otherwise	
Extent of adoption	continuous	Quantity of improved sunflower seeds divided by the total cultivated area (proxy for the proportion of the land area cultivated with improved sunflower varieties in the total cultivated area)	
Explanatory variables: characteristics of the household head			
Age	continuous	Age of household head in years	-
Female	binary	1 = female household head, 0 = otherwise	-
Education	categorical	Categories of increasing level of education: ○ none ○ primary school ○ secondary school or higher education	+
Risk aversion	categorical	Categories of increasing risk aversion: ○ risk lover (“I always take chances”) ○ risk taker (“I often take chances”) ○ risk averse (“I never, rarely, or sometimes take chances”)	−
Explanatory variables: household characteristics			
Household size	continuous	Number of household members	+
Off-farm income	binary	1 = at least one household member has income from off-farm work, 0 = otherwise	+
Explanatory variables: household assets			
Total cultivated area	continuous	Total land area cultivated in acres	+/0
Radio ownership	binary	1 = if the household own radio, 0 = otherwise	+
Mobile phone ownership	binary	1 = if the household own mobile phone, 0 = otherwise	+

Table 4: Variables used in the empirical analysis (part 2)

Variable name	Type	Definition	Direction
Explanatory variables: institutional variables			
Extension service	binary	1 = received government extension services, 0 = otherwise	+
Farmers' group	binary	1 = member in a farmers' group, 0 = otherwise	+
Contract farming	binary	1 = participation in contract farming, 0 = otherwise	+
Iramba District	binary	1 = resides in Iramba district, 0 = resides in Mkalama district	+
Explanatory variables: constraints			
Market constraints	categorical	Categories of being increasingly constrained by the availability of seeds of improved sunflower varieties on the market: ○ not or slightly constrained ○ somewhat constrained ○ severely constrained	−
Liquidity constraints	categorical	Categories of being increasingly constrained from buying seeds of improved sunflower varieties due to limited liquidity: ○ not or slightly constrained ○ somewhat constrained ○ severely constrained	−

Notes: column "Direction" indicates the expected direction of the effect of each explanatory variable on the adoption and the extent of adoption. As only very few household heads indicated that they "never take chances", "rarely take chances", or "sometimes take chances", we subsumed these three levels of risk aversion to one level. As only very few households indicated that they are "not constrained" or "slightly constrained" regarding market and liquidity constraints, we subsumed these two levels under one level.

4. Results and Discussion

4.1. Descriptive Results

Table 5 presents descriptive statistics of the variables that are included in the analysis, for the entire sample as well as separately for adopters and non-adopters of improved sunflower varieties. Adopters and non-adopters differ significantly in some of the variables. For example, on average, adopters have more household members and are less risk averse than non-adopters. Furthermore, adopters are on average more likely to own a radio, to receive government extension service, to be a member of a farmers' group and to have off-farm income than non-adopters. Finally, adopters tend to perceive liquidity constraint for buying sunflower seeds to be less stringent than non-adopters.

Table 5: Descriptive Statistics

	All	Adopters	Non-Adopters	P-value
Extent of adoption [kg/acre]	0.27	2.46	0.00	< 0.001
Age [years]	47.33	48.48	47.19	0.410
Female	0.09	0.09	0.09	1.000
Education				0.364
none	0.02	0.00	0.02	
primary school	0.97	0.98	0.97	
secondary school or higher education	0.01	0.02	0.01	
Risk aversion				0.045
risk lover	0.53	0.59	0.52	
risk taker	0.27	0.35	0.26	
risk averse	0.20	0.07	0.22	
Household size [number]	6.15	6.78	6.07	0.030
Off-farm income	0.30	0.43	0.28	0.041
Total cultivated area [acres]	12.13	13.37	11.97	0.688
Radio ownership	0.74	0.87	0.73	0.047
Mobile phone ownership	0.88	0.91	0.88	0.492
Extension service	0.13	0.37	0.10	< 0.001
Farmers' group	0.08	0.22	0.06	0.001
Contract farming	0.02	0.04	0.02	0.216
District				0.621
Mkalama	0.35	0.39	0.35	
Iramba	0.65	0.61	0.65	
Market constraints				0.495
not or slightly constrained	0.39	0.46	0.38	
somewhat constrained	0.30	0.30	0.30	
severely constrained	0.31	0.24	0.32	
Liquidity constraints				0.035
not or slightly constrained	0.19	0.33	0.17	
somewhat constrained	0.45	0.37	0.46	
severely constrained	0.36	0.30	0.37	
Observations	416	46	370	

Notes: the three columns indicate mean values or proportions of the variables for all households, adopters and non-adopters, respectively; column 'P-value' indicates P-values obtained from two-sample t-tests for equality of mean values for continuous variables and P-values of Pearson's χ^2-tests for equal proportions (using the small-expected-value correction suggested by Hope (1968) with 10,000 Monte Carlo replications) for binary and categorical variables.

4.2. Results and Discussion of the Estimated Double Hurdle Model

The estimation results of the DHM are presented in Table 6.[9] We dropped the level of education as explanatory variable in our empirical analysis due to too little variation in this variable (see Table 5), which resulted in highly statistically insignificant coefficients of the education variable.[10] The upper panel of Table 6 presents the results for the binary decision of adopting improved sunflower varieties, while the lower panel of this table presents the results for the extent of the adoption. The results indicate that the decision about adopting or not adopting improved sunflower varieties is partly related to other factors than the decision about the extent of the adoption. Thus the DHM appears to be more suitable for our analysis than a Tobit model.

We did not find any statistically significant relation between the age and the sex of the household head and the adoption of improved sunflower varieties, neither for the binary adoption decision nor for the extent of adoption.

Our results indicate that risk-averse farmers are less likely to adopt improved sunflower varieties than farmers with a medium (or low) level of risk aversion (P=0.10) and that risk-loving farmers adopt improved sunflower varieties to a higher extent than farmers with a medium (or high) level of risk aversion (P=0.005). This concurs with our theoretical expectation that risk aversion is negatively related to the adoption of new technologies.

We find that the probability of adopting improved sunflower varieties is significantly positively related to household size (P=0.05) but that the extent of adoption is not related to household size. The result regarding the binary adoption decision confirms our theoretical expectation given that large-sized households have more members who potentially get information about the availability of improved sunflower varieties. Our result regarding the binary adoption decision confirms the findings of earlier studies such as Khonje et al. (2015).

Our results indicate that households with off-farm income have a significantly higher likelihood of adopting improved sunflower varieties than households without off-farm income (P=0.07), while the extent of adoption is not significantly related to off-farm income. The former finding supports our theoretical expectation given that off-farm income reduces the income risk of farmers (e.g. due to crop failures) so that even with the same liquidity constraints and the same risk aversion, farmers with off-farm income may be less reluctant to try out new technologies. Our finding regarding the binary adoption decision confirms the result of Armel Nonvide (2020) but it contradicts the results of Verkaart et al. (2017) who find a statistically significant negative association between off-farm income and the adoption of improved crop varieties.

We do not find a relationship between farm size (measured in total area cultivated with crops) and the adoption of improved sunflower varieties but we find that larger farms cultivate a smaller proportion of their land with improved sunflower varieties than smaller farms (P=0.002).

Our study shows that farmers who own a radio are more likely to adopt improved sunflower varieties (P=0.07) and cultivate a larger proportion of their land areas with improved sunflower seeds (P=0.08) than farmers without a radio. The finding is consistent with the theoretical expectation and confirms earlier findings such as those of Simtowe et al. (2010). These results indicate that radios are an important channel for farmers for getting information about improved sunflower varieties, e.g. about their availability and their benefits. Indeed, farmers were informed about the availability of improved sunflower varieties through a rural radio programme called "INUKA" (Salisali, 2012). In contrast, we did not find a statistically significant relationship between ownership of mobile phones and the adoption of improved sunflower varieties, neither for the binary adoption decision nor for the extent of adoption.

[9] All estimations are performed in the statistical software environment "R" (R Core Team, 2020) using the add-on packages "censReg" (Henningsen, 2020), "sampleSelection" (Toomet and Henningsen, 2008; Henningsen and Toomet, 2020), and "mhurdle" (Croissant et al., 2018).

[10] We tried to solve this problem by subsuming the two highest levels of education into one level so that we had only two levels of education ("no education" and "primary school or higher education") but the variation was still too small. Given that all adopters have at least primary education, there was even no variation in this variables among adopters so that this variable could anyway not be used in the second stage of the DHM.

Table 6: Results of the double hurdle estimation

Adoption decision equation			
	Estimate	Std. Error	Pr(> $\|t\|$)
Intercept	-2.166	0.731	0.003
Age	0.006	0.009	0.516
Female	0.132	0.329	0.689
Risk lover	0.032	0.208	0.876
Risk-averse	-0.543	0.331	0.101
Household size	0.078	0.040	0.050
Off-fam income	0.341	0.191	0.073
log(Total cultivated area)	0.047	0.120	0.698
Radio ownership	0.471	0.262	0.072
Mobile phone ownership	-0.247	0.342	0.470
Extension service	0.838	0.232	0.000
Farmers' group	0.632	0.282	0.025
Contract farming	0.440	0.528	0.405
Iramba District	-0.147	0.193	0.447
Somewhat market constrained	-0.068	0.224	0.761
Severely market constrained	-0.054	0.246	0.826
Somewhat liquidity constrained	-0.398	0.239	0.096
Severely liquidity constrained	-0.366	0.259	0.157
Extent of adoption equation			
	Estimate	Std. error	Pr(> $\|t\|$)
Intercept	0.948	1.077	0.379
Age	-0.012	0.012	0.340
Female	-0.277	0.373	0.457
Risk lover	0.838	0.301	0.005
Risk-averse	-0.029	0.475	0.951
Household size	-0.004	0.061	0.947
Off-fam income	0.262	0.222	0.237
log(Total cultivated area)	-0.543	0.178	0.002
Radio ownership	0.511	0.295	0.083
Mobile phone ownership	-0.090	0.432	0.834
Extension service	-0.041	0.224	0.854
Farmers' group	-0.186	0.251	0.459
Contract farming	0.309	0.495	0.532
Iramba District	-0.249	0.249	0.319
Somewhat market constrained	0.740	0.243	0.002
Severely market constrained	0.421	0.316	0.183
Somewhat liquidity constrained	-0.203	0.270	0.452
Severely liquidity constrained	-0.606	0.323	0.061
σ	0.606	0.063	0.000

Our results indicate that farmers who receive government extension service are much more likely to adopt improved sunflower varieties than farmers who do not receive government extension service (P<0.001) but we do not find a significant relationship between receiving government extension service and the extent of adoption. Our finding regarding the binary adoption decision is in line with our theoretical expectations and confirms earlier studies such as Khonje et al. (2015), Seymour et al. (2016), Yigezu et al. (2018) and Armel Nonvide (2020). Our results suggest that extension service could be an important source of information about new technologies. Indeed, there are hardly any other organisations or companies that give advice and training to the farmers (e.g. about new technologies) in our study area as even private entities such as processors of sunflower seeds expect the extension service to be provided through the government extension officers (Kuzilwa and Mpeta, 2017). As such, extension service is a kind of institutional arrangement for solving the predominantly rural market imperfection in information provision.

We find that farmers who are members of a farmers' group are more likely to adopt improved sunflower varieties than farmers who are not members of a farmers' group (P=0.05) but we don't find a significant relationship between membership in a farmers' group and the extent of adoption. The finding regarding the binary adoption decision confirms our theoretical expectation and it is consistent with the results of Ghimire and Huang (2015), Khonje et al. (2015) and Subedi et al. (2019), while it contradicts the finding of Yigezu et al. (2018) who found a statistically significant negative association between adoption of improved crop varieties and membership in a farmers' group. Our results suggest that farmers obtain information about innovation through farmers' groups, which provide a mechanism for sharing information and resources especially in rural areas, where formal institutions function inefficiently. However, the positive relationship we found between membership in a farmers' group and adoption of improved sunflower variety could—at least partly—also originate from omitted confounding factors (e.g. if farmers who are more open to new technologies are more eager to join a farmers' group than farmers who are less open to new technologies).

Our results suggest that participation in contract farming is positively related both to the binary adoption decision and to the extent of adoption of improved sunflower varieties. However, these relationships are statistically insignificant, which is likely due to the very small proportion of contract farmers in our data set (see Table 5).

Contrary to our theoretical expectations, we do not find a statistically significant relationship between market constraints and the binary adoption decision, while we find that somewhat market constrained farmers (P=0.002) and severely market constrained farmers (P=0.18) cultivate larger proportions of their land with improved sunflower varieties than farmers that are not or only slightly market constrained. Our results suggest that limited availability of seeds of improved sunflower varieties on the market is not a substantial barrier to the binary adoption decision. Indeed, improved sunflower seeds can not only be purchased on the market but also obtained by farmers (on credit or for cash) through contract farming arrangements (e.g. MITI, 2016; Mpeta et al., 2017). Our results regarding the relationship between market constraints and the extent of the adoption can be explained by reverse causality: the larger the proportion of their land area sown with improved sunflower seeds, the more likely that farmers experience that the availability of seeds of improved sunflower varieties on the market is at least somewhat constrained.

In line with our theoretical expectations, we find that somewhat liquidity-constrained farmers (P=0.10) and severely liquidity-constrained farmers (P=0.16)[11] are less likely to adopt improved sunflower varieties than farmers who are not or only slightly liquidity constrained. Similarly, we find that severely liquidity-constrained farmers (P=0.06) cultivate a significantly smaller

[11] Although a P-value of 0.16 does not indicate a statistically significant relationship, we mention this relationship here, because it is statistically significant in the two robustness checks (P=0.10 and 0.04 as indicated by Tables 9 and 10, respectively).

proportion of their land with improved sunflower varieties than farmers who are not or only slightly liquidity constrained. All this indicates that liquidity constraints are a larger barrier to the adoption of improved sunflower varieties than market constraints.

4.3. Robustness Checks

We present the results of several robustness checks in Tables 9 to 13 in Section B of the Appendix. Table 9 presents the results of a DHM estimated only with observations from farmers who actually cultivate sunflowers (i.e. excluding farmers who do not cultivate sunflowers),[12] while Table 10 presents the results of a DHM estimated only with observations from farmers who were in the initial selection of farmers for the survey (i.e. excluding farmers who were chosen as replacements for non-available farmers and farmers who were accidentally interviewed). The estimation results are generally very robust to changing the sample that is used in the estimation. There are only a very few notable differences in the results: When using only observations from initially selected farmers, ownership of radios has a weaker and no longer statistically significant relationship to the binary adoption decision but the relationship to the extent of adoption is stronger and statistically significant at a higher level (P=0.02 instead of 0.08). The negative relationship between liquidity constraints and the binary adoption decision is stronger and statistically significant at a higher level in both of the robustness checks, particularly when using only observations from initially selected farmers (P=0.03 and 0.04 instead of 0.10 and 0.16 for somewhat constrained and severely constrained farmers, respectively). In contrast, the relationship between severely liquidity constrained farmers and the extent of adoption becomes weaker and is not longer statistically significant when using only observations from initially selected farmers (P=0.13 instead of 0.06).

In addition to the DHM, we conduct our analysis with the Tobit model in order to compare the results and as a robustness check. Tables 11, 12, and 13 present results of Tobit regressions with the entire sample, with sunflower farmers only, and with initially selected farmers only, respectively. The results of the Tobit models are generally in line with the results of our main DHM presented in Table 6, particularly with the results regarding the binary adoption decision. However, as the Tobit model does not distinguish between the two different dimensions of adoption, it does not find all the relationships that we find with the DHM. For instance, the DHM indicates that the extent of adoption is statistically significantly related to farmers identifying themselves as risk lovers, to the total cultivated land area and to experiencing to be somewhat market constrained (see Table 6) but the Tobit model does not find these relationships.

5. Conclusion and Policy Implications

Although adoption of improved crop varieties by smallholder farmers in developing countries is considered to be a promising way of increasing food production and household welfare, the adoption rate of improved crop varieties by smallholder farmers is still very low in most developing countries. Increasing the adoption of improved crop varieties through policies, development programmes and business decisions requires knowledge about drivers of adoption and barriers to adoption. In order to provide this information, this paper analysed the adoption of improved sunflower varieties amongst smallholder sunflower farmers in Singida region, Tanzania. We used a double-hurdle model (DHM) for our empirical analysis, which allows us to separately analyse the (binary) decision of adopting or not adopting improved sunflower varieties as well as the extent of adoption. We found several factors that are significantly related to the binary adoption decision, to the extent of adoption, or to both of them.

[12] As removing non-sunflower farmers does not change the sample of farmers that are used for analysing the extent of the adoption, the results regarding the extent of adoption are identical in Tables 6 and 9.

The main limitation of our study is that we cannot interpret our estimated coefficients as causal effects because we cannot exclude that some of our results are driven by reverse causality or unobserved heterogeneity (omitted confounding factors). For instance, the positive and highly statistically significant relation that we found between receiving extension service and adoption of improved sunflower variety could—at least partly—also originate from reverse causality (e.g. if extension officers find it more interesting to visit farmers who cultivate improved sunflower varieties than farmers who only cultivate non-improved sunflower varieties or if farmers who cultivate improved sunflower varieties try harder to get in contact with an extension officer than farmers who only cultivate non-improved sunflower varieties) or from unobserved heterogeneity (e.g. if extension officers prefer to visit farmers who they know are more open to new technologies or if farmers who are more open to new technologies try harder to get in contact with extension officers than farmers who are less open to new technologies). In order to separate causal effects from other sources of correlation, we suggest that our most important policy-relevant findings be validated with randomised control trials (RCT).

In spite of this limitation, we can derive some recommendations for policies, development programmes and business decisions. For instance, given that we found that adoption of improved sunflower varieties (including the extent of adoption) is negatively related to risk aversion, we suggest an investigation, e.g. with small pilot projects, of whether weather (index) insurances can alleviate this barrier to the adoption of improved crop varieties (see e.g. Karlan et al., 2014).

Our study also indicates that adoption of improved sunflower varieties (including the extent of adoption) is positively related to various ways of information provision such as ownership of radios, receiving extension service and being a member of a farmers' group. Hence, we suggest an investigation of whether the benefits of providing and expanding these ways of information provision outweigh their costs.

While it seems that the availability of seeds of improved sunflower varieties on the market is not a major barrier, we found that liquidity constraints are significantly negatively related to the adoption of improved sunflower varieties (including the extent of adoption). Thus, we suggest that ways of alleviating liquidity constraints, e.g. loans with reasonable interest rates through Saving and Credit Cooperatives (SACCOs) and Village Community Banks (VICOBA), be investigated.

In addition to the suggestions for further investigations given above, future research could use longitudinal data in order to investigate long-term relationships between various factors, drivers and barriers and the adoption of improved sunflower varieties. Furthermore, given the limited external validity of our study and other studies of adoption of new technologies, a study based on multiple-country data about the adoption of improved varieties of various crops could provide results with much higher external validity.

Finally, as a too small number of contract farmers in our data set may be the reason for not having found a statistically significant relationship between contract farming and the adoption of improved sunflower varieties, we suggest that this relationship be studied with a data set that has more statistical power regarding this relationship.

Appendix

A. Sunflower production and trade in Tanzania

Sunflower production in Tanzania increased from 1,083,000 tons in 2013 to 3,112,500 tons in 2017 (Ministry of Agriculture Livestock and Fisheries, 2016; Food and Agriculture Organization, 2016; Ministry of Agriculture, Livestock and Fisheries, 2018) and accounts for 2.4% of global production (MITI, 2016). Tanzania provides 35% of all sunflower production in Africa, which makes it the largest sunflower producer in East Africa and the second largest sunflower producer in Africa after South Africa (BOT, 2017). Sunflower is the leading oilseed crop in Tanzania, followed by groundnuts, sesame, palm oil, cotton oil and soya (Ministry of Agriculture Livestock and Fisheries, 2016; MITI, 2016). Tanzania exports sunflower seeds for crushing, crude sunflower oil, refined sunflower oil and seed cake, which in total account for about 74.8 million US dollars of Tanzania's export earnings (MITI, 2016). The largest export shares among all sunflower products have sunflower seed cakes and seed meal of which almost half the production is exported, mainly to India and Kenya (MITI, 2016).

B. Additional tables

This section provides tables with supplementary information.

Table 7: Villages and number of selected sunflower farmers in each village

Village	CF	NCF	NSF	Total number
ILUNDA	8	9	0	17
KASELYA	8	8	1	17
KIDARAFA	6	8	1	15
KIKONGE	8	9	0	17
KYENGEGE	8	7	2	17
MALAJA	8	8	1	17
MALUGA	6	8	1	15
TUMULI	8	7	2	17
IAMBI	8	7	2	17
MAMPANTA	8	8	1	17
MBELEKESE	8	6	3	17
MISIGIRI	8	6	3	17
MSIU	8	8	1	17
NGUVUMALI	8	9	0	17
SINGA	8	7	2	17
SONGAMBELE	8	8	1	17
MUGUNGIA	8	7	2	17
MUKULU	8	7	2	17
MWANGA	8	9	0	17
NKUNGI	8	8	1	17
SIMBALUNGWALA	8	8	1	17
ULEMO	8	6	3	17
USURE	8	9	0	17
ZINZILIGI	8	9	0	17
Total	188	186	30	404

Notes: CF = Contract farmer, NCF = Non-contract farmer, NSF = Non-sunflower farmers

Table 8: The regulations, production and quality requirements for sunflower QDS and sunflower certified seeds

Requirement	Sunflower certified seeds	Sunflower QDS
Producer	The producer of certified seeds (i.e. ASA or a private company) must be registered with TOSCI.	The producer of QDS (i.e. independent farmer, sunflower processor or ASA) must be registered with TOSCI.
Parent seeds	The certified seeds are produced from basic/foundation seed.	The QDS are produced from basic/ foundation seed.
Field size	The size of the field in which certified seeds are produced may exceed 5 hectares.	The size of the field in which QDS are produced must not exceed 5 hectares.
Isolation	The distance between the field in which the certified seeds are produced and any other sunflower field must be at least 1000 meters.	The distance between the field in which QDS are produced and any other sunflower field must be at least 200 meters.
Field and seed inspection	TOSCI inspects the fields that are used for producing certified seeds before harvesting and inspects the seeds after harvesting.	TOSCI does not inspect the fields that are used for producing QDS before harvesting but it inspects the seeds after harvesting.
Seed purity	Laboratory standards of seed purity must be at least 99%.	Laboratory standards of seed purity must be at least 98%.
Advice from experts	Before registration, the producer of certified seeds must indicate the number of experts (e.g. agricultural extension officers) who will be involved in seed production and monitoring and this number has to be at least three.	Producers of QDS do not need to indicate the number of experts.
Seed distribution	Certified seed distribution is even outside the district where they are produced.	QDS distribution are restricted to the districts where they are produced.

Source: Tanzania Official Seed Certification Institute (2020)

Table 9: Results of the double hurdle estimation excluding non-sunflower farmers

Adoption decision equation			
	Estimate	Std. Error	Pr(> |t|)
Intercept	-2.061	0.752	0.006
Age	0.008	0.009	0.388
Female	0.017	0.339	0.960
Risk lover	-0.025	0.211	0.907
Risk-averse	-0.570	0.337	0.091
Household size	0.075	0.041	0.068
Off-fam income	0.405	0.195	0.038
log(Total cultivated area)	-0.009	0.125	0.944
Radio ownership	0.464	0.269	0.085
Mobile phone ownership	-0.210	0.353	0.552
Extension service	0.874	0.236	0.000
Farmers' group	0.743	0.288	0.010
Contract farming	0.395	0.529	0.455
Iramba District	-0.108	0.196	0.583
Somewhat market constrained	-0.107	0.229	0.642
Severely market constrained	-0.057	0.250	0.819
Somewhat liquidity constrained	-0.495	0.244	0.043
Severely liquidity constrained	-0.435	0.265	0.100
Extent of adoption equation			
	Estimate	Std. error	Pr(> |t|)
Intercept	0.948	1.077	0.379
Age	-0.012	0.012	0.340
Female	-0.277	0.373	0.457
Risk lover	0.838	0.301	0.005
Risk-averse	-0.029	0.475	0.951
Household size	-0.004	0.061	0.947
Off-fam income	0.262	0.222	0.237
log(Total cultivated area)	-0.543	0.178	0.002
Radio ownership	0.511	0.295	0.083
Mobile phone ownership	-0.090	0.432	0.834
Extension service	-0.041	0.224	0.854
Farmers' group	-0.186	0.251	0.459
Contract farming	0.309	0.495	0.532
Iramba District	-0.249	0.249	0.319
Somewhat market constrained	0.740	0.243	0.002
Severely market constrained	0.421	0.316	0.183
Somewhat liquidity constrained	-0.203	0.270	0.452
Severely liquidity constrained	-0.606	0.323	0.061
σ	0.606	0.063	0.000

Table 10: Results of the double hurdle estimation with initially selected farmers only

Adoption decision equation			
	Estimate	Std. Error	Pr(> $\|t\|$)
Intercept	-2.074	0.777	0.008
Age	0.010	0.010	0.324
Female	-0.162	0.383	0.672
Risk lover	-0.023	0.224	0.918
Risk-averse	-0.537	0.349	0.124
Household size	0.091	0.043	0.036
Off-fam income	0.402	0.210	0.055
log(Total cultivated area)	-0.019	0.133	0.885
Radio ownership	0.356	0.280	0.203
Mobile phone ownership	-0.177	0.359	0.621
Extension service	0.958	0.249	0.000
Farmers' group	0.757	0.313	0.015
Contract farming	0.381	0.538	0.479
Iramba District	-0.142	0.209	0.496
Somewhat market constrained	-0.339	0.254	0.182
Severely market constrained	-0.015	0.256	0.953
Somewhat liquidity constrained	-0.545	0.253	0.031
Severely liquidity constrained	-0.582	0.278	0.037
Extent of adoption equation			
	Estimate	Std. error	Pr(> $\|t\|$)
Intercept	1.015	1.069	0.342
Age	-0.013	0.012	0.278
Female	-0.002	0.399	0.997
Risk lover	0.837	0.305	0.006
Risk-averse	-0.045	0.468	0.923
Household size	-0.052	0.064	0.418
Off-fam income	0.360	0.222	0.106
log(Total cultivated area)	-0.550	0.174	0.002
Radio ownership	0.674	0.294	0.022
Mobile phone ownership	-0.003	0.422	0.994
Extension service	-0.191	0.228	0.402
Farmers' group	-0.106	0.254	0.675
Contract farming	0.249	0.486	0.608
Iramba District	-0.180	0.260	0.488
Somewhat market constrained	0.889	0.264	0.001
Severely market constrained	0.410	0.309	0.185
Somewhat liquidity constrained	-0.115	0.271	0.673
Severely liquidity constrained	-0.497	0.329	0.131
σ	0.584	0.064	0.000

Table 11: Results of the Tobit model estimation

	Estimate	Std. error	$\Pr(>\lvert t \rvert)$
(Intercept)	-8.072	3.414	0.018
Age	0.013	0.039	0.746
Female	0.520	1.418	0.714
Risk lover	0.394	0.911	0.665
Risk-averse	-2.297	1.487	0.122
Household size	0.294	0.177	0.096
Off-fam income	1.352	0.818	0.098
log(Total cultivated area)	-0.068	0.533	0.899
Radio ownership	2.372	1.134	0.036
Mobile phone ownership	-1.622	1.420	0.253
Extension service	3.348	1.027	0.001
Farmers' group	2.323	1.182	0.049
Contract farming	2.709	2.117	0.201
Iramba District	-0.604	0.832	0.468
Somewhat market constrained	0.272	0.939	0.772
Severely market constrained	-0.154	1.072	0.886
Somewhat liquidity constrained	-1.663	1.038	0.109
Severely liquidity constrained	-1.637	1.124	0.145
$\log(\sigma)$	1.490	0.125	0.000

Table 12: Results of the Tobit model estimation excluding non-sunflower farmers

	Estimate	Std. error	Pr(> $|t|$)
(Intercept)	-7.431	3.397	0.029
Age	0.020	0.040	0.620
Female	0.105	1.424	0.941
Risk lover	0.191	0.903	0.833
Risk-averse	-2.312	1.484	0.119
Household size	0.269	0.177	0.128
Off-fam income	1.542	0.821	0.060
log(Total cultivated area)	-0.258	0.538	0.631
Radio ownership	2.317	1.131	0.041
Mobile phone ownership	-1.513	1.413	0.284
Extension service	3.340	1.018	0.001
Farmers' group	2.603	1.192	0.029
Contract farming	2.545	2.079	0.221
Iramba District	-0.442	0.824	0.591
Somewhat market constrained	0.198	0.937	0.833
Severely market constrained	-0.151	1.063	0.887
Somewhat liquidity constrained	-1.961	1.045	0.061
Severely liquidity constrained	-1.819	1.128	0.107
log(σ)	1.470	0.124	0.000

Table 13: Results of the Tobit model estimation with initially selected farmers only

	Estimate	Std. error	Pr(> $\|t\|$)
(Intercept)	-7.532	3.570	0.035
Age	0.027	0.042	0.516
Female	-0.447	1.595	0.779
Risk lover	0.126	0.965	0.896
Risk-averse	-2.239	1.547	0.148
Household size	0.327	0.193	0.090
Off-fam income	1.597	0.891	0.073
log(Total cultivated area)	-0.351	0.576	0.542
Radio ownership	1.967	1.173	0.093
Mobile phone ownership	-1.412	1.450	0.330
Extension service	3.690	1.096	0.001
Farmers' group	2.667	1.296	0.040
Contract farming	2.613	2.131	0.220
Iramba District	-0.550	0.885	0.534
Somewhat market constrained	-0.666	1.047	0.525
Severely market constrained	-0.006	1.108	0.996
Somewhat liquidity constrained	-2.130	1.101	0.053
Severely liquidity constrained	-2.386	1.212	0.049
log(σ)	1.486	0.132	0.000

C. Competing interests

All authors declare that the have no competing interest.

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