FACTORS DETERMINING CHOICE AND IMPACT OF HERMETIC MAIZE STORAGE TECHNOLOGY ADOPTION ON SMALLHOLDER FARMERS' INCOME IN GATSIBO DISTRICT, RWANDA

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DECLARATION

This thesis is my original work and has not been submitted for award of a degree in any other university.

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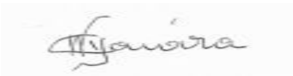
This thesis has been submitted with our approval as university supervisors.



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I dedicate this work to my family.

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LIST OF ACRONYMS AND ABBREVIATIONS

APHLIS	African Post Harvest Information System
CIMMYT	International Maize and Wheat Improvement Centre
CIP	Crop Intensification Program
ESR	Endogenous Switching Regression
FAO	Food and Agriculture Organization of the United Nations
FIML	Full Information Maximum Likelihood
HST	Hermetic Maize Storage Technologies
MINAGRI	Ministry of Agriculture and Animal Resource
MVP	Multivariate Probit Model
NEPAD	The New Partnership for Africa Development
NISR	National Institute of Statistics in Rwanda
OAF	One Acre Fund
PHHS	Post-Harvest Handling and Storage
RCT	Randomized Controlled Trial
SOFA	The State of Food and Agriculture
SSA	sub-Saharan Africa
UN	United Nations
UNDP	United Nations Development Programme
USAID	United State Agency for International Development
WHO	World Health Organization

ABSTRACT

The growing food demand occasioned by the rising global population is a major issue of global concern. It calls for an increase in food production to meet the global food demand. Studies have revealed that over 33% of the food produced globally get lost through post-harvest operations along the food supply chain. Lack of proper storage facilities and food handling practices are among the major causes of food losses. Reducing food losses using appropriate storage technologies is therefore important to curb food losses to ensure food and nutrition security. Thus, this study aimed to examine choices and the impact of adopting hermetic maize storage technologies (HST) on smallholder maize farmers' income in the Gatsibo district, Rwanda. Specific objectives of this study were to characterize different maize storage technologies used by farmers in terms of the level of adoption, benefits, and constraints using descriptive statistics. It also assessed the factors affecting smallholder maize farmers' decisions about using alternative storage technologies, using the multivariate probit model. Finally, the study assessed the impact of hermetic storage technologies adoption on maize storage income among smallholder maize farmers, using an endogenous switching regression (ESR) on a random sample of 301 respondents from Gatsibo District of Rwanda. The results revealed that the common maize storage technologies used among smallholder farmers were polypropylene bags, chemicals, hermetic bags, and silos. Only 41% were HST adopters. Membership in farmer groups, access to credit, the quantity of maize produced, access to training, and selling maize immediately after harvest were the major factors influencing farmers' adoption of alternative storage technologies. The results from the ESR model show that household size, training, access to credit, distance to input provider, and the household head's experience in maize production influenced smallholder farmers' decision to adopt HST. Overall, the adoption of HST had a positive and significant impact on income from stored maize among maize smallholder farmers. The study recommends that the government of Rwanda and other stakeholders should support the dissemination of HST to facilitate access. In addition, policies supporting the training of smallholder maize farmers on post-harvest loss reduction and facilitating smallholder farmers' access to credit are highly recommended.

Keywords: Advanced storage technologies, Hermetic Storage Technology, Post-harvest storage losses, Rwanda

CHAPTER ONE: INTRODUCTION

1.1 Background

The growing global food demand fuelled by the rising population is increasingly grabbing global attention (FSIN, 2021). According to the United Nations [UN] (2017), the world population will increase to 8.6 billion by 2030 and 9.8 billion by 2050. This implies that food production needs to increase to match the global food demand. Meanwhile, in 2016 about 13.8% of the global food production was lost during the post-harvest stage along the food supply chain while in SSA approximately 14% of food produced was lost according to the Food and Agriculture Organization [FAO] 2019 State of Food and Agriculture (SOFA) report. For instance, in 2011, more than 30% of the food produced for human consumption in sub-Saharan Africa (SSA) was lost along the food supply chain and huge volumes are lost after harvesting due to the lack of proper storage. The value of this loss is estimated at USD 4 billion for grains alone, which is equivalent to the value of cereals imported annually in SSA (FAO, 2011). Managerial and technical limitations such as lack of proper storage facilities and food handling practices are among the main causes of food losses in SSA (Parfit *et al.,* 2010; Aulakh & Regmi, 2013; Raezaei & Liu, 2017).

According to Tefera (2012), maize is the leading food staple and a cash crop for smallholder farmers in SSA. However, between 14% and 36% of maize produced is lost due to poor post-harvest handling and storage while between 4.3% and 11.2% of it is lost at the storage stage due to inadequate storage technologies (Gitonga *et al.,* 2013). Farmer's store maize to hedge against seasonal food insecurity and attendant price volatility, and to cope with the damage that occurs during storage. Therefore, reducing food losses could contribute to enhancing food security as well as alleviating poverty, particularly in the rural areas of SSA (*ibid*). Rwanda's total land area is estimated at 2.6 million hectares (FAO, 2019). With a population density of 499 per square kilometer in 2018 and a growth rate of 2.4% in 2020 (World Bank, 2021), this land is hardly enough to support the growing population. According to World Bank indicators, agriculture employs about 62% of the country's working population in 2019.

While it contributes 26% of Rwanda's gross domestic product (GDP) according to the National Institute of Statistics of Rwanda (NISR), 2020. The country increased the budget assigned to agriculture in keeping with the Maputo Declaration of 2003 that required African Union member countries to allocate at least 10% of the public expenditure to agriculture development and 6% annual growth in agricultural GDP (New Partnership for Africa's Development [NEPAD], 2003). Consequently, the agricultural GDP has been rising from -3% in 2003 to 5% in 2019 (NISR, 2020).

Despite the impressive investment in agriculture, household food insecurity and undernutrition in Rwanda remain a huge challenge partly due to low agricultural productivity and post-harvest food losses (NISR, 2018). For instance, the 2018 Comprehensive Food Security and Vulnerability Analysis of the National Institute of Statistics of Rwanda (NISR) 2018, demonstrated that 18.7 % of the household were food insecure. While about 38.2% lived under the poverty line (NISR, 2017). According to the National Institute of Statistics of Rwanda [NISR] (2016), about 38% of children under 5 years' experience chronic malnutrition while stunting, wasting, and underweight are recorded at 37%, 1.7%, and 8% respectively. To address the problem of low agricultural productivity, the Government of Rwanda (RoG) launched the Crop Intensification Program (CIP) in 2007 that provided farm inputs and land use consolidation based on crop suitability (Cantore, 2011). Following the introduction of CIP, maize production increased by more than 400%; however, 32% of that maize has been lost due to low capacity in post-harvest handling and storage (Kathiresan, 2011; MINAGRI, 2018). To address postharvest constraints, the Ministry of Agriculture (MINAGRI) launched the post-harvest handling and storage (PHHS) Task Force in 2010 to advise the government on appropriate and cost-effective strategies for minimizing post-harvest losses (MINAGRI, 2011).

In 2012, the PHHS program introduced hermetic technologies to enable smallholder farmers to cope with postharvest losses in cereals. As result, the postharvest losses in maize fell from 32% in 2011 to 16.4% in 2019 (African Post-Harvest Losses Information System [APHLIS], 2018). This was achieved through training maize farmers in best practices in post-harvest handling and storage technologies, construction of post-harvest management systems, and distribution of post-harvest tools and equipment.

Out of these efforts, silos and hermetic bags became the most adopted hermetic storage technologies among smallholder farmers in Rwanda (World Food Program [WFP], 2016; MINAGRI, 2016). However, postharvest losses remain especially in maize due to rodent infestation (especially rats), insect pests, and microorganism infestation (One Acre Fund [OAF], 2014). These losses reduce farmer incomes and raise consumer prices because of diminished maize supply (Nathan & Kristin, 2013; Mvumi *et al.*, 2012).

Hermetic (air-sealed) storage like silos, Purdue Improved Crop Storage (PICS), cocoon, and super grain bags have been proven to perform better in storage loss reduction compared to traditional storage technologies (Kaminski & Christiaensen, 2014). Hermetic bags preserve the quality of grain and aesthetic appearance by reducing the growth of mould (Moussa *et al.*, 2014; Murashiki *et al.*, 2018). Hermetic technology works synergistically to ensure high carbon dioxide levels produced by aerobic metabolism of insects, micro-organisms, and grain respiration while keeping oxygen levels low (Weinberg *et al.*, 2008). Aerobic metabolism uses up the oxygen and raises the carbon dioxide to levels that are lethal to insects and moulds in the grain mass (Yakubu *et al.*, 2011). Thus, it offers an alternative to chemical and pesticide use in minimizing maize storage losses under smallholder farming conditions (Chigoverah & Mvumi, 2016).

According to Kumar & Kalita (2017), the major difficulty in the adoption of hermetic storage technologies among smallholder farmers is the high initial cost. Use of hermetic storage technologies and investment in improved post-harvest management methods can effectively minimize maize losses and help reinforce food security, thereby increasing smallholder maize farmers' income with no extra production costs. Scientific evidence on choices and impact of adopting HST are therefore needed and recommended for better policy formulation as adding into the literature (FAO, 2008; Hodges *et al.*, 2011; Yusuf & He, 2011). This study hence assessed factors affecting the adoption of hermetic storage technologies vis-à-vis other alternatives, and the impact on household income to inform maize farmers and policymakers. This study was conducted in Gatsibo District, located in the Eastern Province of Rwanda, the largest maize producing region in the country.

1.2 Statement of the problem

Over 65% of Rwanda's population depends on agriculture for livelihood. The agricultural sector of Rwanda, accordingly, accounts for about 31% of the country's GDP and is responsible for about 70% of the country's foreign exchange (NISR, 2017). The sector, like that of most SSA countries, is dominated by resource-poor smallholder farmers cultivating on average 0.6 hectares of land. The sector depends largely on rainfall and is therefore regularly vulnerable to the adverse effects of climate change (PASP, 2013). Arable land scarcity amidst a growing population coupled with low improved input use has resulted in low yields, leading to household food insecurity (Omotajo *et al.,* 2018).

Maize is an important staple food and cash crop in Rwanda and is becoming central to household food security in the country (Tefera, 2012; Kathiresan, 2011). However, over 25% of grains produced are lost post-harvest before reaching the final consumer. According to APHLIS (2017), the national average post-harvest losses were 21.1% in the major season and about 17.5% in the minor season. The higher losses during the major season have been attributed to high rainfall that induces fungal infection and especially aflatoxin (CARANA, 2013).

Most farmers in Rwanda still use traditional storage technologies like polypropylene sacks, chemicals, traditional granaries, and storage over the fire in kitchens (De Groote *et al.,* 2013; Bendito & Twomlow 2015). Gitonga (2013) revealed that traditional grain storage technologies do not provide secured protection against rodents, pests, and fungi. Kimenju *et al*. (2009) and Tefera *et al.* (2011) observed that farmers obtain low market prices to avoid storage losses of the surplus grain produced. Over 60% of maize farmers in Rwanda still use polypropylene sacks while another 38.3% apply chemicals that do not provide an effective barrier against rodents and moisture-induced microorganism contamination (One Acre Fund, 2014).

Studies conducted in Rwanda on postharvest storage show that postharvest handling of crops impacts negatively on crop prices. For example, Nyamulinda *et al.* (2011) found that innovative post-harvest handling activities lead to about a 30% increase in crop prices. According to One Acre Fund (2014), silos and super grain bags perform better in storing maize, given that rats, fungi, and pests are the major causes of storage losses in Rwanda.

However, little is known about the impact of hermetic storage technologies, relative to other storage technologies, on the income of smallholder maize farmers. There is also little evidence of the factors that affect the decision of farmers to use alternative storage technologies in Rwanda (Thamaga-Chitja *et al.*, 2004). Therefore, this study sought to bridge the gap in knowledge by assessing smallholder maize farmers' choices and the impact of hermetic storage technologies adoption on income in District, Rwanda.

1.3 Justification of the study

Assessing the impact of adopting hermetic storage technologies on the income of smallholder farmers, and the factors affecting its adoption will facilitate its sustainable adoption among smallholder farmers. It will also provide valuable information to policymakers and all stakeholders involved. This study is aligned with Government of Rwanda fourth Strategic Plan for Agriculture Transformation (PSTA IV, 2018-2024) which aims to increase agricultural productivity and commercialization leading to agricultural transformation (MINAGRI, 2018). The study contributes to the United Nations' Sustainable Development Goals (SDGs); goals number one and two that respectively aim at eliminating poverty and hunger, especially SDG target 12.3 calls for actions to reduce food waste and food loss along production and supply chains (including post-harvest losses) by 2030.

The empirical results of this study will enable policymakers in Rwanda to get more information on the economic effectiveness of hermetic storage technologies. Thus, it will guide them in formulating policies and strategies aimed at promoting the use of hermitic storage technology (HST) among farmers, which will contribute to the reduction of maize storage losses and increase the income of smallholder maize farmers. This study will also provide smallholder maize farmers with information on the income impact of hermetic storage technologies. Therefore, it will be beneficial to them in making decisions on the use of post-harvest storage technologies by examining the contextual factors that affect the income foregone if farmers fail to use HST.

Furthermore, the empirical results from this study will provide information to maize storage technology developers in designing farmer-preferred technologies. By assessing the impact of the adoption of hermetic storage technologies on smallholder farmer income in the Gatsibo District, this study contributes to the existing stock of academic scientific knowledge.

1.4 Objectives of the study

The main aim of this study was to examine the Factors affecting smallholder maize farmers' choices and the impact of adopting hermetic storage technologies on income in the Gatsibo District, Rwanda. The specific objectives were:

1. To characterize the maize storage technologies used by smallholder maize farmers in Gatsibo District.
2. To evaluate the factors influencing smallholder maize farmers' adoption of various maize storage technologies in the Gatsibo District.
3. To assess the impact of hermetic storage technology adoption on smallholder maize farmers' income in the Gatsibo District.

1.5 Research hypotheses

The following hypotheses were tested:

1. Smallholder farmers in Gatsibo District use the same type of maize storage technologies.
2. Farmer, farm, and institutional characteristics, taken individually, do not affect smallholder maize farmers' adoption of various maize storage technologies in the Gatsibo District.
3. The adoption of hermetic storage technologies has no impact on smallholder maize farmers' income in Gatsibo District.

CHAPTER TWO: LITERATURE REVIEW

2.1 Maize Postharvest losses

Postharvest loss (PHL) is defined as qualitative and quantitative loss of food along the food supply chain from farm to fork (De Lucia &Assenato 1994). The supply chain is composed of interconnected but different activities comprising production, harvesting, food storage, processing, packaging, distribution, and consumption of food (Hodges *et al*., 2011). According to Zorya *et al*, (2011), the causes of post-harvest losses can be grouped into two. The first group comprises technical causes that include harvesting procedures, handling practices, drying methods, storage technology or absence thereof, damage or contamination, rodent, bird, pest infestation, and food-borne pathogens infestation (such as mycotoxin fungi). The second group encompasses governance-related causes that comprise inadequate sales and marketing, procurement, storage, distribution strategies and procedures, the inadequate system for coping with cash flow needs (like drying hangars and warehouse receipts system), ineffective management in handling grain stocks, connected financing or problems dealing with the control, ownership and payment features of grain storage and price stabilization strategy.

Storage losses contribute a high portion of total postharvest losses. For instance, between 10 to 20% of cereal postharvest losses in East and Southern Africa occur due to poor postharvest handling and storage (FAO, 2011). In South East Asia, for example, one-third of harvested rice is lost to pests and spoilage due to lack of proper storage and this frequently forces farmers to sell their produce immediately, which contributes to low produce prices and household food insufficiency (Godfray, 2010). In their study in Uganda, Tanzania, and Malawi, Kaminski, and Christiansen (2014) reported that biotic factors such as rodents, pests (like maize larger grain borer (LGB, *Prostephanus truncatus*)), and fungal contamination are the main causes of maize storage losses. Pest infestation has been identified as the single most important cause of maize storage losses in Uganda, Tanzania, and Malawi.

Aflatoxins is the most common highly toxic mycotoxin compound, found in maize in the tropics and sub-tropics of the world (Reddy *et al.*, 2018). They are toxic metabolites produced by fungal species during growth under favorable conditions of temperature and moisture. The main aflatoxin species that infect maize are *Aspergillus flavus* and *Aspergillus parasiticus* (Cotty &Jaime-Garcia, 2007). Maize like other grains is susceptible to aflatoxigenic fungi from the time of harvest through storage under a high moisture regime (Abramson *et al.*, 1992).

In Rwanda, post-harvest infrastructures are inappropriate especially in rural areas for adequate storage to meet the local production needs and supply (FAO, 2011; Ingabire, 2018). Consequently, some maize processing companies import maize from other countries due to quality and a higher level of aflatoxin; for example, African Improved Food imports more than 50% of its maize needs per year mainly from Zambia (Christien *et al.*, 2019). Proper post-harvest handling and storage are crucial in preventing aflatoxin contamination (Hodges *et al.,* 2011; Aulakh, 2013; Kumar & Kalita, 2017).

2.2 Grain Storage Technologies Used by Farmers

2.2.1 Traditional Grain Storage Technologies

According to De Groote *et al*. (2013) and Bendito and Twomlow (2015), most farmers in SSA still use traditional storage technologies like polypropylene sacks, traditional granaries, clay pots, reeds baskets, open floors, sacks, barns, and barrels. Other store their maize either under shelter outside or over the fire in kitchens. Traditional storage structures such as baskets, granaries, or polypropylene sacks are sometimes used with chemicals. Although these structures and conservation products in some cases seem to be adapted to the prevailing environmental conditions, they are not always effective in protecting maize against pest infestation, leading to storage losses (Gbénou-Sissinto *et al.,* 2018). In Rwanda, smallholder farmers mostly use polypropylene sacks using different substances such as chemical or natural insecticides like ash or hot chili to deter pests. while other farmers store their maize above the cooking fireplace for smoke to keep pests out of the grain (One Acre Fund [OAF], 2014).

2.2.2 Advanced Grain Storage Technologies

2.2.2.1 Use of chemicals

These can be classified into two, chemical compounds and grain storage structures. The main chemicals used include synthetic pesticides such as dust powders, liquid formulations, and fumigants, and non-synthetic pesticides such as pyrethrin, lime sulfur, and sabadilla (Mvumi & Chigoverah, 2018). Although chemical pesticides perform well in preventing pests, their misuse has led to accidental poisoning, the development of insect resistance, and other adverse environmental and health effects (Obeng-Ofori *et al.*, 2015). In many developing countries, the availability of suitable and safe pesticides is low and has led to the use of highly toxic or persistent chemicals such as fenthion, lindane, and dichloro-diphenyl-trichloroethane (DDT) (Obeng-Ofori *et al.*, 2015).

2.2.2.2 Use of Hermetic Storage Technologies

Hermetic storage technologies (HST) are sealed, airtight storage structures that control living organisms in stored, dry agricultural commodities. Some examples are triple-layer grains storage bags, Poly vinyl chloride (PVC) envelopes, cocoons, super grain bags as well as metal and plastic silos (Okolo *et al*., 2017). HST is a form of the bio-generated modified atmosphere. It has the ability to restrict gas exchange between the external environment and the internal environment, which contains the stored commodity (Quezada *et al*., 2006). It controls pests by lowering the oxygen and increasing the carbon dioxide levels in the internal ecosystem of the sealed storage (the storage atmosphere) which is achieved by the respiration of insects, fungi, and grain maintaining the initial levels of moisture. This prevents infestations (molds and insects), and oxidation (Villers *et al*., 2008; Quezada *et al.,* 2006; Moreno *et al*., 2000). When the oxygen in the air in the container is reduced to 3% or lower, the insect dies. Similarly, fungal development ceases when the oxygen content is reduced to 1% or less. This makes HST an ideal storage method for reducing the attack of insects and fungi on stored grain (Quezada *et al*., 2006; Moreno *et al.*, 2000). Hermetic storage also is a chemical-free system of storage (Quezada *et al*., 2006).

Super grain bags are improved polyethylene and woven polypropylene bags, designed to have high density and physical strength as well as high impermeability to gases or ambient air (Jonfia-Essien *et al*., 2010; Okolo *et al*., 2017). Among the known super grain bag types is the Purdue Improved Crop (PIC) storage bags which have double-layer of plastic inside, and hermetic bags that have one-layer inside (Jonfia-Essien *et al*., 2010). Super grain bags reduce insect damage to grain to a large extent while maintaining its quality for many months or longer. Farmers with varying and often small volumes of grain at harvest may still benefit from alternatives to super grain bags for storing their grain (Williams *et al*., 2017).

Plastic and glass containers (e.g., plastic soda bottles) when well-sealed can be considered as HST structures. Although most of them are not originally designed for hermetic storage, they help smallholder farmers who cannot easily access the HST structure (Quezada *et al*., 2006; Williams *et al*., 2017). Grain storage cocoon structures are made of large hermetic envelops called a cocoon, made of polypropylene material like grain bags. The cocoon, also known as volcanic tubes, is made of single-layer density polypropylene thermos-elastic material and are designed for large-scale storage of 30 to 1,500 tons. They are widely used globally for the storage of grains and pulses in countries such as Philippines, China, Sri-lanka and Rwanda (Borlagdan *et al*., 2014).

A silo is a tough-sealed predominantly cylindrical storage container that holds between 100 and 3,000 kg of grain at a time. Examples include canvas, plastic, sisal, and metal silos. Galvanized steel is used to construct metal silos. (FAO, 2008). They provide a long-term solution for all grain crops; they are highly durable and last longer than double-plastic silos. Silos do not require the use of pesticides, they are rodent and pest-proof, and are easy to recycle (Hodges *et al.*, 2011). In Rwanda, silos were introduced in 2012 (MINAGRI, 2016).

2.3 Theoretical review of impact assessment

Fitz-Gibbon (1996) defines impact as any effect of the service (or of an event or initiative) on an individual or group. this definition implies that an impact could be intended or accidental and could also be positive or negative. The process of impact "assessment" or "evaluation" involves data gathering, setting up weightings, selection of goals as well as criteria to enable the comparison of performance against some baseline (Dunn &Mulvenon, 2009). Accordingly, impact assessment requires an ethical justification (Taras, 2012). Impact assessment is an important tool when the aim is to ensure that concerns regarding sustainability are considered in decision making (Pope *et al.*, 2013).

n Impact evaluation aims to establish a cause-effect relationship between an intervention and realized outcome(s) and to describe or measure the resulting changes along the impact pathway (Pope *et al.*, 2013). According to Fitz-Gibbon and Morris (1996), a theory-based assessment of a project, program or policy uses a model or theory to show the causal relationships between an intervention (either a project, program, or policy) and realized outcome(s). Such theories include the theory of change and program or logic theory. The theory of change describes exactly how the intervention will deliver the expected results and explores the assumptions and conditions necessary for the change to occur. Nevertheless, the theory of change has become very popular in impact assessment studies thus it is a greater time investment and requires vast amounts of data (Weiss, 1998).

Program or logic theory refers to a diversity of ways of developing a causal modal that connects programme inputs and activities to a chain of expected or observed outcomes and then using this model to lead the impact evaluation (Donaldson, 2005; Rogers *et al.*, 2000).

2.4 Methods used to conduct impact evaluation

The major methods used for impact evaluation while considering both counterfactual and selection bias problems include randomized evaluation, regression discontinuity design, difference-in-difference, and matching methods.

2.4.1 Randomized evaluation

Randomized evaluations, also called experimental evaluations, randomized controlled trials (RCTs), or randomized field experiments have the goal of creating a fitting comparison group by design from introducing the intervention. Control and treatment groups are randomly selected (Pomeranz, 2017). So that they are similar in both observable and unobservable characteristics. The impact is assessed by comparing the outcomes of the control and the treatment group (Pomeranz, 2017; Ludwig, Kling, and Mullainathan 2011). Thus, the impact measured is due to a systematic difference between the treatment and comparison group that would have existed even without the application of the treatment, implying that the control group represents the counterfactual for the treatment group. Hence, it controls for selection bias which requires much time and budget to conduct (Duflo, Glennerster & Kremer 2008). Therefore, in a study like this, this method would have been preferred, but it has been limited by the time frame and resources assigned to this study.

2.4.2 Regression discontinuity design

Regression discontinuity design (RDDs) is a method that can evaluate the causal effects of interventions by assigning participants to the program (intervention) or comparison groups with control conditions based on a cutoff score or threshold on a pre-intervention measure that typically assesses need or merit. By comparing the outcomes of observations lying closely on either side of the threshold (Imbens and Lemieux, 2008; Lee and Lemieux, 2010). Hence, the counterfactual of the outcomes of individuals who fall above the threshold is represented by entities that fall below the threshold. Therefore, RDD can be considered as the ex-post Facto experiment alternative (Imbens and Lemieux, 2008). The key assumption is that the entities just below the threshold are otherwise almost like those who fall just above. RDD can only be used if an intervention has a particular threshold that shows who is eligible to take part in the intervention (Buddelmeyer &Skoufias, 2004). Hence, RDD cannot be used in this study as they were no threshold assigned to HST adoption. They were no merit-based in the adoption of HST as participants in this program had an equal chance of being either adopters or non-adopters.

2.4.3 Difference-in-difference

The difference-in-differences (DD) estimates the differences between the variation in outcomes that contains two groups, "treatment" and "control" and two time periods, "pre" and "post" intervention. Hence, DD applications exploit changes in outcomes before and after the intervention across groups of units that receive treatment at different times (Goodman, 2021; Galiani *et al.*, 2005). The change for the control group, therefore, is considered as the counterfactual of the change for the treated group. This method assumes that without the intervention, the change in outcome over time would have been the same for the control and treated groups (Bertrand *et al.*, 2004). This method would be suitable for this study as it controls for all the observable and unobservable characteristics that do not change over time and for all the changes over time that affect both groups in the same manner (Goodman, 2021). However, the pre-data for the participants before the interventions were not available.

2.4.4 Matching methods

Matching methods primarily depend on observed characteristics to form a comparison group. The methods assume that, on average, there are no differences between those who took part in the intervention and those who did not take part other than being part of intervention (Jalan & Ravallion 2003; Rosenbaum 2002). A common example of matching methods is propensity score matching (PSM). PSM matches the treatment group to the control group based on the propensity score. PSM relies on the conditional independence assumption that conditional on some observable characteristics, treatment groups can be compared to the control group, as if the treatment has been fully randomized, conditional independence states that given the observable characteristics, and in the absence of treatment, there is no statistically significant dependence between the outcome (Y), and the participation status (P), conditional on the probability of participation (Feroci *et al.*, 2013). Following Khonje *et al.* (2015), let Y_1 represent the outcome for the household i that takes part in an intervention (either project, program, or policy); $P = 1$, and Y_0 represent the outcome for a household that does not take part. The average treatment effect on the treated participants (ATT) is specified as:

$$ATT = E(Y_1|P = 1) - E(Y_0|P = 1) = E\{Y_1 - Y_0|P = 1\} \quad (2.2)$$

The propensity score or the likelihood of receiving treatment is defined as (Rosenbaum & Rubin, 1983):

$$pr(P = 1|X) = p(X) \quad (2.3)$$

The PSM also assumes a common support condition. This condition requires that there are significant covariate overlaps between participants and non-participants. This enables the subjects under comparison to have an equal chance of being either participants or non-participants (Feroci *et al.*, 2013).

Given the conditional independence assumption of the PSM, the ATT estimator is defined as the mean difference in the outcomes of participants juxtaposed with the outcome of non-participants who are balanced on the propensity score, and fall within the common support region (Imbens, 2015). It is expressed as:

$$ATT = E[Y_1|P = 1, p(x)] - E[Y_0|P = 0, p(x)] \quad (2.4)$$

where $p(x)$ is the probability of participating in the intervention; the estimator produces a consistent estimate provided all the factors influencing participation and outcome are incorporated in the model (Khonje *et al.*, 2015). According to Imbens, (2015), one major limitation of the PSM technique is its inability to control for unobservable characteristics that may influence participation (selection bias). However, this deficiency can be controlled by the use of the endogenous switching regression (ESR) model that simultaneously deals with the counterfactual problem within the difference-in-difference framework and controls for selection bias (Lokshin & Sajaia, 2014; Di Falco *et al.*, 2011; Shiferaw *et al.*, 2014; Ngoma, 2018). Due to these strengths, the ESR was used in this study to evaluate the impact of hermetic storage technologies on smallholder farmers' income.

2.5 Empirical review

2.5.1 Factors affecting farmers' adoption of alternative storage technologies

Several studies have focused on factors affecting the adoption, perception, and use of alternative storage technologies. For example, Sekumade and Akinleye (2009) analyzed the factors affecting the use of maize storage technologies in North Central Nigeria using multinomial logit. The study revealed that the age of the household head increased the probability of using local storage, while the quantity of stored maize increased the likelihood of using semi-modern storage, although household head education level and maize production experience increased the probability of using modern storage.

Alemu *et al.*, (2021) assessed the factors affecting farmers' choices of storage technologies in Ethiopia, using a multivariate probit regression model, and found that access to information, the initial cost of the technology, and the storage capacity of the technology influenced the selection of hermetic storage technologies. Gitonga *et al.* (2015) used the ordered logit to evaluate factors that influence the adoption of metal silos in Kenya. The study found that effective protection against storage pests, stored grain security, and storage facility durability were the most crucial factors that the sample households considered when choosing a storage technology. On the other hand, household size, the level of education of the household head literacy, farm size, and access to financial services like having a bank account or mobile money increased the likelihood of adopting metal silos. The study also revealed that distance from the farm to the nearest passable road decreased the odds of adopting metal silos. Similar findings have been made by Kisogo, (2018) who evaluated factors affecting the choice of maize storage technologies among smallholder farmers in Kilosa and Kongwa Districts in Tanzania by using multinomial logit, and found that the selection of hermetic bags and silos have been influenced by household income, access to training and household head education while those factors reduced the probability of using Sulphate bags.

Flock (2015) analyzed the factors that influenced the adoption of hermetic storage technologies in Nepal using probit models. The results identified education and access to savings as important factors that increased the purchase of hermetic technologies among farmers who produce rice, maize, lentils, and wheat. Owach *et al*. (2017) used binary probit regression to assess factors affecting household adoption of improved storage structures among finger millet and common beans farmers in Northern Uganda, found that membership in a farmer group, household size, distance to market, age, and education level influenced the use of improved storage like a silo and hermetic bags.

Most of the reviewed studies in this section reveal factors affecting the choices of alternative storage technologies and factors affecting the adoption of an innovative storage technology differ across regions and countries because of environmental social-economic characteristics conditions. Recommending that studies on the adoption of advanced storage technologies should consider reviewing those factors basing on the area conditions. Therefore, this study hypothesized different factors to reveal their influence in terms of the choices of alternative maize storage technologies in Rwanda context. Hence, the current study seeks to contribute to filling the gap in knowledge on factors affecting farmers 'choice of alternative storage technologies in Rwanda.

2.5.2 Effect of maize storage technologies on postharvest loss reduction

Several studies have been undertaken to focus on the effect of the adoption of maize storage technologies on postharvest loss reduction. For example, Gitonga *et al*. (2013) evaluated the impact of metal silos on household food security and storage losses in Kenya using the PSM and found metal silos to have a near-complete elimination of storage losses caused by pests resulting in a significant reduction in food insecurity by reducing the time of inadequate food provision by five to six weeks over the year. In Afghanistan, Ameri *et al.* (2018) compared PICs bags and hand-woven polypropylene bags in terms of postharvest loss reduction using wheat samples. The study found that PIC bags prevented grain damage as well as maintained grain viability and seed quality compared to polypropylene bags.

De Groote *et al.* (2013) assessed the effectiveness of hermetic storage systems in controlling maize storage pests in Kenya. Metal silos and super grain bags were shown to be effective in controlling insect pests, maize weevils, and larger grain borer (LGB) without insecticides application. Chigoverah &Mvumi (2016) found that hermetic bags reduced post-harvest maize losses better than non-hermetic bags in Zimbabwe. These findings are quite similar to those of Kisogo (2018) who conducted an economic analysis of maize storage technologies adopted by smallholder farmers in Kilosa and Kongwa Districts in Tanzania using cost-Benefit analysis found that metal silos followed by hermetic bags were highly effective in controlling loss as compared to other storage. Similar results have been found in Kenya by Nduku, De Groote, & Nzuma (2013) in their study on maize storage structures feasibility. Cost-benefit analysis results revealed that for farmers who shifted from traditional to advanced storage technologies methods like metal silos their maize storage costs and losses were reduced.

Chegere *et al*. (2020) used a randomized control trial (RCT) to examine the effect of storage technologies and training on sales among small-scale maize farmers in Tanzania. They found that providing farmers with hermetic bags and training them on postharvest management practices significantly improved farmers' likelihood of selling maize, also increased the price of their maize at the farmgate as well as shifted their sales to the lean season while reducing storage protection costs and finally reducing the quantity of maize lost during storage. In Rwanda, Nyamulinda *et al*. (2011) also assessed the effect of post-harvest handling of crops on crop prices and found that innovative post-harvest technologies have led to loss reduction with a 30% increase in the price of crops due.

Ameri *et al*. (2018) assessed the economic benefits of the adoption of hermetic storage technologies by smallholder wheat farmers in Afghanistan. Using on-farm storage trials in three provinces of Afghanistan, they compared the Purdue Improved Crop Storage (PICS) bags and the local woven polypropylene (PP) bags practices and found that the PICS had higher economic returns.

Sissinto *et al.* (2021) evaluated the financial profitability of different maize storage technologies profitability in Benin using experimentations and cost-benefit analysis and found that the most profitable storage technologies in northern Benin were polypropylene bags while in center Benin it was PICS bags. However, in Malawi, Jones *et al.* (2014) found that, on average, PICS bags offered higher profitability levels for farmers than polypropylene bags and chemicals.

The above reviewed studies demonstrated the effectiveness of adopting advanced storage technologies in loss reduction. Future work on the economic impact of HST was recommended to account for the value of the reduced losses and to improve the knowledge and adoption of hermetic storage in different geographical regions. Studies that examine local grain production and vulnerability to poor storage practices were also suggested. This study, therefore, assessed the impact of HST adoption on income among smallholder maize farmers in Gatsibo District, Rwanda.

2.5.3 Impact of maize storage technologies adoption on the welfare of smallholder farmers

Shukla, Baylis, and Pullabhotla (2019) evaluated the impact of on-farm hermetic storage technology on food security in India using a randomized control trial and found that access to hermetic storage technologies facilitated smallholder farmers to store for longer periods, sell at higher prices, food security in terms of availability, access, utilization, and stability and decrease postharvest losses. Suggesting that providing information about the benefits of hermetic storage could support technology adoption and enhance food security. , Bokusheva *et al*. (2012) also assessed the impact of the adoption of postharvest storage technology as well as the determinants of its uptake in Central America The results showed that adopters had improvements in food availability compared to non-adopters. Therefore, this study will fill the gaps by evaluating the impact of HST adoption on smallholder farmers' income.

In SSA, several studies have been done on the impact of improved storage technology. For instance, Gitonga *et al*. (2015) used the treatment effect and ordered probit models to assess the impact of metal silos on the food security of rural households in Kenya. The results revealed that adopters of metal silos sold a little portion of their harvest to meet cash needs and kept the bulk of it until after the fifth month after harvest. They concluded that the adoption of metal silo technology significantly improves the food security of rural households.

Using randomized control trial (RCT) to assess the impact and profitability of hermetic bags for farmers in Kenya, Ndegwa *et al.* (2016) reported that hermetic bags were profitable. Similarly, Kimenju and De Groote (2010) reported an increasing return to metal silos, but only in the long run after benefits have accrued.

In Tanzania, Kotu *et al*. (2019) assessed the potential impact of improved storage technologies adoption on food security and income of smallholder maize farm households using on-farm experiments and by comparing modern storage methods (PICS bags, metal silos, and chemical-treated PP bags) and found that between poor rural households PICS bags (or PP bags plus Actellic Super) are convenient to address food security and increase income while farmers with bigger surplus grain to sale metallic silos with bigger storage capacity were useful to increase their income. Cungura and Darnhofer (2011) found that the adoption and use of improved granaries had no significant impact on household income in Mozambique. Therefore, there is a need for other studies to produce further evidence to identify socio-economic factors associated with income from adopting improved storage by different groups of farmers and identify possible differences in the returns they acquire depending on different types of storage technologies used.

2.6 Summary

Based on the identified research gaps, differences in findings from the literature reviewed in the foregoing sections where different studies demonstrated that factors affecting the farmers' choice of alternative storage technologies differ depending on regions and countries, there is, a need to undertake further research on factors affecting the choices of different storage technologies used among smallholder maize farmers in Rwanda to bring more facts to support policy formulation. In addition, from the reviewed literature a lot of studies have been done on the impact of HST on post-harvest loss reduction in maize and food security in SSA using different methods of operationalization notably PSM, Randomized evaluation, Experiment. Hence, little is known about HST income impact. For instance, in Rwanda, except for Nyamulinda *et al.* (2011) who assessed the effect of post-harvest handling of crops on crop prices, therefore additional literature on the impact of adopting HST on smallholder maize farmer's income in Rwanda is of high importance. This study attempts to fill that knowledge gap.

CHAPTER THREE: ASSESSMENT OF FACTORS INFLUENCING SMALLHOLDER FARMERS' CHOICE OF ALTERNATIVE MAIZE STORAGE TECHNOLOGIES IN GATSIBO DISTRICT, RWANDA

Abstract

Storage is an important aspect of food security in developing countries. Therefore, it is crucial for farmers to have access to sustainable storage technologies to cope with storage losses. Maize is an important staple and commercial food in Rwanda, but maize farmers are still being challenged by storage losses because of the lack of proper storage facilities. It is in that regard that advanced maize storage technology, notably hermetic maize storage technology, has been introduced in Rwanda in 2012. However, since its introduction, the adoption rate is low among smallholder maize farmers. Understanding the factors influencing farmers' choice of alternative maize storage technology could provide Rwandan policymakers with important information for designing policies and programs aimed at reducing maize post-harvest losses to enhance household food security. This study used a multivariate probit model on a randomly selected cross-sectional sample of 301 smallholder maize farmers from the Gatsibo District of Rwanda to take part. The results revealed that the common maize storage technologies used among smallholder farmers were polypropylene sacks with and without chemicals, hermetic bags, and silos. Only 41% of respondents used hermetic maize storage technology. The model results showed that membership in a farmer group, access to credit, the quantity of maize produced, access to training, and selling maize soon after it dries, were the major factors influencing the decision of smallholder farmers to use alternative maize storage technologies. The study recommends that the policymakers and other stakeholders in post-harvest loss reduction should support the dissemination of advanced storage technologies to facilitate access. The government should support farmer acquisition of post-harvest maize loss reduction technologies either through subsidization of hermetic bags or provision of cheap credit.

Keywords: Hermetic Storage Technology, Post-harvest storage losses, Rwanda

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3.1 Introduction

The measures and actions aimed at reducing food losses are contributing factors to enhancing food security as well as alleviating poverty among smallholder farmers in sub-Saharan Africa (SSA). And, although the global food systems produce sufficient food to feed everyone, still in 2016 about 13.8% of food produced in the world get lost annually either through post-harvest mishandling, infestation by pests and diseases, or just mere waste at the table (Food and Agriculture Organization [FAO], 2019). Over 30% of the food produced in SSA gets lost post-harvest along the food supply chain because of financial, managerial, and technical constraints (The Rockefeller Foundation, 2015; Gustavsson *et al*., 2013; FAO 2011). Estimates by FAO showed that post-harvest losses (PHL) in SSA reach up to 20% for cereals valued at US$4 billion, which is equivalent to the value of cereals imported annually in SSA (FAO, 2011). Although governments and development partners availed investment to reduce PHL, the 2019 State of Food and Agriculture (SOFA) report by the Food and Agriculture Organization [FAO] reveals that approximately 14% of food produced in SSA still gets lost. It is therefore imperative that those post-harvest methods and requite technologies be accorded similar attention by policymakers as they do to food production (Obeng-Ofori *et al*., 2015).

In the east and southern Africa, maize is the most important food staple and a cash crop for most resource-poor smallholder farmers (Shiferaw *et al*., 2011; Tefera, 2012; CIMMYT, 2010). Farmers store the maize to bridge seasonal supply shortfalls and attendant price fluctuation (Gitonga *et al*., 2013). However, between 14 and 36% of maize produced in eastern and southern Africa is lost during post-harvest because of poor handling and improper storage. Of this loss, between 4.3 and 11.2% is lost, during storage, due to infestation by rodents, insect pests, and mycotoxins which are associated with the lack of effective storage technology (Giertz *et al.*, 2015; Gitonga *et al.*, 2013).

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In Rwanda, about 32% of the total volume was lost because of the lack of capacity in post-harvest handling and storage (Kathiresan, 2011; MINAGRI, 2018). In response to the high post-harvest maize losses, the Government of Rwanda launched the post-harvest handling and storage (PHHS) task force in 2010 with the mandate of minimizing post-harvest losses through training of maize farmers in best practices in post-harvest handling and storage technologies, construction of post-harvest management systems, and distribution of post-harvest equipment including hermetic storage technologies (MINAGRI, 2016). As a result, the post-harvest losses in maize fell from 32% in 2011 to 16.4% in 2019 (African Post-Harvest Losses Information System [APHLIS], 2019).

The hermetic storage technologies were introduced in Rwanda in 2012 and comprised hermetic bags and silos among smallholder farmers. The government subsidized both silos and hermetic bags at 75% to encourage adoption (MINAGRI, 2011; WFP, 2017). However, by 2014, One Acre Fund [OAF] reported that only 37% of the smallholder maize farmers adopted the hermetic storage technology. In Rwanda, grain losses are among the major causes of food shortage, food insecurity, high prices, and prohibiting farmers' access and affordability (Umubyeyi & Rukazambuga, 2016). Likewise, maize farmers are facing challenges in producing the required quality and quantity of maize. Due to the damages experienced at storage from rodents, pests, and aflatoxin contamination, their maize is sold at a lower price or rejected by buyers. It results in food insecurity and low income because of losses incurred by farmers (MINAGRI 2018). Although studies (e.g., Nyamulinda *et al.*, 2011 and OAF, 2015) have shown unequivocally the effectiveness of the hermetic storage technologies in loss reduction.

This study aligns with the Government of Rwanda’s fourth Strategic Plan for Agriculture Transformation (PSTA IV, 2018-2024) that aims to increase agricultural productivity and commercialization, leading to agricultural transformation (MINAGRI, 2018). The study contributes to the United Nations’ Sustainable Development Goals (SDGs); goals number one and two that, respectively, aim at eliminating poverty and hunger, and SDG target 12.3 that calls for actions to reducing food waste and food loss along production and supply chains by 2030.

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Therefore, this study sought to bridge the gap in knowledge by providing information on factors influencing smallholder maize farmers' choice of alternative storage technologies in the Gatsibo District of Rwanda. It will guide policymakers in formulating policies and strategies aimed at promoting the use of hermetic storage technology (HST) among farmers, which will contribute to the reduction of maize storage losses. In addition, the findings will assist maize farmers in gaining knowledge on the effectiveness of different storage technologies to increase the adoption of improved maize storage technologies.

3.2 Methodology

3.2.1 Theoretical framework

This study was based upon the random utility theory which states that faced with a choice, a decision-maker will choose the alternative that maximizes his utility from a set of alternatives (Greene & Hensher, 2010; Greene, 2012). Each alternative in the decision maker's choice set is associated with a true value that reflects its utility (Soufiani *et al*., 2014). The random utility model recognizes that the decision-maker has both observable (e.g., gender, age, education, and farm characteristics) and unobservable characteristics (e.g., motivation and ability) that influence his choice of a utility-maximizing alternative (Greene & Hensher, 2010).

When applied to this study, a farmer will choose the technology that maximizes their utility derived from the profits obtained from the adoption decision. This utility is succinctly captured in a utility function consisting of a systematic component, V_{ij}, that captures the observable characteristics of the chooser and the choice, and an error component, ε_{ij} that captures the unobservable characteristics including measurement errors (Greene, 2012; Cascetta, 2009). Thus, the utility function derived by the farmer i from using technology alternative j chosen from a choice set C_a is given by:

$$U_{ij} = V_{ij} + \varepsilon_{ij} \quad (3.1)$$

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Given a choice between two storage technologies, j and k with associated utilities, U_j and U_k respectively, the probability of farmer i choosing j over k from the choice set C_a is given by (Greene, 2012):

$$P(j|C_a) = P(U_{ij} > max(U_{ik}))$$

$$= P(V_{ij} + \varepsilon_{ij} > max(V_{ik} + \varepsilon_{ik})) \quad \forall j \neq k \in C_a \qquad (3.2)$$

3.2.2 Empirical model

This study used the chi-square test, t-test, proportional test, and ANOVA to assess the level of usage of advanced storage technologies (hermetic storage technologies) vis-à-vis other storage technologies and the constraints and opportunities for different storage technologies. The Multivariate probit model (MVP) was employed to assess the factors that affect smallholder maize farmers' choices and decisions on the alternative storage technologies in Rwanda. This study shows that the most-used storage technologies are four, namely polypropylene sacks, polypropylene sacks with a chemical application, and hermetic technologies (silos and hermetic bag). The MVP is a natural extension for the probit model. It can accommodate over one equation, and accounts for the likelihood of correlation of the error term across the different equations for alternative storage technologies (Greene, 2003; Gujarati, 2009).

The probit model is among the statistical probability models that have two categories in the explained variable (Liao, 1994). It generates the marginal effects of the explanatory variables on the probability of adoption (Hosmer& Lemeshow, 2000). According to Aldrich (1984) and Owach (2017), the analysis of the probit model is based on the cumulative normal probability distribution of the error terms, that makes it more preferred for regression analysis. However, MVP does not require the assumption that choices are independent across alternatives (Greene, 2003; Gujarati, 2009; Otieno, 2010).

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The multivariate probit model presupposes that the decision by a smallholder maize farmer to adopt any of the alternative storage technologies or not would depend on an unobservable index Y_{ij} determined by explanatory variables, where the higher the index, the greater the probability of smallholder maize farmers to adopt a specific storage technology.

The expression takes the form:

The expression takes the form:

$$Y_{ij}^{*} = \beta_i X_i + \varepsilon_i \, , j = 1, \dots, m \tag{3.3}$$

Where Y_{ij}^{*} (j=1,…, m) in equation(4) represents an unobservable latent variable of the storage technologies j used by smallholder farmer i (in this case m=4); X: is a (1 x k) vector of observed variables that affect storage technology adoption decision; β: is a (k x 1) vector of unknown parameters to be estimated and ε_i is a vector of the stochastic error terms. A smallholder maize farmer will choose j technology if the utility of choosing it exceeds the gain of not using it. These preferences may be correlated with individual and farm characteristics and institutional factors that are captured in β. Since the latent variable is unobservable, two index functions are defined. Referring to equation (3.3), with using any of the alternative storage technology, this is:

$$Y_{ij} = 1 \quad if \; Y_{ij}^{*} > 0 \tag{3.3a}$$

$$Y_{ij} = 0 \quad if \; Y_{ij}^{*} \leq 0 \tag{3.3b}$$

By considering Y_{ij} as a dummy variable with values 1, if the i^{th} smallholder maize farmer adopts the j^{th} technology, and 0 otherwise; where the value of j ranges from 1 to 4 representing polypropylene sacks only, polypropylene sacks + chemical application, silos, and hermetic bags, respectively.

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Therefore, the system of equation is written as follows:

$$\begin{cases} Y_1^* = \beta_I X_1 + \varepsilon_1 \ , Y_1^* > 0; \ Y_1 = 0 \ otherwise \\ Y_2^* = \beta_2 X_2 + \varepsilon_2 \ , Y_2^* > 0; \ Y_2 = 0 \ otherwise \\ Y_3^* = \beta_3 X_3 + \varepsilon_3 \ , Y_3^* > 0; \ Y_3 = 0 \ otherwise \\ Y_4^* = \beta_4 X_4 + \varepsilon_4 \ , Y_4^* > 0; \ Y_4 = 0 \ otherwise \end{cases} \tag{3.4}$$

The system of equations (3.4) will be jointly estimated using maximum likelihood. The choice of alternative storage technology will depend on smallholder maize farmer and farm-level characteristics, as well as institutional factors.

3.2.3 Study area

Gatsibo District is one of the seven districts that make up the Eastern province, the largest, and the highest in terms of percentage of households (NISR, 2018). It was selected for this study because of the high adoption of Hermetic storage technologies. About 40% of maize farmers supported by Rwanda's post-harvest handling and storage task force are from Gatsibo District (MINAGRI, 2016). Therefore, Gatsibo district was selected to better analyze the factors determining the choice of alternative storage technologies and the relationship between adopting HST and income among maize farmers. It borders Nyagatare District in the North, Gicumbi District in the West, Gasabo District in the South-West, Rwamagana District in the South, and Kayonza District in the East (Figure 3.1). Gatsibo District is divided into 14 sectors, 69 cells, and 603 villages. About 89% of the residents depend on agriculture for their livelihood, with maize representing 49% of the total land area under the Crop Intensification Program, and about 54% of the marketed produce (MINAGRI, 2018).

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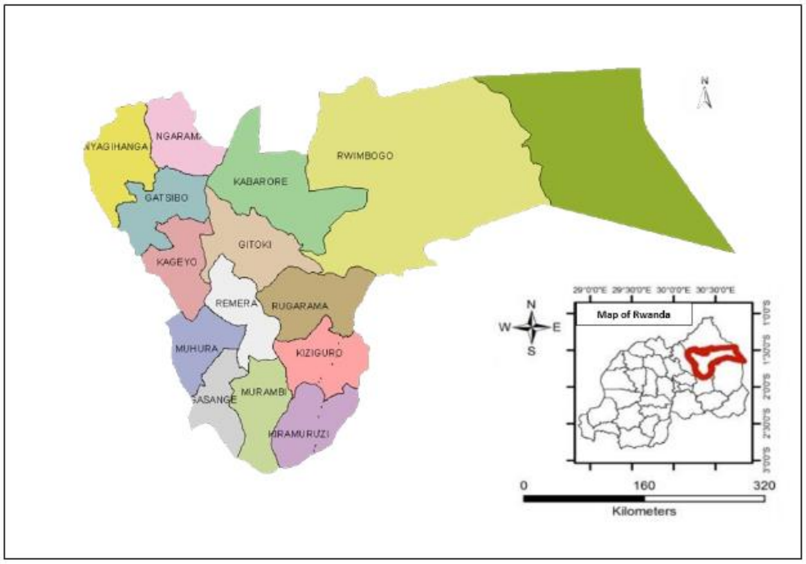

Figure 3. 1: Map of Gatsibo District demonstrating the sectors where the study have been conducted, Rwanda
Source: Gatsibo District (2018)

3.2.4 Sampling and data collection procedures

A multistage sampling technique was used to identify the sampling units. In the first stage, Gatsibo District was selected based, as stated above, on having the highest number of smallholder maize farmers that use drying hangers in Rwanda's Eastern Province. A list of all smallholder maize farmers in Gatsibo District who used drying hangers and were supported by Rwanda post-harvest handling and storage task force (PHHS) was got from Gatsibo District Agricultural Division. The list contained 75,000 farmers. In the second stage, 12 cells were selected based on the location of the drying hungers. Because the population of farmers who were using drying hangers in the district was known, the Yamane (1967) formula for calculating a sample size from a known population was used:

$$n = \frac{N}{1+N(e)^2} \quad (3.1)$$

where n is the sample size; N is the number of farmers using drying hangers in the district, and e is the level of precision.

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Inserting 75000 maize farmers in equation (3.7) and assuming a 95% confidence level and a 5% precision gave 398 households (The fact that maize farmers live and work near their farmrs, it was relatively easy to find them during the survey. For this reason 5% level of precision was deemed appropriate). However, due to invalid response and missing data, the study ended up using only 301 maize farmers in the analysis.

Figure 3. 2: Maize drying hanger (made of corrugated iron sheet roof and partial walls, concrete floor, and fitted with rows of metal bars from which maize on the cob is hung using the husk)
Source: Gatsibo District- Agricultural division

This study used primary data that have been obtained through a household survey using face-to-face interviews and focus group discussions and secondary data that have been sourced from Gatsibo district Agricultural division, Rwanda post-harvest and storage task force, and MINAGRI. Trained enumerators interviewed selected farmers using a pre-tested semi-structured questionnaire. The questionnaire gathered smallholder maize farmers' socio-demographic and economic characteristics, as well as the adoption and utilization of hermetic storage technology. Among the selected smallholder maize farmers. The data were analysed using STATA with the use of econometrics models- Multivariate Probit (MVP).

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3.3 Results and Discussion

3.3.1 Farmers' socio-demographic characteristics

Out of the total of 301 respondents, 41% of the smallholder maize farmers in Gatsibo district have adopted hermetic storage technologies (silos and hermetic bag) while 59% used polypropylene sacks with and without chemicals (Table 3.1). The majority (76%) of heads of households were male. Referring to Table 3.3, the pooled average age of the household heads in Gatsibo District was 47 years (range from 25 to 69 years old). The HST adopters were significantly older than non-adopters with more experience in maize production. However, the household heads of the two groups had attained a similar level of formal education of 5.8 years, against the national average of 4.4 (United Nations Development Programme [UNDP], 2020).

The majority (90%) of household heads belonged to maize farmer groups, and 60% had received government extension services twelve months preceding the survey. This is against the 2017 Rwanda agricultural household survey report that 12.5% of agricultural households have at least one member belonging to agricultural cooperatives and 29.6% receiving agricultural extension services or training (NISR, 2018). Of the 301 maize farming households, 64% received training on post-harvest handling and storage (Table 3.1). HST adopters had greater access to extension services and training related to post-harvest handling and storage compared to non-adopters. They, therefore, seem to have higher social capital from better access to information and social services.

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Table 3. 1: Summary statistics of socio-demographic characteristics of hermetic storage technologies adopters and non-adopters in Gatsibo District, Rwanda

Variables	Percentage			χ2-value
	Adopters N = 122	Non-Adopters N = 179	Overall N = 301	
Awareness of HST (1 = aware; 0 = not aware)	100	36	61	116.21***
Sex of household head (1 = male; 0 = female)	75	76	76	0.013
Selling maize soon after it dries (1 = Yes)	75	77	76	0.11
Buying maize (1 = yes)	6	12	9	3.09*
Access to extension services (1 = yes; 0 = no)	88	42	60	63.68***
Access to training (1 = yes; 0 = no)	94	43	64	82.50***
Group membership (1 = yes; 0 = no)	90	89	90	0.004
Access to credit (1 = yes; 0 = no)	39	26	31	6.29**

*, **, *** significant at 10%, 5% and 1% respectively
HST stands for Hermetic storage technologies in maize

Access to credit was low, as reported by 31% of respondents. The major sources of credit (42%) were from village saving associations (VSAs) (42%), cooperatives (37%), friends and family (12%), and 8% from banks and other financial institutions. The farmers decried the high interest rates on bank loans and irregular cash flow from farming because of the seasonal nature of production, making monthly loan payments untenable. It is in line with the 2017 Agricultural Household Survey that revealed that countrywide, only 4.7% of households had at least one household member who requested an agricultural loan (Table 3.1).

The average area under maize farm was 0.47 hectares. On average, HST adopters had significantly more land under maize than non-adopters (Table 3.2). However, the average land size under maize was smaller than the national agricultural land average of 0.6 (NISR, 2018). Refering to Table 3.1, probably as a result, more (12%) HST non-adopters bought maize within the season than adopters (6%), suggesting the latter was more self-sufficient in maize than the former. Similarly, the average quantities of maize produced and stored were significantly higher among the HST adopters compared to non-adopters. It suggests that in terms of maize production, HST adopters were better off relative to non-adopters (Table 3.2).

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Table 3. 2: Summary statistics of socio-demographic characteristics of hermetic storage technologies adopters and non-adopters in Gatsibo District, Rwanda(Cont'd)

Variables	**Mean**			**2-tailed t-test**
	Adopters n = 122	**Non-Adopters n = 179**	**Overall n = 301**	
Size of maize plot (Ha)	0.54 (39.69)	0.42 (33)	0.47 (36.3)	3.02***
Quantity of maize produced (Kg)	757.3 (264)	658.3 (291.4)	698.4 (284.4)	3.006***
Quantity of stored maize (Kg)	232.3 (182)	187.2 (142.21)	205.5 (160.8)	2.41***
Distance home- input provider (Km)	1.57 (1.35)	1.86 (1.45)	1.73 (1.4)	- 1.67**
Off farm income in (USD)	58 (150.9)	43.3 (102.7)	49.3 (124.5)	1.002
Other crops plot number	4 (2.86)	3.2 (2.49)	3.5 (2.7)	2.44***
Age of household head(Years)	48.2 (11.87)	45.7 (11.96)	46.7 (12.00)	1.79**
Year of schooling-household head	6.07 (3.52)	5.67 (3.47)	5.83 (3.50)	0.96
Size of household (Number of members)	5.17 (2.13)	4.45 (2.01)	4.74 (2.10)	2.98***
Experience- maize production (Years)	11.52 (9.44)	10.15 (8.2)	10.7 (8.70)	1.34*
Maize income (USD)	61.8 (53.12)	49.8 (44.23)	54.67 (49.82)	2.41***

*, **, *** significant at 10%, 5% and 1% respectively. Standard deviations are in parentheses; 1plot = 0.03ha
USD stands for United States of America dollar

HST stands for Hermetic storage technologies in maize

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Figure (3.3) presents various maize storage technologies commonly reported by maize farmers in Gatsibo District. Polypropylene sacks with chemicals were the most popular, followed by polypropylene sacks without chemicals and hermetic bags. Considering HST, i.e., silos and hermetic bags, 41% of farmers had adopted at the time of the survey against 37% nationally (OAF, 2014), showing that HST is getting attention in Gatsibo District. The fact that 59% of farmers did not use HST suggests the need for much more effort to facilitate the adoption of HST in Gatsibo District, Rwanda.

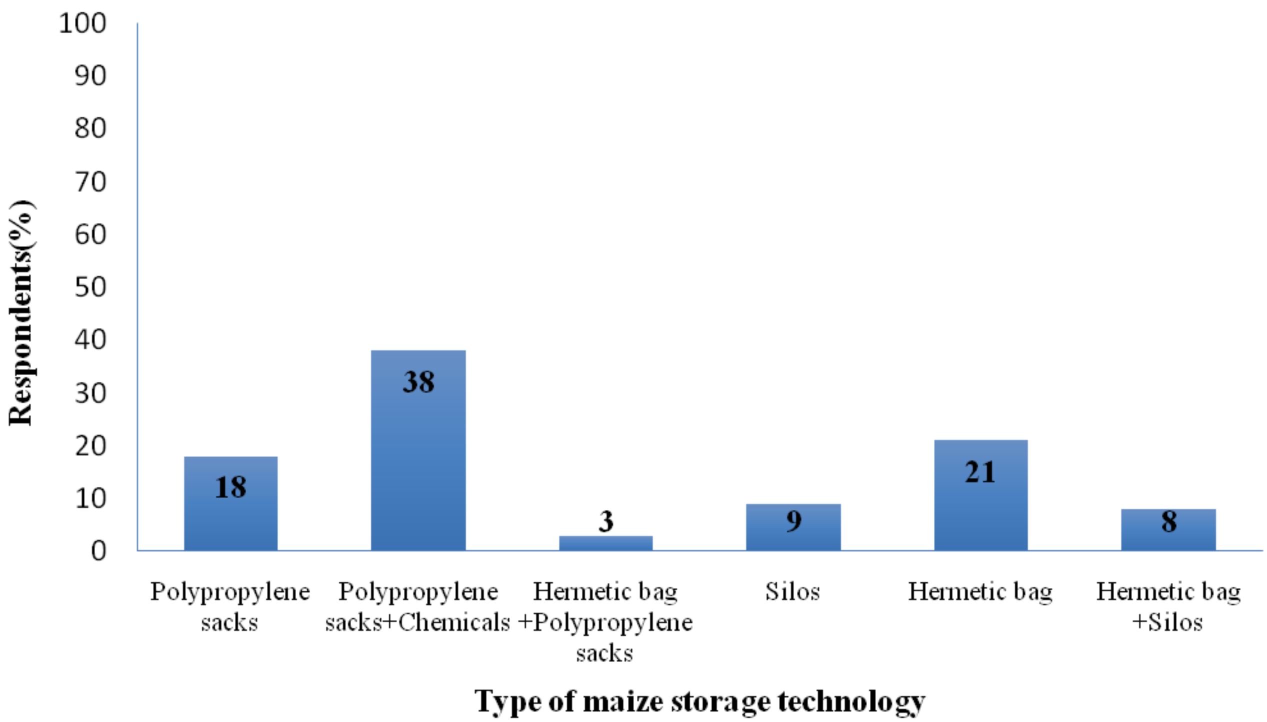

Figure 3. 3: Alternative maize storage technologies used by smallholder farmers in Gatsibo District, Rwanda

[1] Benimana, G. U., Ritho, C., & Irungu, P. (2021). Assessment of factors affecting the decision of smallholder farmers to use alternative maize storage technologies in Gatsibo District-Rwanda. *Heliyon*, *7*(10), e08235. Available from: https://doi.org/10.1016/j.heliyon.2021.e08235

3.3.2 Potential substitutability between alternative maize storage technologies

The specific objective of this paper was to assess the factors affecting smallholder farmers' decision to use alternative maize storage technologies. To accommodate the four alternative technologies identified, the multivariate probit model (MVP) was applied. The appropriateness of the model was assessed by considering the pairwise correlation between error terms of the adoption equations first (Table 3.4). The correlation coefficients were found to be statistically significant, implying that the decision to use one specific maize storage technology affects his likelihood of using the other maize storage technologies.

Table 3. 3: Pairwise correlation coefficients of the error terms of the adoption equations of the four maize storage technologies used in Gatsibo District, Rwanda

Technology	Polypropylene sacks	Polypropylene sacks and chemicals	Silos	Hermetic bags
Polypropylene sacks	1.00			
Polypropylene sacks and chemicals	-0.43*** (0.00)	1.00		
Silos	-0.22*** (0.00)	-0.4*** (0.00)	1.00	
Hermetic bags	-0.32*** (0.00)	-0.46*** (0.00)	0.14** (0.02)	1.00

Numbers in parenthesis are p-values; *p < 0.1, **p < 0.05, ***p < 0.01

Source: Author's analysis of household survey data, 2019

The correlation between hermetic and non-hermetic maize storage technologies was negative and statistically significant, showing the potential substitutability between the two groups of storage technologies. Thus, the promotion of HST is likely to reduce the use of non-hermetic storage technologies among maize farmers if the right conditions, including pricing, affordability, and availability, are provided.

[1] Benimana, G. U., Ritho, C., & Irungu, P. (2021). Assessment of factors affecting the decision of smallholder farmers to use alternative maize storage technologies in Gatsibo District-Rwanda. *Heliyon*, *7*(10), e08235. Available from: https://doi.org/10.1016/j.heliyon.2021.e08235

There is also a positive correlation between hermetic bags and silos, implying that they are complementary (i.e., silos and hermetic bags, are perceived by farmers to work well together). About 8% of farmers who used both silos and hermetic bags noted that hermetic bags are preferred for short-term storage of smaller quantities of maize. Silos are also used for the long-term storage of large quantities of maize (above 100Kg). This finding is consistent with that of Alemu *et al.* (2021), who revealed that the selection of a specific hermetic storage technology to use depends on its storage capacity. The preference is rational because it avoids repeated breaking of the hermetically sealed silos, which reduces the risk of fungal growth and aflatoxin contamination, especially in warm and humid storage environments. According to Villers *et al.*(2008), uncompromised hermetic seals ensure that the moisture levels in the silo remain constant, preventing fungal growth.

3.3.3 Factors influencing smallholder farmers' choice of alternative maize storage technologies in Gatsibo District of Rwanda

The Multivariate probit results are shown in Table 3.4, got referring to the system of equations (5), which revealed that the MVP model fitted the data well (Wald χ^2 = 248.12; p = 0.0000). Since the Likelihood Ratio Chi-Square value (χ^2) (6) = 134 was significant at $p< 0.01$, we reject the null hypothesis that the covariances of the error terms in the adoption equations are not correlated. It implies that farmers' decision to adopt one technology affects the decision to adopt other technologies. It leads to the conclusion that the results of the multivariate regression are more reliable compared to results from separate univariate regressions. In the following discussion of the results, the effect of a variable on the decision to adopt different storage technologies is considered statistically significant if it is at the 10% significance level or lower, as stated in the table.

Among the socio-demographic characteristics, gender of the household head, family size, and years of schooling of the household head had a significant effect on farmers' choice of alternative maize storage technologies in Gatsibo District. Male-headed households were 12% more likely to use polypropylene sacks with chemicals but 13% less likely to use silos,

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implying that female-headed households were more likely than male-headed ones to use silos. Since silos avail longer-term chemical-free storage for maize, they complement the caregiving role and household food security concerns of women in the area. This finding contradicts that of Gitonga *et al.* (2015), who found that the sex of the household head had no significant effect on the adoption of grain silos.

The results in Table 3.4 below show that an increase in family size decreased the probability of choosing polypropylene sack with chemicals by 11% but increased the likelihood of choosing silos by the same margin. This is consistent with the higher food and income needs of larger households, as silos can store more maize and ensure its safety for a long time without requiring the use of chemicals (Hodges *et al*., 2011). It also points to household efforts to avoid the use of chemicals for maize storage, which is not only expensive but also perceived as detrimental to human health (Umubyeyi & Rukazambuga, 2016).

The number of years of formal schooling by the household head decreased the probability of using polypropylene sacks with chemicals by 6% but increased the probability of using polypropylene sacks without chemicals by 9%. This is because more educated farmers can seek, read, and interpret health-related messages more effectively relative to their uneducated counterparts. Therefore, they are more aware of the side effects of different chemicals used in maize storage on health. This result is supported by the fact that 54% and 24% of farmers who used polypropylene sacks with chemicals used malathion dust and phosphine (fumigant tablets) respectively. It is worth noting that 22% of farmers stated that they often used unauthorized chemicals like Dichlorodiphenyltrichloroethane (DDT). It is an example of a chemical, which is no longer recommended for stored-grain pest control, as it is classified as a health hazard (RAB, 2018). Markets which enforce stringent quality standards rejected maize that has been stored using this chemical, deeming it to be of lower quality. This finding is like that of Gitonga *et al*. (2015), who observed that an increase in the number of years spent at school by the household head increased the likelihood of adopting storage technologies that maintain the quality of stored maize and do not require the use of chemicals.

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Table 3. 4 Maximum likelihood estimates of factors influencing smallholder farmers' choice of alternative maize storage technologies in Gatsibo District, Rwanda

	Polypropylene sacks alone			**Polypropylene sacks & chemicals**			**Silos**			**Hermetic bags**		
Variables	**COEF.**	**R.SD**	**MFX**	**COEF.**	**R.SE**	**MFX**	**COEF.**	**R.SE**	**MFX**	**COEF.**	**R.SE**	**MFX**
Household characteristics												
Age of household head	0.55	0.37	0.12	-0.32	0.34	-0.1	0.4	0.4	0.07	-0.6	0.37	-0.16
Sex of household head (1 = Male)	-0.07	0.2	-0.016	0.4*	0.2	0.12	-0.7***	0.26	-0.13	-0.2	0.22	-0.05
Family size (number)	0.07	0.2	0.01	-0.33*	0.2	-0.11	0.6**	0.25	0.11	0.3	0.2	0.08
Schooling of household head (Years)	0.4***	0.14	0.09	-0.2*	0.12	-0.06	0.09	0.15	0.02	0.016	0.16	0.004
Off farm Income (USD)	-0.02	0.05	-0.004	-0.012	0.05	-0.004	0.08	0.056	0.01	0.02	0.05	0.06
Buying maize(1 = yes)	0.15	0.3	0.03	0.3	0.33	0.1	0.03	0.44	0.01	-0.2	0.4	-0.05
Institutional characteristics												
Access to training (1 = Yes)	-0.51**	0.21	-0.11	-1.1***	0.19	-0.35	1.8***	0.34	0.32	1.4***	0.24	0.4
Access to credit (1 = Yes)	-0.42*	0.23	-0.1	0.3	0.21	0.1	-0.8***	0.3	-0.15	0.5**	0.21	0.14
Agri-group membership (1 = Yes)	-0.62**	0.3	-0.14	0.43	0.3	0.14	0.5	0.35	0.1	-0.3	0.3	-0.08
Farm characteristics												
Other crop plot number	-0.11	0.19	-0.02	-0.13	0.7	-0.4	0.33*	0.2	0.06	0.37**	0.18	0.1
Quantity of maize (Kg)	-0.3*	0.16	-0.07	0.02	0.14	0.007	0.15	0.22	0.03	0.22	0.17	0.06
Distance from hhd to input market (Km)	0.22	0.14	0.05	0.21**	0.1	0.07	-1.36***	0.13	-0.07	-0.13	0.1	-0.036
Selling maize soon after it dries (1 = Yes)	1.32***	0.32	0.3	-0.2	0.2	-0.06	-0.31	0.26	-0.06	-0.34	0.22	-0.09
Constant	-2	1.54	-0.44	2	1.5	0.66	-5.8***	2.1	-1	-1.1	1.7	-0.32
Log likelihood	-454											
Wald Chi2(χ2)	248.12***											
Likelihood ratio test χ2(6)	134***											

***, **, * represent statistical significance at 1%, 5%, 10% respectively. **COEF:** Coefficient; **RSE:** Robust standard Errors, **MFX:** marginal effect; **hhd:** Household**; Agri:** Agricultural; 1plot = 0.03ha; n **=** 301

[1] Benimana, G. U., Ritho, C., & Irungu, P. (2021). Assessment of factors affecting the decision of smallholder farmers to use alternative maize storage technologies in Gatsibo District-Rwanda. *Heliyon*, *7*(10), e08235. Available from: https://doi.org/10.1016/j.heliyon.2021.e08235

Among the institutional factors, training on post-harvest handling and storage of grain reduced the probability of choosing polypropylene sacks with and without chemicals. However, it increased the probability of choosing silos and hermetic bags by 32% and 40%, respectively. This can be taken as evidence that training on post-harvest handling and storage of grains increased farmer awareness of the importance of hermetic maize storage technologies in Gatsibo District. These results are consistent with the findings of Kisogo (2018), who revealed that the selection of hermetic bags and silos have been influenced by access to training while reducing the probability of using Sulphate bags. These results support the conclusion of Kassie *et al.* (2015) that certain knowledge and skills (imparted during post-harvest handling and storage training) are necessary at the initial introduction of the technology as for its continued use.

Access to credit had a positive and significant effect on the probability of a farmer choosing hermetic bags. A shift from credit no-access to access would increase the choice probability by 14%. However, it would reduce the probability of choosing polypropylene sacks without chemicals by 10% and silos by 15%. This could be since farmers who had access to credit get the financial means to purchase hermetic storage technologies to reduce storage losses. The average price of a hermetic bag and a polypropylene sack was 1400 RwFr (1.6 USD) and 300RwFr (0.33USD), respectively, which is affordable by Rwandese standards. During the survey, farmers intimated that at 83,500 RwFr (92.6 USD), a 500kg silo was too expensive for them to afford, particularly given that the average credit amount received by farmers was RwFr 23,403 (USD 26). The positive role of credit access to technology adoption observed in this study is consistent with Teklewold *et al.* (2013), who reported that liquidity-constrained households are less likely to adopt sustainable agricultural practices and technologies which require investment beyond their means. This result is also in line with Adegbola (2010), who found that access to credit reduced the probability of adopting improved wooden granary in Benin.

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Membership in farmer groups decreased the probability of choosing polypropylene bags without chemicals by 14%. It suggests that membership in a maize farmer group exposed farmers to information about different advanced storage technologies, reducing their inclination to use polypropylene sacks without chemicals and motivating them to use storage technology that reduces storage losses. This finding is consistent with the argument advanced by Teklewold *et al.* (2013) and Shiferaw *et al*. (2006) that social network (membership in farmer group or association) enhances the uptake of technological innovations through the mobilization of resources and information sharing.

The number of plots allocated to other crops had a positive and significant effect on the probability of choosing silos and hermetic bags. An additional plot committed to other crops would increase the likelihood of choosing the two technologies by 6% and 10%, respectively. Most likely since the household has food alternative, the amount of maize harvested will be used over a longer period of time and hence the need for effective storage. This result allies with that of Gitonga *et al*. (2015), who observed that the increase in farm size influenced the adoption of HST in Kenya. Maonga *et al.* (2013) also found that farmers with large farm sizes were likely to adopt advanced storage technologies in Malawi.

Distance to input markets had a positive and significant effect on the use of polypropylene bags with chemicals. A 1km increase in the distance to the input provider would increase the probability of choosing polypropylene sacks and reduce that for choosing silos by 7%. The farmers complained that, unlike polypropylene sacks and chemicals, silos were not available in the nearest input markets. Therefore, an increase in transaction cost associated with the transport and search for information to acquire silos over longer distances is a plausible explanation for them choosing polypropylene bags with chemicals found in the nearest input markets. These results are consistent with those of Owach *et al*. (2017), who found that farmers near (42%) the input market were more informed and more likely to use silo and hermetic bags in Northern Uganda.

[1] Benimana, G. U., Ritho, C., & Irungu, P. (2021). Assessment of factors affecting the decision of smallholder farmers to use alternative maize storage technologies in Gatsibo District-Rwanda. *Heliyon*, *7*(10), e08235. Available from: https://doi.org/10.1016/j.heliyon.2021.e08235

Selling maize soon after it dries had a positive effect on the use of polypropylene bags without chemicals. A smallholder farmer who sells his/her maize soon after drying is 30% more likely to use polypropylene sacks. Such farmers hardly store their maize for any length of time; therefore, polypropylene bags meet their needs and are easily affordable. This result is consistent with that of Bokusheva (2012), who reported that farmers who sold their maize immediately after harvest were more likely to use polypropylene sacks as they did not have a plan to store them for a long period. Similarly, Gitonga *et al.* (2015) found that non-adopters of hermetic maize storage technologies sold most of their maize immediately after harvest, with the quantity consumed at home being higher than that sold.

3.4 Conclusion

This study sought to determine factors affecting the adoption of alternative storage technologies by using the multivariate probit model. The results show that polypropylene sacks, chemicals, hermetic bags, and grain silos are the commonest storage technologies used by smallholder maize farmers in Gatsibo District. Despite government and donor support, only 41% of the respondents had adopted hermetic maize storage technologies at the time of this study. Hermetic and non-hermetic maize storage technologies had potential substitutability, suggesting that the promotion of HST is likely to reduce the use of non-hermetic storage technologies among maize farmers if the right conditions, including pricing, affordability, and availability, are provided. Hence, the adopters of hermetic maize storage technologies differed significantly from non-adopters in terms of their socio-economic characteristics.

The model results revealed that the probability of choosing polypropylene sacks with and without chemicals increased with the household head's years of schooling, his/her gender, selling maize before it dries, and the distance to the input provider. while it decreased with access to training in post-harvest handling and storage, access to credit, group membership, and household size. It suggests that policies facilitating farmers' easy access to input markets, credit and training related to post-harvest and storage loss reduction are recommended to help farmers abandon inadequate storage technologies.

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Farmers' choice of silos and hermetic bags, both of which are hermetic maize storage technologies, have been positively influenced by household size, training in post-harvest handling, and storage. Thus, it has been negatively affected by the sex of the household head and the distance to the input provider. Therefore, there is a need to facilitate maize farmers' access to information on post-harvest handling and storage by investing in capacity building and technical support to farmer groups. There is the need to enhance easy access to maize storage technologies, such as hermetic bags and silos through smart subsidies (e.g., grants, and discounted charges for vulnerable farmers) to facilitate their wide adoption.

The number of plots allocated to other crops positively influenced the probability of choosing hermetic storage technologies. There is, therefore, the need to promote crop diversification practices to help farmers increase the quantity of maize stored by complementing it with other crops. It will not only contribute to household food security but also income. If this were to happen, it would motivate farmers to use advanced storage technologies to secure their stored maize.

[1] Benimana, G. U., Ritho, C., & Irungu, P. (2021). Assessment of factors affecting the decision of smallholder farmers to use alternative maize storage technologies in Gatsibo District-Rwanda. *Heliyon*, *7*(10), e08235. Available from: https://doi.org/10.1016/j.heliyon.2021.e08235

CHAPTER FOUR: IMPACT OF ADOPTION OF MAIZE HERMETIC STORAGE TECHNOLOGIES ON SMALLHOLDER FARMERS' INCOME IN GATSIBO DISTRICT

Abstract

Rapid population growth has resulted in increased demand for food while some studies have revealed that more than one-third of the global food production is lost through postharvest operations along food supply chain. Managerial and technical limitations such as a lack of proper storage facilities, and food handling practices are among the main causes of food losses. Maize is among the important staple and cash crops in most of sub-Saharan Africa. In Rwanda, most of the maize produced incur losses at storage level. Hermetic storage technologies (HST) are proven to be effective in the control of post-harvest storage losses in maize. However, the adoption of hermetic maize storage technology (HST) has been low and farmers keep using non-advanced storage technologies. Therefore, this study aimed to assess the impact of hermetic maize storage technologies adoption, on the income of smallholder maize farmers, using the endogenous switching regression (ESR) model on a random sample of 301 smallholder maize farmers from Gatsibo District of Rwanda who had been selected using a multi-stage sampling technique. The results revealed Household size, training, access to credit, distance to input provider, and the household head's experience in maize production were the major factors influencing farmers' decision to adopt HST. The occupation of the household head, number of plots reserved for other crops, training, household size, age of the household head, and household maize self-sufficiency goal significantly influenced income for both HST adopters and non-adopters. Overall, the adoption of HST had a positive and significant impact on income from stored maize, among those who adopted it. The study recommends that the government of Rwanda and other stakeholders should support the dissemination of HST to facilitate access. Thus, increased access to institutional support services such as training, credit access, and input supply, should be a major part of efforts aimed at promoting the use of hermetic maize storage technologies among smallholder maize farmers, and to increase their effectiveness in improving household income through storage loss reduction.

Keywords: Hermetic Storage Technology, Post-harvest storage losses, Rwanda

4.1 Introduction

Post-harvest crop losses have an impact on global food security. Although, above one-third of food is lost globally in postharvest actions along food supply chain (Hodges *et al*., 2011). State of Food and Agriculture (SOFA) of Food and Agriculture Organization [FAO] 2019, also reported that in 2016 about 14% of the food produced for human consumption in sub-Saharan Africa (SSA) was lost during the post-harvest stage along with the food supply. According to the United Nations [UN], (2017 and FSIN, (2021), food production needs to increase to match the global food demand associated with a rapid increase in the world population growth rate. Meanwhile, Managerial and technical limitations such as lack of proper storage facilities and food handling practices are among the main causes of food losses in SSA (Parfit *et al.,* 2010; Aulakh &Regmi, 2013).

Among resource-poor smallholder farmers in the East-African sub-region, maize is a crucial food staple and cash crop providing them with food, as well as income. It has also consistently been central to household food security for most Africans in general (Tefera, 2012; Kathiresan, 2011). However, a large amount of maize produced has continuously been lost through postharvest operations along the food supply chain. Between 4.3 and 11.2% of produced maize are lost due to inadequate storage technologies (Gitonga *et al.,* 2013). Farmers store maize to hedge against seasonal food insecurity and attendant price volatility, and to cope with the damage that occurs during storage. Therefore, reducing food losses could contribute to enhancing food security as well as alleviate poverty, particularly in the rural areas of SSA (APHLIS, 2017; Gitonga *et al.*, 2013).

Hermetic storage (sealed storage) like silos, cocoons, and super grain bags has been proven to be advantageous in storage losses reduction compared to traditional storage technologies (Kaminski & Christiaensen, 2014). Hermetic storage technologies have been known to preserve the quality of grain and aesthetic appearance by reducing mould growth (Moussa *et al*., 2014; Murashiki *et al*., 2018). Hermetic technologies work synergistically to promote conditions of low oxygen and high carbon dioxide levels produced by the aerobic metabolism of insects, micro-organisms, and grain respiration. Aerobic metabolism uses up oxygen and produces carbon dioxide to levels that are lethal to insects and moulds in the grain mass (Wareing, 2002).

Thus, it can be an adequate chemical-free alternative to synthetic pesticides, in minimizing maize storage losses under smallholder farming conditions (Chigoverah &Mvumi, 2016). Nonetheless, the impact of these technologies is not accurately estimated, hence further study is required (Kaminski &Christiaensen, 2014).

In Rwanda, a significant percentage of the volume of maize produced incurs losses at the storage level, with rats being the greatest cause of the losses. They account for 2.9% of the 4.9% storage losses in maize alone, followed by insect pests and microorganism infestation (One Acre Fund; 2014). To better address these post-harvest and storage losses, the Rwandan Ministry of Agriculture (MINAGRI) launched the post-harvest handling and storage (PHHS) task force in 2010 with the mandate of advising the government on an appropriate and cost-effective way to minimize post-harvest and storage losses, to be achieved through training and extension services to maize farmers in best practices in post-harvest handling and storage technologies, construction of post-harvest management systems, and the distribution of post-harvest tools and equipment including hermetic storage technologies (MINAGRI, 2016 & 2011).

Hermetic technologies were introduced in Rwanda among smallholder farmers in 2012. Silos and hermetic bags were the most adopted among smallholder farmers. Despite increasing efforts to address post-harvest storage losses among smallholder farmers, through the dissemination of HST, its adoption is still low (World Food Program, 2017; MINAGRI, 2016). In 2014, over 60% of maize farmers in Rwanda were still using polypropylene sacks while another 38.3% applied chemicals, which do not provide an effective barrier against rodents and moisture-related microorganism contamination (Udoh *et al.*, 2000; Hell *et al.*, 2000; One Acre Fund, 2014).

There have been many studies about hermetic maize technology's effectiveness against post-harvest pests in SSA but little information exists on the welfare impact of hermetic maize storage technology compared to other storage technologies used by smallholder farmers (Thamaga-Chitja *et al.*, 2004; Zorya *et al.*, 2011; Brennan, 2017; Affognon *et al.*, 2015). Therefore, this study sought to bridge this gap in knowledge by assessing the impact of hermetic maize storage technology adoption on smallholder maize farmers' income in Rwanda.

The availability of such information is needed among farmers to understand economic benefit of using hermetic maize storage technology, and for policymakers to help maize farmers cope with storage losses and to protect the quality of their stored maize. This study contributes to the United Nations' Sustainable Development Goals (SDGs); goals number one and two that respectively aim at eliminating poverty and hunger and especially SDG target 12(3) which calls for actions to reduce food waste and food loss along production and supply chains (including post-harvest losses) by 2030.

4.2 Methodology

4.2.1 Theoretical framework

The theory underpinning this study is the program or logic that explains the set of cause-and-effect relationships through which a program is thought to work and the outcomes it seeks to affect. This theory also clarifies how an intervention (a project, a program, a policy, a strategy) is acknowledged to facilitate and contribute to a chain of results that produce the intended impacts (Bickman, 2000; Rogers *et al.*, 2000; Donaldson, 2005).

The assessment of an intervention (project, policy, strategy, or program) on an outcome is analogous to identifying the intervention's causal effect (Gertler *et al.*, 2016). However, there are chances that factors other than the intervention, e.g., environment contributed to the outcome. Impact assessment methods, therefore, help to eliminate such possibilities to establish causality between the intervention and the outcome (Rogers and Patricia, 2012; Rogers, 2008). According to Gertler *et al*. (2016), the impact of an intervention, δ, is given by:

$$\delta = (Y \mid P = 1) - (Y \mid P = 0) \qquad (4.1)$$

In equation (4.1), δ is the impact, Y represents the outcome of interest and P is the intervention. The formula implies that the impact δ, of the intervention, P, on the outcome, Y, is given by the difference between the outcome when the intervention is in place, i.e., $P = 1$, and the outcome when there is no intervention, i.e., $P = 0$.

Equation (4.1) measures the outcome of an intervention in two different states, i.e., with and without intervention, for the same unit of observation (either a household or individual), at the same point time.

However, is the impossibility of observing a study subject simultaneously in two different states of nature (i.e., with and without intervention) leads to the counterfactual problem. The counterfactual problem refers to what the outcome would have been for a participant of an intervention (project, program, or policy) had not participated (Heckman *et al.*, 2001). The impact of an intervention cannot be estimated without an estimate of the counterfactual (Gertler *et al.*, 2016).

Estimating the counterfactual requires the use of a comparison group, the so-called "control group" Puhani, (2012). Various methods have been proposed in social science literature for constructing comparison groups to enable the estimation of the counterfactual. These include the "with and without" comparison between subjects that choose to participate and those that do not, and the "before and after" or "pre-post" comparison that compares the outcome of an intervention prior and subsequent to its introduction (Khandker *et al.*, 2009). A "before and after" comparison attempts to establish the impact of an intervention by observing changes in the outcomes for program participants over time (Gertler *et al.*, 2011).

Frequently, the two approaches ("with and without" and "before and after") are combined to take into account the difference in outcome for treated and control groups in an impact evaluation (Goodman-Bacon, 2021). Irrespective of which approach is used to obtain the counterfactual, Gertler *et al.* (2016) argue that there are likely to be unobservable underlying differences between the participants and non-participants of an intervention. For example, those who participate may have a higher motivation than those who do not see their livelihoods improve and may therefore expect a high return from participating, leading to a selection bias problem. Selection bias leads to over-estimation of the impact of the intervention such that the results are not useful for policy prescription (Gertler *et al.*, 2016).

The major methods used for impact evaluation while considering both counterfactual and selection bias problems include randomized evaluation, regression discontinuity design, difference-in-difference, and matching methods. Regarding the scope of this study, difference-in-difference was the ideal method to eliminate selection bias as it allows time-invariant differences in outcomes between the participants and non-participants of an intervention.

Although it requires two sets of data for the pre-treatment period (Conley & Taber, 2011; Heckman *et al.*, 1998) which were not available. Therefore, by taking into consideration this study timeline and available resources, PSM fits well this study, but it has a major limitation of its inability to control selection bias (Imbens, 2015). However, the endogenous switching regression (ESR) model can control this deficiency by simultaneously controlling selection bias and dealing with the counterfactual problem within the difference-in-difference framework (Lokshin and Sajaia, 2014; Di Falco *et al*., 2011; Shiferaw *et al*., 2014; Ngoma, 2018). Hence this study used ESR because of these strengths to evaluate the impact of hermetic storage technologies on smallholder farmers' income.

4.2.2 Conceptual framework

Referring to Fig. (4.1), This study hypothesized different factors that influence farmers' adoption of HST notably; institutional factors, farm, and socio-economic household characteristics anticipating that if smallholder maize farmers have access to and adopt the HST, then they will experience the reduction in maize storage loss, ultimately leading to the increase in the income from stored maize.

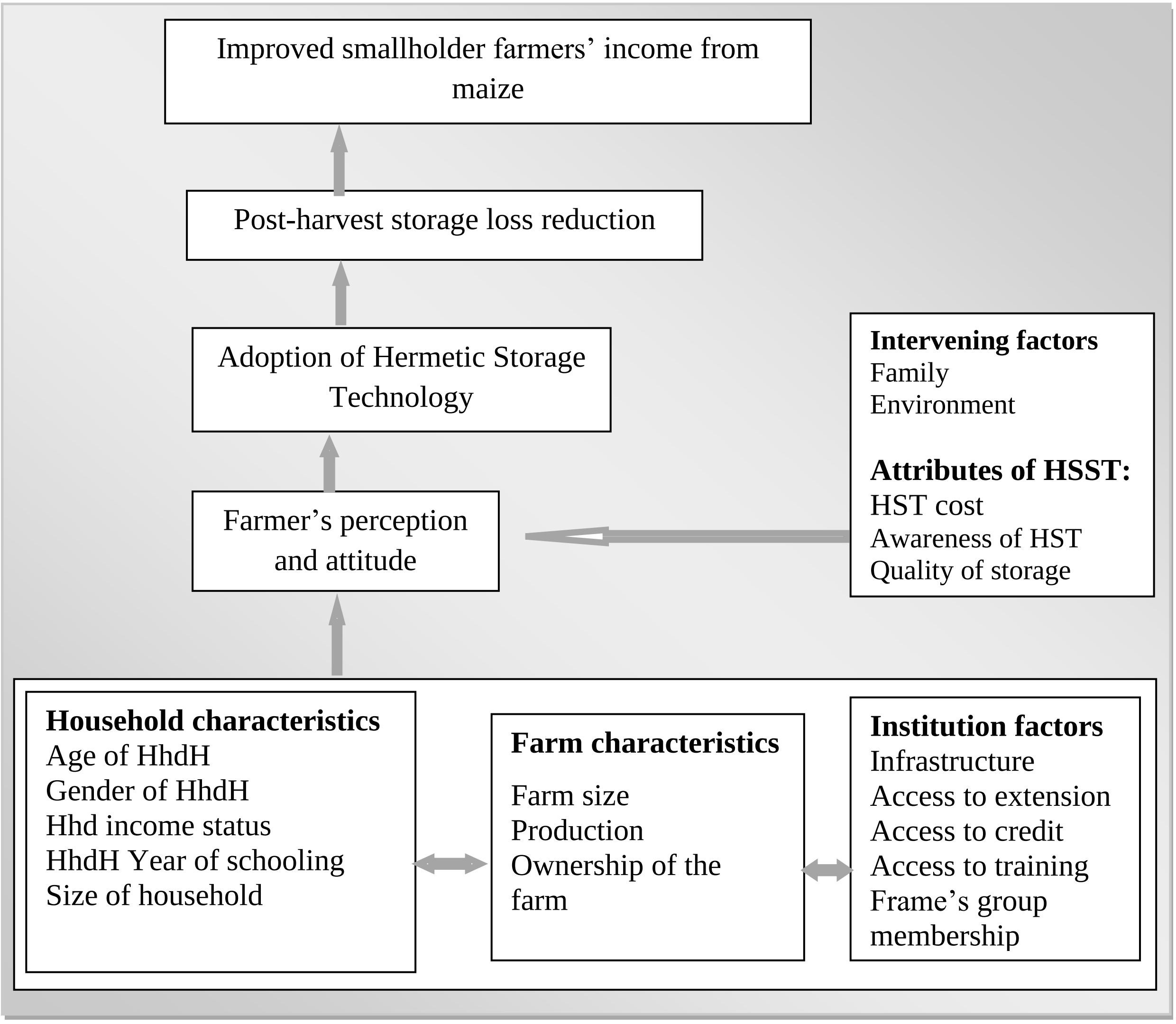

Figure 4. 1: Conceptual framework of the impact of HST adoption on income

4.2.3 Empirical model

A common issue usually faced with impact assessment is selection bias. It is impossible to observe the change in income because of HST adoption. It can only be observed for HST adopters. Therefore, it is unobservable or latent for non-adopters. Therefore, if we were to estimate the change in income because of HST adoption based on observable characteristics of the farmers, then we would get biased estimates (Di Falco *et al.*, 2011; Amare *et al.*, 2012; Khonje, 2015; Shiferaw *et al.*, 2013).

To assess the causal effect of HST adoption on income among smallholder maize farmers, the endogenous switching regression (ESR) is employed. The model addresses selection bias and efficiently estimates the impact of HST adoption using actual and counterfactual outcomes. ESR addresses this problem by including an additional regressor that corrects for the bias in the adoption decision (Missiame *et al*., 2021, Di Falco *et al.*, 2011). The ESR model utilizes conditional expectations in estimating the counterfactual outcomes while controlling for unobserved heterogeneities (Shiferaw *et al.*, 2013). The ESR model is estimated in two stages (Khonje, 2015). The first stage involves the estimation of the decision equation, that is, the farmer's decision whether to adopt HST, using the probit model. In the second stage, two separate equations are estimated as linear regressions for both HST adopters and non-adopters, indicating the factors that affect their income from stored maize.

4.2.3.1 The first stage

The probit model is specified as follows (Wooldridge, 2010):

$$P_i^* = \alpha Z_i + \varepsilon_i \text{ with } \qquad P_i = \begin{cases} 1 & if\ P_i^* > 0 \\ 0, & if\ otherwise \end{cases} \tag{4.2}$$

where P_i^* in equation (4.2) is a latent variable that measures the potential benefit of adopting HST; Z_i is a $n\ x\ j$ matrix of smallholder maize farmer, and farm-level characteristics that affect the HST adoption, α denotes a $j \times 1$ vector of the unknown parameter and ε_i represents a $n \times 1$ vector of normally-distributed error terms. A smallholder maize farmer will adopt HST if the utility of adopting exceeds the gain of non-adopting.

4.2.3.2 The second stage

Conditional on adoption, the separate outcome equations can be specified for both regimes of HST adoption as follows:

$$Y_1 = X_1\beta_i + \varepsilon_1, \quad for \;\; P_i = 1 \quad (Adopters) \tag{4.3}$$

$$Y_0 = X_0\beta_0 + \varepsilon_0, \quad for \;\; P_i = 0 \quad (Non-adopters) \tag{4.4}$$

where Y_1 and Y_0 in equation (4.3) and (4.4) are expected incomes of adopters and non-adopters of HST, respectively; X_j $(j = 0,1)$ are $n\ x\ k$ matrices of covariates; β_j $(j = 0,1)$ is a k × 1 vector of model parameters; ε_j $(j = 0,1)$ is an n × 1 vector of error terms.

Self-selection into HST adopter and non-adopter categories may lead to nonzero covariance in the error terms of the selection equation (4.2), and outcome equations (4.3) and (4.4). This may be because of some unobservable that may influence adoption decisions and may also influence the incomes of the farmers. One of the assumptions of the ESR framework is that the error terms ε, ε_1, and ε_0 follow a trivariate normal distribution, having a zero mean, and a non-zero covariance matrix specified as:

$$cov(\varepsilon, \varepsilon_1, \varepsilon_0) = \begin{bmatrix} \sigma_\varepsilon^2 & \sigma_{\varepsilon\varepsilon_1} & \sigma_{\varepsilon\varepsilon_0} \\ \sigma_{\varepsilon_1\varepsilon} & \sigma_{\varepsilon_1}^2 & \sigma_{\varepsilon_1\varepsilon_0} \\ \sigma_{\varepsilon_0\varepsilon} & \sigma_{\varepsilon_0\varepsilon_1} & \sigma_{\varepsilon_0}^2 \end{bmatrix} \tag{4.5}$$

where σ_ε^2 , $\sigma_{\varepsilon_1}^2$ and $\sigma_{\varepsilon_0}^2$ in equation (4.5) are variances of the error terms in equations (4.2), (4.3), and (4.4), respectively, with σ_ε^2 from the selection equation normalized to 1; $\sigma_{\varepsilon_1\varepsilon}$ and $\sigma_{\varepsilon_0\varepsilon}$ are covariances between ε and ε_1, and between ε and ε_0, respectively. $\sigma_{\varepsilon_1\varepsilon_0}$ represents the covariance between ε_1 and ε_0. It is not defined since the two states Y_1 and Y_0 cannot be observed simultaneously; as a result, when there is selection bias, the expected values of the error terms for HST adopters in eq. (4.3) and non-adopters in equation (4.4), conditional on HST adoption, are given by:

$$E(\varepsilon_1|P_i = 1) = E(\varepsilon_1|\varepsilon > -\alpha Z_i) = \sigma_{\varepsilon_1\varepsilon}\left[\frac{\theta(Z_i\alpha)}{\varphi(Z_i\alpha)}\right] = \sigma_{\varepsilon_1\varepsilon}\lambda_1 \tag{4.6}$$

$$E(\varepsilon_0|P_i = 0) = E(\varepsilon_0|\varepsilon \le -\alpha Z_i) = \sigma_{\varepsilon_0\varepsilon}\left[\frac{-\theta(Z_i\alpha)}{1-\varphi(Z_i\alpha)}\right] = \sigma_{\varepsilon_0\varepsilon}\lambda_0 \tag{4.7}$$

Referring to equations (4.6) and (4.7) θ is the probability density function (PDF) and φ is the cumulative density function (CDF); λ_1 and λ_0 represent the ratio $\theta(\cdot)/\varphi(\cdot)$ for HST adopters and non-adopters, respectively, referred to as the Inverse Mill Ratio (IMR). It provides the correlation between the adoption of HST and maize storage income. Selection bias is controlled for by incorporating the IMR in the outcome equations (4.2) and (4.3). They are re-specified as:

$$Y_1 = X_1\beta_1 + \sigma_{\varepsilon_1\varepsilon}\lambda_1 + \mu_1, \quad for \ P_i = 1 \tag{4.8}$$

$$Y_0 = X_0\beta_0 + \sigma_{\varepsilon_0\varepsilon}\lambda_0 + \mu_0, \quad for \ P_i = 0 \tag{4.9}$$

The model was estimated using the full information maximum likelihood (FIML) estimator. It simultaneously estimates the decision and outcome equations. The FIML was estimated using the *movestay* command in Stata (Lokshin and Sajaia 2004).

4.2.3.3 Estimating actual and counterfactual outcomes

Consistent conditional expectations can be derived, which can be used to compute the actual and counterfactual outcomes for HST adopters and non-adopters. Counterfactual outcomes are the expected incomes for HST adopters had they decided not to adopt. For non-adopters, it is the expected income had they adopted. The conditional expectations for the various outcome scenarios can be derived as follows:

$$E(Y_1|P_i = 1) = X_1\beta_1 + \sigma_{\varepsilon_1\varepsilon}\lambda_1 \tag{4.10}$$

$$E(Y_0|P_i = 0) = X_0\beta_0 + \sigma_{\varepsilon_0\varepsilon}\lambda_0 \tag{4.11}$$

$$E(Y_0|P_i = 1) = X_1\beta_0 + \sigma_{\varepsilon_0\varepsilon}\lambda_1 \tag{4.12}$$

$$E(Y_1|P_i = 0) = X_0\beta_1 + \sigma_{\varepsilon_1\varepsilon}\lambda_1 \tag{4.13}$$

Equations (4.10) and (4.11) are the expected incomes from stored maize conditional on HST adoption, and non-adoption, respectively. Equation (4.12) is the expected income from stored maize for non-adopters had they adopted (counterfactual for non-adopters). Equation (4.13) is the expected income from stored maize for adopters, had they did not adopt (counterfactual for adopters). The average treatment effect on the treated (ATT) measures the gap between the outcomes in equations (4.10) and (4.12). It measures the difference between the incomes from stored maize, adopters earned after adopting, and what they would have earned had they not adopted (Heckman *et al*., 2001; Di Falco *et al*., 2011). The ATT is specified in equation (4.14) as:

$$ATT = E(Y_1|P_i = 1) - E(Y_0|P_i = 1)$$
$$= X_1(\beta_1 - \beta_0) + \lambda_1(\sigma_{\varepsilon_1\varepsilon} - \sigma_{\varepsilon_0\varepsilon}) \quad (4.14)$$

The average treatment effect on the untreated (ATU) measures the difference between the expected outcomes in equations (4.13) and (4.11). It captures the difference between the income adopters would have earned had they had not adopted and what they had by not adopting HST:

$$ATU = E(Y_1|P_i = 0) - E(Y_0|P_i = 0)$$
$$= X_0(\beta_1 - \beta_0) + \lambda_0(\sigma_{\varepsilon_1\varepsilon} - \sigma_{\varepsilon_0\varepsilon}) \quad (4.15)$$

Following Ngoma (2018), the heterogeneity effects are computed using the conditionally expected outcomes in equations (4.10) to (4.13). This is of the essence since HST adopters may have had higher incomes from stored maize compared to non-adopters, not necessarily as a result of adopting HST, but because of unobserved factors. A base heterogeneity (BH) effect measures the difference between equations. (4.10) and (4.13). For adopters (BH_1):

$$BH_1 = E(Y_1|P_i = 1) - E(Y_1|P_i = 0)$$
$$= \beta_1(X_1 - X_0) + \sigma_{\varepsilon_1\varepsilon}(\lambda_1 - \lambda_0) \quad (4.16)$$

And, for non-adopters (BH_2), the difference between equations. (4.12) and (4.11):

$$BH_2 = E(Y_0|P_i = 1) - E(Y_0|P_i = 0)$$
$$= \beta_0(X_1 - X_0) + \sigma_{\varepsilon_0\varepsilon}(\lambda_1 - \lambda_0) \quad (4.17)$$

To assess whether the impact of using HST is higher or lower for farmers that adopted HST had they not adopted, or for farmers that did not adopt HST had they adopted calls for the computation of the transitional heterogeneity (TH) effects. The TH effect equals the difference between BH_1 and BH_2.

$$TH = BH_1 - BH_2 = ATT - ATU \quad (4.18)$$

Table 4. 1: Signs of variables that were expected in this study regarding the adoption of hermetic maize storage technologies.

Variable	Description and measurement	expected sign
HHHAGE	Years lived by household head (No.)	-
EDUC	Years spend in formal education (No.)	+
HHSIZE	Family size (No.)	+
DISMKT	Distance from home to input market (Km)	-
OCPLOT	Other crops plot (No): 1plot = 0.03ha	+
OFINC	Amount of off-farm income (US$)	+
EXP	Experience in maize production (Years)	+
PHHTRAIN	Access to post-harvest handling training dummy: 1 = Yes 0 = No	+
CREDIT	Access to credit dummy: 1 = Yes 0 = No	+
BMAIZE	Bought maize last dummy: 1 = Yes 0 = No	-

4.2.4 Justification for inclusion of regressors in the model

Ngoma (2018) reported that the age of the household head reduces the probability of minimum tillage adoption among smallholder farmers in Zambia. However, Khanal *et al.* (2018) found the age of the household head to have a positive effect on rice yield.

Based on that, this study hypothesized that the age of the household head would have a mixed effect on the adoption of HST and a positive effect on the income of the smallholder farmers in Gatsibo District.

Khanal *et al.* (2018) also reported that the education of the household head positively influenced smallholder farmers' adaptation to climate change, as well as the rice yield. Therefore, this study hypothesized that the number of years spent by the household head on education would have a positive influence on the adoption of HST, and the income of smallholder maize farmers in Gatsibo District. Following the findings of Khonje *et al.* (2015) that household size positively influences the adoption of improved maize varieties, this study hypothesized a similar effect on the adoption of HST, and the income from stored maize.

FAO and WHO (2019), Gitonga *et al*. (2015), Kassie *et al.* (2015), and Maonga *et al.* (2013) reported that off-farm income, access to training, access to credit, and farm size (for other crops), negatively affected the probability of non-HST adoption.

Adetunji (2007), Gitonga *et al*. (2013), and Tesfaye and Tirivayi, (2018) also reported that the same regressors affected positively the probability of adopting HST among maize farmers. Therefore, this study hypothesized off-farm income, access to training, access to credit, and farm size (for other crops) to have a positive effect on the adoption of HST. This study hypothesized that the distance to input providers and buying of maize (representing household maize insufficiency) would have negative effects on the adoption of HST among smallholder maize farmers in the Gatsibo District. This was based on the findings of Teklewold *et al.* (2013) and Bokusheva (2012).

4.2.5 Study Area

Gatsibo District is one of the seven districts that make up the Eastern province the largest, and the second most populous of Rwanda’s fifth provinces. It was selected for this study because of the high adoption rate of Hermetic storage technologies. About 40% of maize farmers supported by the post-harvest handling and storage task force are from Gatsibo District (MINAGRI, 2016).

Therefore, Gatsibo district was selected to better analyze the relationship between adopting HST and income among maize farmers. It borders Nyagatare District in the North, Gicumbi District in the West, Gasabo District in the South-West, Rwamagana District in the South, and Kayonza District in the East (Figure 3.1). Gatsibo District is divided into 14 sectors, 69 cells, and 603 villages. About 89% of the district residents depend on agriculture for their livelihood with maize representing 49% of the total land area under the Crops intensification program, and about 54% of the marketed produce (MINAGRI, 2018).

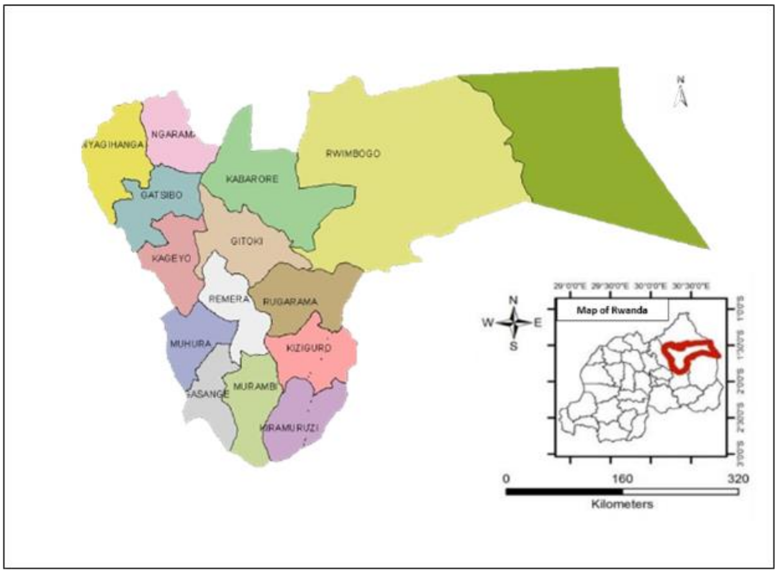

Figure 4. 2: Map of Gatsibo District, Rwanda demonstrating the sectors where the study have been conducted
Source: Gatsibo District (2018)

4.2.6 Sampling and data collection procedures

A multistage sampling technique was used to identify the sampling units. In the first stage, Gatsibo District was purposively selected because of the highest number of smallholder maize farmers that use drying hunger as well as the high adoption rate of Hermetic storage technologies. A list of all smallholder maize farmers in Gatsibo District who used drying hangers was obtained from Gatsibo district administration-Agricultural Division. The list contained 75,000 farmers. In the second stage, 12 cells have been selected referring to the location of drying hungers.

Yamane (1967) formula for calculating a sample size from a known population was selected and used as follows:

$$n = \frac{N}{1+N(e)^2} \quad (4.18)$$

where *n* is the sample size; *N* is the number of farmers using drying hangers in the district, and *e* is the level of precision. Inserting 75000 maize farmers in equation (4.18) and assuming a 95% confidence, and a 5% precision (This study chose a 5% sampling error because (5% sampling error have been chosen because maize farmers live and work near their farmrs, so it was relatively easy to find them during the survey). This study, however, targeted 398 households. Due to the issue of invalid responses and missing data, the study considered only 301 maize smallholder farmers for the analysis.

Figure 4. 3: Maize drying hanger (made of corrugated iron sheet roof and partial walls, concrete floor, and fitted with rows of metal bars from which maize on the cob is hung using the husk)
Source: Agricultural Division of Gatsibo District

The study used interviews and focus group discussion. From 30 April to 14 May 2019, trained enumerators used a semi-structured questionnaire to gather key information on farmers' adoption of hermetic storage technology (HST) in the Eastern province from selected maize smallholder farmers. Smallholder maize farmers who adopted HST were used as the treatment group and those who did not adopt were treated as the control group. The data were analyzed endogenous switching regression (ESR) to assess the impact of hermetic storage technologies on smallholder maize farmers in Gatsibo District in 2019.

4.3. Results and discussion

4.3.1. Factors affecting the adoption of hermetic maize storage technology

Table (4.2) below presents the full information maximum likelihood estimates of the factors affecting the adoption (selection equations: stage 1), and smallholder maize farmers' income (outcome equations for adoption: stage 2), using the endogenous switching regression model. The results of the likelihood ratio test for joint independence of the selection and outcome equations were significant at a 1% level (Chi-square (χ^2) = 40.18), leading to the conclusion that the error terms were normally distributed and the probit model was appropriate for estimating the first stage (the selection equation).

The estimated correlation coefficients ρ_A and ρ_{NA} between the error terms in the selection equation and the outcome equation are negative and significant. This implies that the income for adopters of HST is relatively higher than that of non-adopters. Moreover, as demonstrated in Table(4.2), the negative and significant values of $\rho_{NA}$and ρ_A suggest that there is self-selection in maize HST adoption (Lokshin & Sajaia, 2004; Abdoulaye *et al.*, 2018; Tufa *et al.*, 2019). The significance of the two models as shown by σ_A and σ_{NA} values is additional evidence of the presence of selection bias in the adoption of maize HST and underscores the use of an endogenous switching model to correcting for self-selection.

Table 4. 2: Factors affecting the adoption of maize hermetic storage technologies and Smallholder Farmers' Income in Gatsibo District

Variable	**Stage 1**		**Stage 2**			
	Selection equation		**Outcome Equations**			
			HST Adopters		**HST non-adopters**	
	Coef.	**SE**	**Coef.**	**SE**	**Coef.**	**SE**
Constant	-0.1	1.25	0.94	0.67	-0.47	0.41
Household characteristics						
Household age	-0.53	0.33	0.04	0.17	0.26**	0.1
Year of schooling	-0.13	0.12	-0.02	0.06	0.04	0.04
Family size	0.12	0.16	0.24***	0.09	0.07	0.05
Household head occupation (1 = agriculture)	0.17	0.35	-0.64***	0.15	-0.21**	0.1
Experience-maize production	0.19**	0.1				
Institutional characteristics						
Training access (1= yes; 0 = no)	1.68***	0.22	-0.2	0.21	-0.50***	0.06
Credit access (1 = yes; 0 = no)	0.20*	0.11				
Farm characteristics						
Plot number -other crops	0.05*	0.03	0.03**	0.01	0.02	0.1
Buying Maize (1= yes 0 = no)	0.04	0.31	-0.28*	0.17	-0.01	0.09
Off farm income	0.04	0.04				
Distance input market	-0.20**	0.09				
σA			-0.80***	0.1		
ρA			-0.55**	0.27		
σNA					-0.97***	0.06
ρNA					-2.50***	0.51
Number of observations	301		122		179	
Wald chi2(χ^2)	37.36***					
Log-likelihood	-227.11					
LR test of the independent equation:χ^2	40.18***					

***, **, * represent significance at 1%, 5% and 10% respectively; **HST**: Maize hermetic storage technologies; **A =** adopters, and **NA** = non-adopters; **ρA or NA**is the correlation coefficient for the error terms between selection equation and adoption equation and **σA or NA** is the square root of the variance, 1plot = 0.03ha

The results in Table 4.2 (probit model for adoption) indicate that the likelihood of adopting hermetic maize storage technology increases with the farmer's years of experience in growing maize. A plausible explanation is that farmers with more years of experience have faced the problem of maize storage losses for a long time and are likely to have tried their own solutions that did not work. They are therefore open to new alternatives; as such, they will adopt new technology with the expectation that it will reduce storage losses.

Smallholder farmers who accessed credit were more likely to adopt hermetic storage technologies. This is probably because the price of HST is higher compared to the price of non-HST as maize farmers mention it during interviews and focus group discussion. Therefore, access to credit is crucial in enabling smallholder maize farmers with financial means to adopt. This concurs with previous findings by Gitonga *et al*. (2013), and Tesfaye and Tirivayi (2018) who found that access to credit brings in additional financial means to relax capital or income constraints which ease the use of improved storage technologies. This result is also related to that of Gitonga *et al*. (2015) who reported that access to financial services increased the likelihood of adopting silos.

Smallholder farmers with a larger number of plots allocated to other crops (except maize) are more likely to adopt hermetic storage technologies. Most likely since the household has food alternative, the amount of maize harvested will be used over a longer period of time and hence the need for effective storagl. This result is consistent with that of Gitonga *et al*. (2013) that found that the area of land under cultivation for other crops (maize) increased the probability of adopting hermetic maize storage technologies among smallholder maize farmers in Kenya. Monga *et al*. (2013) also found that land size had a positive impact on the adoption of hermetic maize storage technologies among smallholder maize farmers in Malawi. Ngoma (2018), Ndiritu *et al*. (2014), and Murithi *et al*. (2018) found that land size was positively associated with the adoption of advanced agricultural practices and technologies.

Smallholder maize farmers who live farther away from input providers are less likely to adopt hermetic maize storage technologies. This result was expected given that the increase in both the transportation and other transaction costs act as incentives for maize farmers to choose substitutes for hermetic storage technologies.

These results are consistent with those of Owach *et al*. (2017) who revealed that the increase in distance from a household to the nearest local produce market decrease the likelihood of adopting improved storage structure in Northern Uganda. Teklewold *et al.* (2013) also found that distance to the input market decreased the probability of adopting improved seeds in rural Ethiopia.

4.3.2 Determinants of smallholder maize farmers' income from maize

Results in Table 4.2 (results from outcome equation) indicate that an increase in the age of the household head increased non-adopters income. Therefore, taking age as a proxy for experience, experienced smallholder farmers are more likely to be knowledgeable and proactive about the problem and potential solutions for postharvest storage losses, as a result, their income from maize is likely to increase. This result is consistent with the findings of Kassie *et al*. (2015) who found that older farmers with longer farming experience have experienced prolonged maize losses, therefore they have more experience in loss reduction, and consequently the income they obtain from selling the stored maize. However, this finding contradicts Gitonga *et al*. (2013) who found that farming experience decreased the likelihood of adopting hermetic maize storage technology in Kenya.

The results indicate that an additional household member increased adopters' income. This is intuitive as a larger household size calls for more secure maize storage and income. Conteh *et al.* (2015) in their study conducted in Sierra Leone revealed that they were a positive correlation between household size and HST adoption as hermetic storage technologies are labor intensive suggesting that large family will serve as human labor to facilitate HST adoption. Thus, the adoption of HST secures large households with consumption and good market prices during off-season periods. Although, this finding contradicts that of Gitonga *et al*. (2013) who found that household size does not affect the hermetic storage adopter's income.

The results in Table 1. also suggest that engaging in agriculture as a primary occupation decreases income from maize for both adopters and non-adopters. This result was not expected; however, a possible explanation is that having other main occupation aside from agriculture brings in additional income resources that reduce capital or income constraints.

Farmers are likely to concentrate their efforts on the other occupations that serve as an immediate source of income. Hence, farmers will allocate less time to the post-harvest handling of maize, since storing maize delays the income. It may discourage the adoption of improved storage technologies, consequently reducing the income they may get from storing maize with HST. This result is in the same line with the World Bank Group (2015) study which revealed that having a household head who had agriculture as the main occupation was positively associated with household poverty in Rwanda.

Access to training about maize postharvest handling and storage decreases non-adopters income. This result was expected since information about the risks of storing maize in non-advanced storage technologies prompted non-adopters to sell their stored maize earlier often at lower prices in other to cope with storage losses. These results are consistent with the findings of Conteh *et al.* (2015) that showed that farmers who had access to information tend to sell their maize earlier to avoid huge storage loss in the future that may be delivered from inadequate storage technologies.

An increase in the number of plots allocated to other crops (except maize) increased the income for adopters. A possible explanation for this result may be that the number of plots as a proxy for land size, contributes to the production of agricultural produce that complements maize in a household. It may also produce extra income which may help farmers to acquire HSTs, consequently leading to a reduction in maize storage- losses, and an increase in income they would get from selling the maize. This result is consistent with the findings of Gitonga *et al*. (2013), and Maonga *et al*. (2013) who found that land under cultivation (but not in maize) increased the probability of adopting hermetic maize storage technologies. The result further indicates that not being self-sufficient in maize decreases adopters' income from stored maize. A likely explanation is that when a household is not self-sufficient in maize, there will not be much maize to store and the income from stored maize may be used to buy maize for consumption. Therefore, their income from stored maize is likely to decrease. This result concurs with previous findings by Gitonga *et al*. (2015) who found that farmers who are not self-sufficient are less likely to adopt hermetic maize storage technologies.

4.3.3 Impact of adoption of HST on smallholder maize farmers' income in Gatsibo District

The ESR model allowed the estimation of the impact of hermetic maize storage technologies adoption on smallholder maize farmers' income in Gatsibo District. The expected income from under actual and counterfactual scenarios are presented in Table 4.3.

Table 4. 3: Impact of adopting HST on smallholder maize farmers' income in Gatsibo District: actual and counterfactual net income from stored maize

Outcome variable	*n*	Sub-sample	Decision		Treatment effect		% change
			To adopt	**Not to adopt**			
Income from maize (USD)	122	HST adopter	61.52 (2.22)	-12.63 (1.3)	ATT	74.15*** (1.33)	
	179	Non-adopter	90.40 (1.9)	52.5 (1.32)	ATU	37.9*** (1.23)	
					TH	36.25*** (1.8)	A = 49%
					ATE	9.02*** (2.43)	

***, **, * represent statistical significance at 1%, 5%, 10% respectively; standard error in parentheses, ATT: Average treatment on the treated; ATU: average treatment on untreated; TH: Transitional heterogeneity effect; ATE: Average treatment effect; A = 100*TH/ATT

From the results in Table 4.3, the ATE is positive. This implies that income for adopters was higher by US$9.02 than the income for non-adopters. The ATT was also positive, showing that income from maize for adopters was US$74.15 more than the income non-adopters would have earned, had they adopted. The ATU was also positive implying that the income of HST adopters, if they did not adopt, was US$37.9 higher than the income of non-adopters. By comparing ATT and ATU, the transitional heterogeneity (TH) was positive, implying that there are systematic differences among smallholder maize farmers. HST adopters had an income of US$36.25 higher than the income of non-adopters, suggesting that adopters were better off compared to non-adopters. This result is consistent with the findings of Kimenju and De Groote (2010) who revealed that storage with hermetic maize storage technology records the highest gain compared to non-hermetic in Kenya.

Gitonga *et al*. (2013) also found that the adoption of metal silos significantly reduced storage loss, where losses for non-use were very high compared to non-user. Sissinto *et al*. (2021) study indicated that the most profitable storage technologies were the PICS bag (Hermetic bag) with treatment in the center of Benin.

The result is consistent with the findings of Shukla *et al*. (2019) which revealed that access to hermetic storage increases maize income as it allows smallholder farmers to sell their maize at higher prices in India. Kotu *et al.* (2019) also showed that the use of PICS bags addressed food security and income objectives among poor rural households, while metal silos increased the income of farmers who sold surplus grain in Tanzania.

4.4 Conclusion

The objective of this study was to assess the impact of hermetic storage technologies adoption on smallholder maize farmers. The results showed that adopters of hermetic maize storage technologies had higher incomes than their counterparts. The gains due to adoption were US$36 for a farmer who adopted HST within 6 months of agricultural season A (Starting from September to March), which implies that the adoption of hermetic maize storage technologies significantly increased income from maize. Thus, promoting the use of hermetic storage technologies among smallholder maize farmers would increase household income through storage loss reduction. In addition, the results revealed that adopters and non-adopters of hermetic maize storage technologies differed in terms of their socio-economic characteristics. These results point to the need for widespread adoption to enable more farmers to benefit from the technology. It can be done by addressing the factors that influence the adoption of hermetic maize storage technologies.

The study found that experience in maize production and access to training on post-harvest handling and storage increased the likelihood of adopting HST. This implies that strategies enhancing all categories of farmers' access to information and HSTs to make maize hermetic technologies attractive are crucial. Distance from the household to the input provider reduced the probability of adopting HST among maize smallholder farmers. Therefore, policies that involve the reduction of transaction costs related to accessing those technologies are important for suitable adoption. Access to credit was found to increase the adoption of hermetic maize storage technologies. Therefore, the effort is needed to avail and make it easier for smallholder maize farmers to access credit. Number of plots allocated to other crops increased the adoption of HST implying that there is a need to promote HSTs adoption and educate farmers about the benefits of crop diversification. This will provide additional income to relax farmers' capital constraints regarding their access to hermetic maize storage technologies.

CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSION, AND RECOMMENDATIONS

5.1. General Discussion

Maize is an important staple food and cash crop in sub-Saharan Africa. In Rwanda, maize consumption has been increasing, and it is becoming central to household food security. However, post-harvest loss of maize along the supply chain is a serious problem. In Rwanda, most of the maize losses occur at the storage level. Hermetic maize technologies (HST) have been shown to be effective in reducing post-harvest storage losses. On that account, there is the need for maize farmers to adopt storage technologies that effectively reduce losses. Therefore, the study sort to characterize different storage technologies used by farmers in terms of the level of adoption and constraints using, and to identify the factors affecting smallholder maize farmers' choice of alternative storage technologies and the impact of hermetic maize storage technologies adoption on household income. The results from this study indicated that the most-used storage technologies among smallholder maize farmers were polypropylene sacks, chemicals, silos, and hermetic bags. Approximately, only 41% of the respondents adopted hermetic maize storage technologies. Hermetic bags and silos were the most hermetic storage technologies adopted among smallholder maize farmers.

The first paper (chapter 3) assessed factors affecting smallholder farmers' decision to use alternative maize storage technologies in Gatsibo District-Rwanda, using a multivariate probit model. The results revealed that the quantity of maize produced, access to training, access to credit, and group membership reduced the use of polypropylene sacks while the education of household heads and selling maize directly after drying increased the use of polypropylene sacks. The use of polypropylene sacks with chemicals reduced with access to training, education of household head and size of the household while it increased with distance to input market and sex of household head.

Number of plots allocated to other crops, access to training, distance to input market and household size increased the use of silos while it decreased with access to credit and sex of household head. The use of hermetic bags increased with access to training, access to credit, and number of plots allocated to other crops.

The paper suggested the need for technical knowledge such as training and education for farmers and policies that increase access to institutional support services, input supply, crop diversification as a major part of any efforts aimed at promoting the use of advanced storage technologies. Efforts should be made to help farmers increase their maize production and returns from it, as higher quantities of maize are consumed or sold over a longer period. Hence, encouraging the use of more effective storage technologies is crucial to help farmers cope with storage losses and price fluctuation.

The second paper (chapter 4) assessed the impact of hermetic maize storage technologies on income among smallholder maize farmers, using an endogenous switching regression (ESR). The results showed that the decision of smallholder maize farmers to adopt hermetic maize storage technologies is increased by household size, access to training, access to credit, the experience of household head in maize cultivation, and the number of plots reserved for other crops while it is decreased by distance to input market. In addition, the results revealed that income from maize, increased with the size of households and the number of plots reserved for other crops, while it reduced with the buying of maize for consumption. Hence, there is a need to enhance policies that facilitate maize production, easy access to training and credit, as well as decentralization of HSTs related inputs among smallholder maize farmers to assure their successful adoption.

The results of ESR also, indicate that smallholder maize farmers who adopted hermetic maize storage technologies had a significantly increase in income from maize compared to their counterpart smallholder maize farmers who did not adopt. Smallholder maize farmers are therefore better off using HST as it decreases storage losses and leads to an increase in income, as demonstrated in this study.

5.2. Conclusion

This study identified impact of adopting HST on income and factors influencing choice of storage technologies among maize smallholder farmers in Gatsibo District of Rwanda. The results revealed that there is an increase in income through the adoption of hermetic maize storage technologies. Hence, enhancing easy access to HST by disseminating and possibly subsidizing HST to enable more farmers access to those technologies is highly recommended.

In addition, the results showed that adopters and non-adopters of hermetic maize storage technologies differed in terms of their socioeconomic factors. Access to training was among the important factors that determined the farmers’ choices of storage technologies. Therefore, any policies aiming to facilitate maize farmers’ access to information on postharvest handling and storage, like the capacity building of farmers and farmer field schools, would increase HST adoption.

Experience in maize production and distance to the input provider were among the major factors that contributed to the adoption of hermetic maize storage technologies. Therefore, strategies to reduce transaction costs related to those technologies access, like improvement of transport infrastructure and input availability to all farmers, are crucial and needed. Access to credit also contributed to the adoption of hermetic maize storage technologies. Therefore, the effort is needed to avail and ease access to credit. This is important because it will help maize farmers to have additional financial means to relax capital or income constraints related to hermetic maize storage technologies access.

The fact that adopters of HST gained more income implies that there is a beneficial return from investing in HST. However, only 41% of the respondents were using HST. Therefore, effort should be made to upscale the use of HST in Gatsibo District, and to enable farmers to adopt HST to preserve their maize. The latter could be achieved through the provision of smart subsidies, perhaps delivered through farmer cooperatives and savings groups.

5.3. Recommendations

The following recommendations are made:

1. Following the positive effect of training on the decision of smallholder maize farmers to use hermetic maize storage technologies, the police makers and other stakeholders involved in post-harvest handling and storage should increase and disseminate training on hermetic maize storage technologies in Rwanda.

2. Considering the fact that access to credit had a positive and significant effect on hermetic maize storage technologies adoption, this study recommends the policy makers and other stakeholders to provide and ease access to credit for smallholder maize farmers to encourage the adoption of HST.

3. Distance to HST provider had a negative influence on the decision to adopt HST. It is therefore recommended that government, and especially the local government to facilitate farmers easy access to government-subsidized HST as well as improve infrastructure like public dryers and roads to reduce transaction costs.

4. This study revealed that adopting HST increased the income of smallholder maize farmers, therefore further studies on the impact of hermetic maize storage technologies on household food security are suggested to connect the gain in income and food security to formulate further recommendations to improve household welfare. Furthermore, this study demonstrated that the adoption of HST is low and farmers still use non-advanced storage technologies despite government and other stakeholders' efforts, hence this study recommends further study on willingness-to-pay for HST and cost-benefit analysis of using HST among maize farmers in Rwanda.

This research, however, was subject to budget and timeline limitations that have resulted in focusing only on one District among 30 districts of Rwanda. Therefore, this study recommended a study that may represent all regions in Rwanda to provide more research evidence-based that will be applicable in every region of Rwanda for better policy formulation.

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APPENDICES

Appendix 1: Household Survey Questionnaire

HHD NO: [ ]

ENUMERATOR'S NAME:	**DATE:**
CELL:	**VILLAGE:**

SEEKING CONSENT

Good day Sir/Madam,

My name is _____________________ and I'm working with the University of Nairobi, Kenya, which is conducting a research on Impact of Adopting Maize Hermetic Storage Technologies on Smallholder Farmers' Income in Gatsibo District. The objective of the survey is to characterize the alternative maize storage technologies used , assess the factors influencing smallholder maize farmers' decision on the use of alternatives maize storage technologies and to assess the impact of hermetic storage technology adoption on smallholder maize farmers'income in Gatsibo District. The information we are collecting will be used for policy formulation and reform, academic references and it will provide answers and solution to farmers on effective measures to cope with post-harvest storage losses. You are one of the 378 respondents who have been randomly selected from Gatsibo District to participate in this survey. The information captured by this survey will be treated with utmost confidentiality. May I proceed with the interview?

If **NO**, mark **00** here |___|___| and end the interview. **Find a replacement household.**

If **YES**, mark **01** here |___|___| to acknowledge that consent was granted by the respondent

<u>SECTION A: INFORMATION ON HOUSEHOLD HEAD</u>

A1. Are you the head of this household? 1=Yes [ ] 0=No [ ]

A2. If NO, who is the head of the household? _________________________________

A3. ***[ENUMERATOR:*** *If the Respondent is* ***NOT/OR*** *the household head, ask him/her the following questions about the household head]*

Sex of responde	Relationship to HHD	Sex of househol	Age of househol	Marital	Level of formal	Experience in maize	Primary occupatio

nt If not the HHD head (Code A)	head(code B)	d head(code A)	d head	status (code C)	education completed by Household Head (D)	production (no. of years)	n of the household head (code E)

Code A: *1= Female 2= Male*

Code B: *1= household head 2= spouse 3=children 4= relative 5.other (specify)……………..*

Code C: *1= Single 2= Married 3= Separated 4= Widow/widower 5=Divorced 6=Other(specify)…………………*

Code D: *0= None 1= Primary 2= Secondary 3= Tertiary 4= Adult literacy classes 5.Other (specify)…………………*

Code E: *1= Farming 2 = Business person 3= Casual Laborer 4 = Salaried Employee 5= Other (specify)……………………..*

A4. What is the total number of members living in this household..................................?

Household members	**Male**	**Female**
Household members aged below 5 years		
Household members aged between 6 to 14 Years		
Household member aged between 15 to 30 years		
Household members aged between 31 to 65		
Household members aged above 65 years		

SECTION B. FARM CHARACTERISTICS:

B1. Living Environment **1=** Near the farm [ ] **2=**Far from the farm[ ] **3=**Storage technology accommodating [ ] **4=**Other (specify)________________

B2. Farm environment (Erosion and rain vulnerability) **1=** High risk zone[ ] **2=** Moderate[ ] **3=** Low risk zone[ ]

B3. Land ownership (Please fill the table below)

Plot Description	Plot number	Size of this plot (acres)	Tenure system (code 1)	If plot **is *owned,**** who owns (code 2**)**	If rented, rent value (RwFr/year)
Homestead crop					
Cash crop					
Food crop					
Maize crop					
other (specify)					
	Total=________	Total=______			Total=______

code 1	**code 2**
1. = Owned with title 2. = Owned without title 3. = Communal/public 4. = Rented in 5. = Rented out 6. =other (specify)	1. = HH head 2. = Spouse 3. = Joint (HH head & spouse) 4. = Children 5. = Others (specify)

SECTION C: CROP PRODUCTION

C1. Which crops did you grow last season? **(Please complete the table below)**

Crop	Plot1 (plot=0.03ha)	Approximate quantity produced (Kgs)/per plot	Approximate quantity consumed in the household (Kgs)	Approximate quantity sold (Kgs)	Which market?
Homestead	1				
	2				
	3				
Cash crop	1				

	2				
	3				
Food crop	1				
	2				
	3				
Maize crop	1				
	2				
	3				
other (specify)	1				
	2				

C2. Did you use **irrigation** last season? **1=** Yes [ ] **2=** No [ ]

C3. If yes, where did you get the irrigation water? **1=** Well [ ] **2=** Dam [ ] **3=** Stream [ ] **4=** River [ ] **5=**Other (Specify) ________

SECTION D: INCOME SOURCES

D1. Please give the approximate income obtained from each source over the last season.

Income source	**Frequency of receiving income** 1=Daily 2=Weekly 3=Monthly 4=By season 5=Other(specify)	**Approximate Amount over last season (RWF)** ***(Multiply Frequency of receiving income by season months to get seasonal amount)***
Have you sold fish?		
Have you sold Livestock?		
Have you sold livestock (e.g., milk, ghee, hides & skins, etc)		
Have you got any salary from employment?		
Have you earn any wage employment?		
Do you get pension/retirement benefit		
Did you get any remittances?		

Do you earn any income from a business?		
Do you got any household member income contribution?		
Other income source (Specify)		

D2. Who mainly earns/controls income? **1=**HHhead (male)[ ]
2=HHhead spouse (female)[ ] **3=**Family member [**4=** Other specify________________________

D3. How frequently do you receive remittances? ________________________________

D4. From whom do you usually get remittances? ________________________________

D5. How many of the following livestock type do you have NOW?

Species	Total	Number owned	Number not owned
Cattle			
Sheep			
Goats			
Chickens/Fowls			
Other (specify)			

SECTION E: INSTITUTION CHARACTERISTICS

E1.ACCESS TO EXTENSION/TRAING SERVICES

E1.1.Have you received any extension services on maize storage/post-harvest loss (PHL) reduction/technologies? ***1= no ( ) 2= yes ( )*** **if Yes**, proceed with questions in the table below

E1.2. Have you receive any training on maize storage/post-harvest loss (PHL) reduction/technologies? ***1= no ( ) 2= yes ( )*** **if Yes**, proceed with questions in the table below

	What was it about?(Code A)	How were these provided? (Code B)	Which organization/ institution provided it?(Code C)	Starting year	Frequency (last season)	What was the benefit from it? (Code D)

Training						
Extension services						
Code A **1=Maize storage** **2=PHL reduction** **3=Aflatoxin knowledge** **4=others (specify)**		Code B **1=Farm visit** **2=Demonstration** **3=Group training/tour** **4=Field day** **5= Others (specify)**		Code C **1=MINAGRI/PHHS task force/ Government** **2= Peer Farmer Trainers** **3= Private sectors (specify)**		**Code D** 1.Quality maize 2=PHL Reduction 3=Knowledge about advanced technology 4=storage facilities 5=Others (specify)

E2. How far is the storage technology from the farm? ……………………………km

E3. How far is the all-weather road from storage technology? ……………………km

E4. How far is the nearest market from storage technology? …………………… km

E5. How far the nearest maize **inputs provider** from your homestead? **.............**km

E6. How far is the nearest **extension service provider** from your homestead? …....km

E7. How far is the nearest **water source** from your homestead? ………………….km

E8. How far is the nearest **primary school** from your homestead? ………………..km

E9. How far is the nearest **hospital/health center** from your homestead? …………km

E10. ACCESS TO CREDIT

E10.1. Did you receive any type of credit for production during the last season ?1=Yes 2=No

If yes, what was your source of credit? **1= PHHS task force 2= Cooperatives**
3= Microfinance institutions 4= NGO (Specify) ……………………………………
5= Social network (specify) ……………… 6= Other (Specify) ………………..

E10.2. What were the problems in getting credit?

E10.3. How have you used the credit received to improve your storage activities? **1= Buying storage facilities 2=Getting a new storage technology 3= Other (specify)………………**

E10.3. Has using storage technologies (specify) improved your access to credit? **1=Yes 2=No**

If **YES**, in what way(s)? **………………………………………………………………**

E11.GROUP MEMBERSHIP

E11. Have you been a member of any group in the last 12 months? 1= Yes 2= No

If YES, which type of group?(fill the table below)

Type of group **1=**Cooperative **2=** PHH task force **3**=Women group **4=**Social marketing **5=**Input supply/service association **6**=.Other (specify)	**Social network** 1= Yes 2=No	**Position held in this group** 1=Chairman 2=Executive committee 3=Member 4=Other (specify)	**Benefits of belonging to the group(Related to PHL reduction)**

SECTION F.POLICY/ POST HARVEST HANDLING AND STORAGE (PHHS) TASK FORCE

Number	Question	Measure /code	Answer
F1	Are you aware of PHHS task force?	1=Yes 2=No (proceed to F11)	
F2	Are you under PHHS task force?	1= Yes 2= No (proceed to F10)	
	How many years have you been under PHHS task force?		
F3	Which services do you get from PHHS task force?	1.Drying ground 2.Training 3.Storage facilities 4.Common silos 5.Drying hangars/ Warehouse 6. Other (Specify)	
F4	Has participation in PHHS task force improved your access to credit?	1= Yes 2= No	

F5	Has participation in PHHS task force improved your access to extension?	1= Yes 2= No	
F6	Has participation in PHHS task force improved your maize production?	1=Yes (how-specify) 2=No	
F7	Has participation in PHHS task force facilitated you to get access to advanced storage technology?	1=Yes (specify type) 2=No	
F8	What benefits do you get from the PHHS task force program?	1= Storage facilities (Specify) 2.Loans/ Credit 3= Extension Services 4= Markets 5= Other (specify)	
F9	Have you received any storage technology as subsidies from PHH task force	1.Metal Silos 2.PIC bags 3.Other (specify)	
F10	What are the shortcomings of the PHHS task force program?	1=Reaching on part of people 2=late services 3.expensive storage technologies 4.Other (specify)	
F11	What can recommend the government about maize storage?		

SECTION G: MAIZE STORAGE –SEASON B 2018

No	Question	Measurement	Answer
G1	Where do you dry your maize?	1=common drying hangars 2=homestead 3= Other (specify)	
G2	Do you store maize after drying?	1= Yes 2= No –why? Proceed to G13	

G3	Why do you store your maize?	1=To avoid rodent attack 2=To avoid insect pesticide attack 3=To merge season 4=To avoid price fluctuation 4=To avoid aflotoxin/mycotoxin 5=Other (Specify)	
G4	Out of your total maize output, how much was stored last season?(respect to the plots assigned to maize production	1.bags/plot1 2.bags/plot2 3.bags/plot3 4. bags total	1. 2. 3. 4.
G5	How long have you stored your maize last season?	In months	
G6	Out of your total stored maize, how much was sold in last season?	bags	
G7	Which market outlet have you used to sell your maize after storage last season?	1= co-operative; 2 = farm gate; 3= trader; 4= local market ;5= large scale holder; 6 = international market 7 = NGO 8.Other(specify)	
G8	What was the price per kilogram(last season)	RwF/kg	
G9	Have you ever incurred post-harvest storage losses?	1= Yes 2=No (go to E15)	
G10	How much storage losses	Bags	

	incurred in last one year?		
G11	Which was the status of your maize after incurring loss?	1= Grain damages 2= Aflatoxin/Mycotoxin 3= Reduction in Market value(low selling price) 4= Other (specify)	
G12	What were the main causes of your losses?	1= Rats 2=Pests 3=Fungi 4=poor storage 5=Other (specify)	
G13	Did you buy any maize for home consumption last one year?	1=Yes (how much) 2= No	
G14	Are you aware of advanced storage?	1= Yes (proceed to G15) 2=No	
G15	Which advanced storage technology do you use?	1=None 2=Metal silos 3=plastic silos 4=PIC bags 5=Hermetic bag 6=Advanced granaries 7=Other (specify)	

SECTION H. STORAGE TECHNOLOGIES

KNOWLEDGE, ATTIUDE AND PRACTICES (KAP) ABOUT ALTERNATIVES STORAGE TECHNOLOGIES USED BY SMALLHOLDER MAIZE FARMERS

(In this section the question will be based on the type of storage technologies smallholder maize farmers are using.)

REDUCING STORAGE LOSSES – PRACTICES / SEEKING BEHAVIOR			
Number	**Question**	**Measure/Code**	**Answer**
H1	What do you do usually to reduce storage losses?(last season)	1=Apply chemical 2=Sell the maize after harvest	

		3=Use traditional storage 4=Use advanced storage 5=Other (specify)	
H2	How have you get storage technologies last season?	1= Market 2= NGOs 3= Government 4=Farmers group 4= Other (specify)	
H3	Where have you stored your maize last season?	Specify	
STORAGE TECHNOLOGIES KNOWLEDGE AND AWARENESS			
H4	Which storage technologies do you know?	List them	
H5	Where did you first learn about those storage technologies?	1=News paper and magazines 2= Television 3=Extension officer 4= Farmer group 5= Social network 6= Other (specify)	
H6	Which of the technologies have you used for the last season?	1=Traditional 2=Polypropylene alone 3=Polypropylene with chemicals 4=PIC bags 5=Metal silos 6=Others-specify	
H7	Which reasons that made you not choose other technologies?	1= Not sure about it 2= cost 3= Space to fix it 3= Maintenance 4= Other (specify	

H8	What is the main source of the technologies you use?	1=PHHS task force 2=NGOs (Specify) 3=Farmer group 4=Relatives/friends 5=Own sourcing 6= Other (specify)	
H9	What is the cost of the used technologies?	1=Transport(storage)RwF 2=Information 3=Chemicals 4=Maintenance 5=Other (specify)……… (For labor, check labor table)	1=……… RwF 2=………. RwF 3=………. RwF 4=………. RwF 5=………. RwF
H10	How long the technology you used can store maize?	Each technologies used	
H11	How much storage losses incurred out of total maize stored while using storage technology ?	Each technologies used	
H12	What are the advantages of technologies you are using compared to other storage technologies?	Each technologies used	
H13	How secure are you by storing your maize for each of the technologies you use?	1= Very secured 2= Somehow secured 3= Not very secured Why?	
ATTITUDES			
H14	Do you think the technologies you are using are the best compared to other technologies?	1=Strongly agree 2= Agree 3=Disagree 4=Strongly disagree (for each technology used-	

		why?)	
H15	Do you think to get those technologies are easy?	1=Yes (……..) 2= No (why?)	
H16	What do you think have made it easier for you to get it/them?	1= self-motivation 2= Cooperative 3= PHHS task force 4= Other (specify)	
H17	What motivated you to use that/those technologies?	1=Subsidized material/ Free charges 2= Government policy 3= Security of my stored maize 4=Durability of MSST 5=Length of storage 6= Other (specify)	
H18	What do you think about the cost of storage technologies?	1=. reasonably priced 2= Moderately expensive 3= Is very expensive 4= Other (specify)	
H19	Do you thing the government should invest in dissemination of storage technologies?	1=Yes 2= No (why?)	
H20	In your community, how is storage technologies perceived?		
MSST AWARENESS AND SOURCES OF INFORMATION			
H21	Do you feel well informed about storage technologies?	1= Yes 2=No	
H22	Do you wish you could get more information about storage technologies?	1= Yes 2=No	

H23	What are the sources of information that you think can be most effective?	1=Newspaper and magazines 2= Television 3=Extension officer 4= Farmer group 5= Social network 6= Other (specify)	
H24	What worries you the most about storage technologies?		

SECTION I. PERCEPTIONS ON STORAGE TECHNOLOGIES

I1. Kindly indicate your level of agreement or disagreement to the following statement about the type of storage technologies you are using

Statement	Technologies used (Code A below)	Levels (use Code B below) combined with Code A
Perception on Maize Storage Losses Reduction (PercSTLR)		
Reduce maize storage losses		
Maize stored had better quality		
Increases the length of storing maize without damage		
Perception on Ease of Handling (PercEaseofHandling)		
Easy to fix at home and it can last for longtime		
Easy to handle when it is installed (maintenance)		
Easy handle when storing maize		
Perception on the security of stored maize (PercSecStMz)		
Protect maize against Rodents, microorganism and insects		
It is free from the use of chemicals		
Perception on Maize Market (PercOnMzMrk)		
Reduce price fluctuation		
Increase access to high quality maize market		
Increase income by selling maize at higher price		

Technology used	**Level**
1=Traditional 2=Polypropylene alone 3=Polypropylene with chemicals 4=PIC bags 5=Metal silos 6=Others-specify	1=Strongly agree 2=Strongly disagree 3= neutral 4=Disagree 5= Strongly disagree

SECTION J: LABOUR DEMAND IN STORAGE ACTIVITIES

J1. Did you employ any casual labourer in storage activities in the last season? ***0= no ( )1= yes( )*** **If yes,** enter the following details:

	Number of labourer	**Categories 1=Adult 2=Children (>18 yrs)**	**Gender of labourer 1= Male 0= Female**	**Frequency (Code B)**	**Total Work frequency**	**Cost /unit**	**Total Wage (RwF)**	**Activities engaged in (code A)**
Non-household member								
1								
2								
3								
Household member								
1								
2								
3								

Code A	**Code B**
1. Transport of the production from the far to the storage technology 2. Fixing the technology 3. Storing maize 4. Transport of stored miss to the market 5. Taking care of the technology 6. Maintenance of the technology 7. All 8. Other (specify) ________________	**1= per day** **2= per week** **3= per month** **4= per year** **5=Other specify**

Appendix 2: Maximum Likelihood estimation of MVP Model for Factors Affecting the Decision of Smallholder Maize Farmers to Use Alternative Storage Technologies

```
Multivariate probit (MSL, # draws = 5)          Number of obs   =        301
                                                Wald chi2(52)   =     248.12
Log pseudolikelihood = -454.04184               Prob > chi2     =     0.0000
```

	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf.	Interval]
PolypleneBag						
lnPlotNumber	-.112712	.1938576	-0.58	0.561	-.4926659	.2672419
lnQteMZ_1	-.2913509	.1606973	-1.81	0.070	-.6063118	.0236099
Training	-.5093092	.2107226	-2.42	0.016	-.9223178	-.0963006
AccssCrdt	-.4248374	.2375147	-1.79	0.074	-.8903577	.0406829
lnAgeHHDH_1	.5535561	.3712038	1.49	0.136	-.1739899	1.281102
lnDollaOffFarmIncome	-.0180537	.053586	-0.34	0.736	-.1230803	.0869729
lnYearSchool	.3858616	.1409453	2.74	0.006	.109614	.6621093
lnDstHmeInput_1	.2253752	.1418018	1.59	0.112	-.0525512	.5033016
lnHHDmember	.0673433	.1851696	0.36	0.716	-.2955825	.4302691
SexHHDH2	-.0714558	.2128054	-0.34	0.737	-.4885467	.345635
GrpMbrShpp	-.6175955	.2896856	-2.13	0.033	-1.185369	-.0498222
SellDry	1.320221	.3166229	4.17	0.000	.6996517	1.940791
ByngMzConp	.1520693	.3249337	0.47	0.640	-.4847891	.7889277
_cons	-1.952915	1.544698	-1.26	0.206	-4.980468	1.074638
PolypChemicals						
lnPlotNumber	-.1303613	.1675278	-0.78	0.436	-.4587097	.1979872
lnQteMZ_1	.021197	.1433411	0.15	0.882	-.2597464	.3021404
Training	-1.093059	.1881874	-5.81	0.000	-1.461899	-.7242182
AccssCrdt	.2942032	.2157762	1.36	0.173	-.1287104	.7171168
lnAgeHHDH_1	-.3195129	.3440964	-0.93	0.353	-.9939295	.3549038
lnDollaOffFarmIncome	-.0126665	.0465216	-0.27	0.785	-.1038471	.0785142
lnYearSchool	-.2000919	.1179578	-1.70	0.090	-.431285	.0311011
lnDstHmeInput_1	.2083853	.0989604	2.11	0.035	.0144265	.4023441
lnHHDmember	-.3353541	.1796804	-1.87	0.062	-.6875213	.016813
SexHHDH2	.370365	.1963946	1.89	0.059	-.0145613	.7552913
GrpMbrShpp	.4305156	.2942136	1.46	0.143	-.1461326	1.007164
SellDry	-.1955232	.2126115	-0.92	0.358	-.612234	.2211877
ByngMzConp	.2829944	.3300787	0.86	0.391	-.363948	.9299367
_cons	2.031252	1.502365	1.35	0.176	-.9133289	4.975834
Silos						
lnPlotNumber	.331364	.1883344	1.76	0.079	-.0377647	.7004927
lnQteMZ_1	.1470846	.2178229	0.68	0.500	-.2798404	.5740095
Training	1.776335	.3388268	5.24	0.000	1.112247	2.440423
AccssCrdt	-.7978502	.2908932	-2.74	0.006	-1.36799	-.22771
lnAgeHHDH_1	.3856367	.4004027	0.96	0.335	-.3991382	1.170412
lnDollaOffFarmIncome	.0794616	.0569929	1.39	0.163	-.0322425	.1911657
lnYearSchool	.0937767	.1536025	0.61	0.542	-.2072787	.3948321
lnDstHmeInput_1	-.3589772	.1298636	-2.76	0.006	-.6135052	-.1044492
lnHHDmember	.5796578	.2507236	2.31	0.021	.0882487	1.071067
SexHHDH2	-.6971336	.2558738	-2.72	0.006	-1.198637	-.1956301
GrpMbrShpp	.4897755	.3664747	1.34	0.181	-.2285017	1.208053
SellDry	-.3158123	.2569086	-1.23	0.219	-.8193439	.1877192
ByngMzConp	.0341027	.4373253	0.08	0.938	-.8230391	.8912446
_cons	-5.812103	2.069445	-2.81	0.005	-9.86814	-1.756065
HermeticBag						
lnPlotNumber	.3679999	.1824221	2.02	0.044	.0104591	.7255406
lnQteMZ_1	.2228552	.1732749	1.29	0.198	-.1167574	.5624679
Training	1.432326	.2442837	5.86	0.000	.953539	1.911113
AccssCrdt	.5145266	.2131766	2.41	0.016	.0967081	.9323451
lnAgeHHDH_1	-.5830878	.3696223	-1.58	0.115	-1.307534	.1413586
lnDollaOffFarmIncome	.0203334	.0465764	0.44	0.662	-.0709547	.1116215
lnYearSchool	.0161628	.1567655	0.10	0.918	-.2910919	.3234175
lnDstHmeInput_1	-.1297282	.098848	-1.31	0.189	-.3234667	.0640104
lnHHDmember	.2850706	.1813347	1.57	0.116	-.070339	.6404801
SexHHDH2	-.1933636	.2230108	-0.87	0.386	-.6304568	.2437295
GrpMbrShpp	-.2946463	.2778493	-1.06	0.289	-.8392209	.2499283
SellDry	-.3383439	.2239156	-1.51	0.131	-.7772104	.1005225
ByngMzConp	-.1973969	.3857126	-0.51	0.609	-.9533797	.558586
_cons	-1.149503	1.720339	-0.67	0.504	-4.521305	2.222298

/atrho21	-.5486026	.1074079	-5.11	0.000	-.7591183	-.3380869
/atrho31	-.0848825	.130872	-0.65	0.517	-.341387	.1716219
/atrho41	-.1867935	.1323578	-1.41	0.158	-.4462101	.072623
/atrho32	-.507261	.1305848	-3.88	0.000	-.7632025	-.2513195
/atrho42	-.7036276	.1983243	-3.55	0.000	-1.092336	-.3149191
/atrho43	.2039333	.1044965	1.95	0.051	-.000876	.4087426
rho21	-.4994721	.0806126	-6.20	0.000	-.6405573	-.3257684
rho31	-.0846793	.1299336	-0.65	0.515	-.3287151	.1699565
rho41	-.1846509	.1278449	-1.44	0.149	-.4187787	.0724956
rho32	-.4678083	.102007	-4.59	0.000	-.6429594	-.2461586
rho42	-.6066653	.1253325	-4.84	0.000	-.7977292	-.3049056
rho43	.2011524	.1002683	2.01	0.045	-.000876	.3874045

Likelihood ratio test of rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0:
chi2(6) = 133.974 Prob > chi2 = 0.0000

Appendix 3: Marginal Effects after Multivariate Probit Model

Marginal effect: Polypropylene Sacks

Variable	Obs	Mean	Std. Dev.	Min	Max
mfx_Po~umber	301	-.0254223	.0140159	-.044951	-.0000727
mfx_Polypl~l	301	-.0657145	.0362299	-.1161945	-.0001879
mfx_Polypl~g	301	-.1148752	.0633333	-.2031192	-.0003284
mfx_Polypl~t	301	-.0958225	.0528291	-.1694307	-.0002739
mfx_Polypl~H	301	.1248552	.0688354	.0003569	.2207654
mfx_Polypl~e	301	-.004072	.002245	-.0072001	-.0000116
mfx_Polypl~l	301	.0870315	.0479824	.0002488	.1538867
mfx_bPolyp~l	301	.0508336	.0280257	.0001453	.0898826
mfx_Po~ember	301	.0151894	.0083742	.0000434	.0268574
mfx_Polypl~2	301	-.0161169	.0088856	-.0284975	-.0000461
mfx_Polyp~pp	301	-.1392993	.0767988	-.2463052	-.0003982
mfx_Polypl~y	301	.2977772	.1641712	.0008512	.5265214
mfx_Polyp~np	301	.0342994	.01891	.000098	.0606472
mfx_Polypl~s	301	-.4404821	.2428475	-.7788481	-.0012592

Marginal Effect: Polypropylene sack with chemicals

Variable	Obs	Mean	Std. Dev.	Min	Max
mfx_PolypC..	301	-.0422566	.0087008	-.0520066	-.0098968
mfx_PolypC..	301	.006871	.0014148	.0016092	.0084564
mfx_PolypC~g	301	-.3543149	.0729549	-.436067	-.0829829
mfx_PolypC~t	301	.0953659	.0196362	.0223353	.11737
mfx_PolypC~H	301	-.1035701	.0213255	-.1274671	-.0242568
mfx_PolypC~e	301	-.0041058	.0008454	-.0050532	-.0009616
mfx_PolypC~l	301	-.0648598	.0133549	-.079825	-.0151906
mfx_Poly~t_l	301	.0675481	.0139084	.0158202	.0831336
mfx_PolypC..	301	-.108705	.0223828	-.1337868	-.0254594
mfx_PolypC~2	301	.1200538	.0247196	.0281174	.1477541
mfx_PolypC..	301	.1395516	.0287342	.0326839	.1717507
mfx_PolypC~y	301	-.0633788	.01305	-.0780024	-.0148437
mfx_PolypC..	301	.0917326	.0188881	.0214844	.1128983
mfx_PolypC~s	301	.6584301	.1355734	.1542086	.8103514

Marginal Effect: Silos

Variable	Obs	Mean	Std. Dev.	Min	Max
mfx_Si~umber	301	.0603476	.046656	.0000157	.1321951
mfx_Silo~Z_1	301	.0267869	.0207095	6.99e-06	.0586782
mfx_Silos_~g	301	.3235042	.2501078	.0000844	.7086549
mfx_Silos_~t	301	-.1453036	.1123372	-.3182961	-.0000379
mfx_Silos_~H	301	.0702317	.0542976	.0000183	.1538467
mfx_Silos_~e	301	.0144715	.0111882	3.77e-06	.0317006
mfx_Silos_~l	301	.0170785	.0132037	4.45e-06	.0374115
mfx_Silo~t_l	301	-.0653765	.0505439	-.1432111	-.0000171
mfx_Si~ember	301	.1055666	.0816158	.0000275	.2312499
mfx_Silos_~2	301	-.1269612	.0981563	-.278116	-.0000331
mfx_Silos~pp	301	.0891974	.0689603	.0000233	.1953921
mfx_Silos_~y	301	-.0575154	.0444663	-.1259908	-.000015
mfx_Silos~np	301	.0062107	.0048017	1.62e-06	.013605
mfx_Silos_~s	301	-1.058494	.8183434	-2.318693	-.0002761

Marginal Effect: Hermetic bag

Variable	Obs	Mean	Std. Dev.	Min	Max
mfx_He~umber	301	.1014564	.0450013	.0047458	.1468107
mfx_Herm_L~s	301	.0614404	.0272521	.002874	.0889064
mfx_Herm_T~g	301	.3948876	.1751537	.0184716	.5714154
mfx_Herm_A~t	301	.1418533	.0629195	.0066354	.2052664
mfx_Herm~H_1	301	-.1607554	.0713036	-.2326184	-.0075196
mfx_Herm_l~e	301	.0056059	.0024865	.0002622	.0081119
mfx_Herm_l~l	301	.004456	.0019765	.0002084	.006448
mfx_Herm~t_1	301	-.0357656	.015864	-.0517541	-.001673
mfx_He~ember	301	.078593	.0348602	.0036763	.1137267
mfx_Herm_S~2	301	-.0533097	.0236457	-.0771409	-.0024937
mfx_Herm_G~p	301	-.081233	.0360312	-.1175469	-.0037998
mfx_Herm_S~y	301	-.0932803	.0413748	-.1349797	-.0043634
mfx_Herm_B~p	301	-.0544217	.0241389	-.07875	-.0025457
mfx_Herm_C~s	301	-.3169142	.1405684	-.4585853	-.0148242

Appendix 4: Test for Multicollinearity amongst explanatory variables in the MVP model

```
.  pwcorr lnPlotNumber lnQteMZ_1  Training AccssCrdt lnAgeHHDH_1 lnDollaOffFarmIncome lnYearSchoo
> l   lnDstHmeInput_1 lnHHDmember SexHHDH2 GrpMbrShpp SellDry ByngMzConp, star (1)
```

	lnPlot~r	lnQteM~1	Training	AccssC~t	lnAgeH~1	lnDoll~e	lnYear~l
lnPlotNumber	1.0000						
lnQteMZ_1	0.2802*	1.0000					
Training	-0.0542	0.0734	1.0000				
AccssCrdt	-0.0961	0.2108*	0.0752	1.0000			
lnAgeHHDH_1	0.0690	0.0816	0.1618*	0.0949	1.0000		
lnDollaOff~e	0.0747	0.2427*	-0.2241*	0.3283*	-0.0305	1.0000	
lnYearSchool	-0.1531*	0.0593	0.1034	0.1713*	-0.2289*	0.2410*	1.0000
lnDstHmeIn~1	0.0370	-0.0243	0.0179	-0.1182	0.0568	-0.1267	-0.0518
lnHHDmember	0.1597*	0.0831	0.1058	0.1546*	0.2543*	-0.0088	-0.0066
SexHHDH2	0.1107	0.0780	0.0414	0.0970	-0.0485	0.0757	0.1848*
GrpMbrShpp	0.1290	0.0696	-0.1122	0.0328	0.0821	0.1104	-0.0717
SellDry	0.0760	-0.0423	0.1838*	-0.2673*	-0.0991	-0.3886*	-0.1199
ByngMzConp	-0.0449	-0.0308	-0.0919	-0.1171	-0.0090	-0.0510	-0.2387*

	lnDstH~1	lnHHDm~r	SexHHDH2	GrpMbr~p	SellDry	ByngMz~p
lnDstHmeIn~1	1.0000					
lnHHDmember	0.0389	1.0000				
SexHHDH2	0.0541	0.2430*	1.0000			
GrpMbrShpp	-0.1217	-0.0049	0.0187	1.0000		
SellDry	0.0260	-0.1855*	-0.0770	-0.0542	1.0000	
ByngMzConp	0.0529	0.1182	0.0211	0.0684	0.0432	1.0000

Appendix 5: Full information maximum likelihood estimation of the ESR model

Endogenous switching regression model	Number of obs	=	301
	Wald chi2(7)	=	37.36
Log likelihood = -227.11277	Prob > chi2	=	0.0000

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
IncomeStoredMZ_1						
PlotNumber	.0322988	.0139373	2.32	0.020	.0049822	.0596154
YearSchooling	-.0237335	.057586	-0.41	0.680	-.1366	.0891329
HHDSize	.2434651	.0920474	2.64	0.008	.0630556	.4238747
Training	-.1966187	.2119093	-0.93	0.353	-.6119533	.218716
HHDHAge	.0368836	.1666682	0.22	0.825	-.2897801	.3635474
OccupationHHD	-.6406676	.152813	-4.19	0.000	-.9401757	-.3411595
ByngMzConp	-.2796446	.1702543	-1.64	0.100	-.6133368	.0540476
_cons	.9388008	.6739521	1.39	0.164	-.382121	2.259723
IncomeStoredMZ_0						
PlotNumber	.0156203	.0101651	1.54	0.124	-.004303	.0355435
YearSchooling	.0406389	.0368957	1.10	0.271	-.0316752	.1129531
HHDSize	.0693788	.0508957	1.36	0.173	-.030375	.1691326
Training	-.5071223	.0576709	-8.79	0.000	-.6201552	-.3940894
HHDHAge	.2621296	.1046726	2.50	0.012	.0569751	.4672842
OccupationHHD	-.2061731	.0927173	-2.22	0.026	-.3878958	-.0244504
ByngMzConp	-.0098043	.0873152	-0.11	0.911	-.180939	.1613305
_cons	-.4675099	.4078107	-1.15	0.252	-1.266804	.3317844
CURRENTUse_AST						
PlotNumber	.052457	.0314329	1.67	0.095	-.0091504	.1140645
YearSchooling	-.1290417	.1212808	-1.06	0.287	-.3667476	.1086643
HHDSize	.1238724	.1645526	0.75	0.452	-.1986448	.4463896
Training	1.667289	.2211843	7.54	0.000	1.233776	2.100802
HHDHAge	-.5320238	.3292346	-1.62	0.106	-1.177312	.1132642
OccupationHHD	.1671004	.3473134	0.48	0.630	-.5136215	.8478222
ByngMzConp	.0136026	.3066423	0.04	0.965	-.5874052	.6146104
lnDollaOffFarmIncome	.0430861	.0395464	1.09	0.276	-.0344234	.1205955
SexHHDH2	.0251302	.1401496	0.18	0.858	-.249558	.2998184
AccssCrdt	.1988451	.1145871	1.74	0.083	-.0257415	.4234317
HHDHExprncMZ	.1935922	.0976566	1.98	0.047	.0021888	.3849956
DistHmeInputMrkt	-.2001308	.0902496	-2.22	0.027	-.3770167	-.0232449
_cons	-.1023245	1.247799	-0.08	0.935	-2.547965	2.343316
/lns1	-.8016067	.0954986	-8.39	0.000	-.9887804	-.614433
/lns2	-.9719796	.0612925	-15.86	0.000	-1.092111	-.8518486
/r1	-.5522187	.2730682	-2.02	0.043	-1.087423	-.0170148
/r2	-2.500867	.5077027	-4.93	0.000	-3.495945	-1.505788
sigma_1	.4486076	.0428414			.3720301	.5409475
sigma_2	.3783333	.023189			.3355076	.4266256
rho_1	-.5021812	.2042042			-.7959355	-.0170132
rho_2	-.9866373	.0134779			-.9981631	-.9061887

LR test of indep. eqns. : chi2(1) = 40.18 Prob > chi2 = 0.0000

Appendix 6: Test for Multicollinearity amongst explanatory variables in the ESR model

```
. pwcorr IncomeStoredMZ PlotNumber YearSchooling  HHDSize  Training HHDHAge OccupationHHD ByngMzC
> onp   lnDollaOffFarmIncome SexHHDH2 AccssCrdt  HHDHExprncMZ  DistHmeInputMrkt, star(1)
```

	Income~Z	PlotNu~r	YearSc~g	HHDSize	Training	HHDHAge	Occupa~D
IncomeStor~Z	1.0000						
PlotNumber	0.2679*	1.0000					
YearSchool~g	0.0706	-0.1167	1.0000				
HHDSize	0.2312*	0.1578*	-0.0066	1.0000			
Training	-0.1103	0.0097	0.1034	0.1058	1.0000		
HHDHAge	0.0997	0.0365	-0.2289*	0.2543*	0.1618*	1.0000	
Occupation~D	-0.3055*	0.0451	-0.2837*	0.1645*	0.2223*	0.1840*	1.0000
ByngMzConp	-0.0751	0.0028	-0.2387*	0.1182	-0.0919	-0.0090	-0.0420
lnDollaOff~e	0.4058*	0.0483	0.2410*	-0.0088	-0.2241*	-0.0305	-0.5781*
SexHHDH2	0.0969	0.1367	0.1848*	0.2430*	0.0414	-0.0485	-0.0132
AccssCrdt	0.3268*	-0.0901	0.1713*	0.1546*	0.0752	0.0949	-0.1490*
HHDHExprncMZ	0.3781*	-0.1337	0.0449	0.2749*	0.0003	0.3074*	-0.0626
DistHmeInp~t	-0.0532	0.0466	-0.0518	0.0389	0.0179	0.0568	0.0574

	ByngMz~p	lnDoll~e	SexHHDH2	AccssC~t	HHDHEx~Z	DistHm~t
ByngMzConp	1.0000					
lnDollaOff~e	-0.0510	1.0000				
SexHHDH2	0.0211	0.0757	1.0000			
AccssCrdt	-0.1171	0.3283*	0.0970	1.0000		
HHDHExprncMZ	-0.1034	0.2846*	0.0951	0.2688*	1.0000	
DistHmeInp~t	0.0529	-0.1267	0.0541	-0.1182	-0.0231	1.0000