ECONOMIC STUDIES

DEPARTMENT OF ECONOMICS
SCHOOL OF BUSINESS, ECONOMICS AND LAW
UNIVERSITY OF GOTHENBURG
230

Post-Harvest Losses, Intimate Partner Violence and Food Security in Tanzania

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UNIVERSITY OF
GOTHENBURG

ISBN 978-91-88199-15-7 (printed)
ISBN 978-91-88199-16-4 (pdf)
ISSN 1651-4289 (printed)
ISSN 1651-4297 (online)

Printed in Sweden,
Gothenburg University 2017

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To my beloved family,
my dearest parents,
my brothers and
my sister

Acknowledgements

My immense gratitude goes to the Almighty God for His unending blessings that have enabled me to reach this far in my life. His graces made it possible for me to endure all the years of my studies up to their peak. All glory and honor to you, my Lord.

I appreciate the guidance, efforts and countless hours my supervisors Håkan Eggert and Måns Söderbom have put into my thesis. Their advice, trust, encouragement and optimism helped me to accomplish this piece of work. I have learnt a lot about research from you; thank you.

I would like to thank the Swedish International Development Cooperation Agency through the Environmental Economics Unit at the University of Gothenburg, the International Science Programme at Uppsala University, and the University of Dar es Salaam for funding my PhD studies. Their financial support has been priceless. I appreciate their readiness to attend to all my requests so that I could concentrate on my PhD.

Without the advice, encouragement and recommendations given by Adolf Mkenda and Razack Lokina, I would not have enrolled in this PhD programme. Kindly receive my heartfelt gratitude for that, my professors.

My classmates, I would like to thank you for all the experiences, knowledge shared and gained, and the difficulties endured together during our study period. Your memories will never fade. My teachers, I am grateful for the knowledge I gained from you. It will always be treasured.

My sincere gratitude goes to Joseph Vecci and Roeder Kerstin, the discussants in my final seminars, for all their critical and helpful comments to improve the papers and shape up the thesis. I am also thankful to all those who gave me comments after reading my work or during seminars and conferences, and to Cyndi Berck for editing this thesis.

I am grateful to all academic and administrative staff of the Department of Economics at the University of Gothenburg. You made the PhD-life ecosystem balanced. My colleagues at the Department of Economics at the University of Dar es Salaam, thank you for being a family always.

I would like to thank all those who supported me in my field work: my research assistants, local authority leaders, agricultural extension officers, and the management and staff of AGRA, the NAFAKA project, A to Z Textile Mills Ltd. and Pee Pee (T) Ltd.

I am very grateful for your friendship, support and company, Gakii. Thank you Tensay, Eyoual, Tewodros and Samson for many wonderful moments together. Special thanks to Remidius and his family, and to Simon Wagura and Sied Hassen for your support and mentorship and the good moments we had. Thanks to all the footballers who made Thursday evening the nicest moment.

I wish to express my sincere gratitude to my parents, my brothers and my sister. You have always been on my side, to support and encourage me. This is the fruit of your work too.

My wife, Winnie, your love, care and support are immeasurable. I deeply thank you for all the sacrifices you made to make sure that I achieved this goal. My daughter, Achsah, you have been a bundle of joy to us. Thanks for patiently waiting for me.

MAY GOD BLESS YOU ALL

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Introduction

Eradication of hunger, food insecurity and malnutrition is one of the biggest challenges facing global societies. The Food and Agricultural Organization estimates that about 12.5 percent of the world's population (868 million people) is undernourished in terms of energy intake and 26 percent of the world's children are stunted (FAO, 2013). The cost of malnutrition to the global economy as a result of lost productivity and direct health care costs can account for as much as 5 percent of global GDP, which is equivalent to USD 3.5 trillion per year or USD 500 per person (FAO, 2013). In recent years, the rapid increase in food prices, growing consumer demand, increased weather variability, difficulty in adapting to climate change, and low agricultural productivity in developing countries have called for a revision of strategies to achieve food security (Aulakh and Regmi, 2013; Pieters et al., 2013).

The role of agriculture in producing food and generating income is vital, but the entire food chain is important in improving incomes and ensuring food security (FAO, 2013). Over the past decade, substantial effort and resources have been allocated to increase agricultural productivity. However, increasing agricultural productivity may not be sufficient. Currently, food production expansion is faced with challenges such as limited land and water resources and increased weather variability due to climate change (Aulakh and Regmi, 2013). An additional factor that aggravates food insecurity has received little attention in the literature: post-harvest losses (World Bank, 2011).

Post-harvest losses (PHL) cause not only the loss of the economic value of the food produced but also the waste of scarce resources such as labour, land, and water, as well as non-renewable resources such as fertilizer and energy, all of which are used to produce, process, handle, and transport food (FAO, 2011). Production of food that will not be consumed results in unnecessary greenhouse gas emissions which may accelerate climate change and has other negative impacts on the environment (FAO, 2011; World Bank, 2011). Increasingly, it is recognized that PHL reduction can provide an environmentally sustainable and cost-effective contribution to food security and income improvement, compared to sole reliance on increasing production in a world with limited natural resources, and in an era of high and volatile food prices (FAO and World Bank, 2010; Aulakh and Regmi, 2013).

It is estimated that 10-20 percent of the total grain produced in Sub-Saharan Africa (SSA) suffers post-harvest physical losses. This loss is valued at USD 4 billion annually, which is equivalent to the annual calorific requirement of 48 million people (World Bank, 2011). This suggests that PHL reduction can complement efforts to address food security challenges and improve farm incomes. FAO estimates that about half of the USD 940 billion needed for investment to eradicate hunger in SSA by 2050 should be geared toward reduction of post-harvest losses, by investing in cold and dry storage, rural roads, rural and wholesale market facilities, and first-stage processing (FAO and World Bank, 2010). The first two chapters of this thesis are devoted to analysing the economics of PHL mitigation.

Interest in PHL reduction started as far back as the mid-1970s after the food crisis of that time, followed immediately by the United Nations' declaration that PHL reduction in developing countries should be undertaken as a matter of priority (World Bank, 2011). Initially, considerable investments were made in PHL reduction in grains and, in later years, the coverage extended to roots, tubers, fruits and vegetables (World Bank, 2011; Affognon et al., 2015). In SSA, food losses at post-harvest handling and storage stages are relatively higher compared to the losses during distribution and consumption; this is due to inadequate handling, poor storage facilities and lack of infrastructure (FAO, 2011). This led to interventions with a producer perspective, putting more efforts toward improving harvest techniques, farmer education and storage facilities (FAO, 2011; Affognon et al., 2015).

After food prices stabilized and due to low adoption of PHL technologies promoted in various SSA countries, the importance of PHL in the African grain sector seemed to be forgotten. International programs which were involved, such as FAO's Prevention of Food Losses Program and the Global Postharvest Forum (PhAction), became dormant (World Bank, 2011). Recently, the discussion on PHL reduction has been revitalized following the food price surge in 2008 and continuing challenges facing expansion of food production.

The **first paper** in this thesis, *'Post-Harvest Losses Reduction By Small Scale Maize Farmers: The Role of Handling Practice'*, aims to identify and quantify Post-Harvest Losses (PHL) experienced by maize farmers at different stages in the post-harvest system; it also examines the role of post-harvest handling practices in PHL reduction and conducts a cost-benefit analysis of investing in PHL mitigation. To the best of our knowledge, this is the first study to assess the economic feasibility of post-harvest handling practices (apart from storage methods) in mitigating PHL among small-scale farmers in a developing country. We use survey data collected from 420 maize farmers in a rural district in Tanzania in 2015.

First, we find that maize farmers experience a total of 11.7 percent of the amount harvested as physical PHL. About two-thirds of this loss (7.8 percent) occurs during storage, whereas 2.9 percent is lost during the processes before storage and 1.0 percent is lost during marketing. The value of the losses is estimated to be USD 64.4 per household, which is about 1.2 times the median household monthly income. This loss of value is too high to ignore, and should be considered as a lower boundary. Qualitative losses have not been considered in this study but are also of significance because they reduce income, due to lost market opportunities, and affect the nutritional value of the grain. Further analysis shows that maize PHL are negatively correlated with household food security. These findings imply that reducing PHL can potentially improve farmers' income and food security.

Second, we find that 'good' post-harvest handling practices are highly correlated with low levels of PHL. We go a step further to analyse why some farmers do not adopt PHL mitigating practices despite their large marginal effects. Farmers will invest in mitigating PHL if there is an economic motivation to do so. We conduct a cost-benefit analysis of adopting PHL mitigating practices. The results show that most of the practices are on average economically beneficial. However, the average net gains of adoption per ton of maize are small for most of the practices. This means that some farmers might actually be facing negative net benefits or be at the margins of zero net benefits and thus adoption may not be a beneficial option for them. Our findings imply that investment in infrastructure and technologies that lower the cost of adopting good practices may improve the adoption of PHL mitigating practices.

The **second paper**, *'How economically effective are hermetic bags in maize storage? An RCT with small-scale farmers'*, analyses the impact on PHL reduction and the economic effectiveness of two randomized interventions with small-scale maize farmers in rural Tanzania. In the first intervention, farmers were trained on post-harvest management practices; in the second intervention, farmers received the same kind of training on post-harvest management practices and, in addition, were provided with a new maize storage technology: hermetic (airtight) bags. By combining the provision of hermetic bags with training on post-harvest handling practices, our study differs from previous studies (De Groote et al., 2013; Ndegwa et al., 2016) that analyse the economic effectiveness of adoption of this storage technology. We argue that efficient use of hermetic bags should go along with the application of appropriate post-harvest handling practices (Baoua et al., 2014). We also consider benefits beyond PHL reduction, including farmers receiving a higher market price for maize (due to improved quality of storage grain) and savings from using less insecticide in protecting stored maize, as well as costs beyond those of buying the bag, including the costs of supporting practices that come along with the adoption of hermetic bags.

We find that both interventions had significant effects in reducing storage losses but not pre-storage losses. Compared to the control group, a greater proportion of farmers in the treatment groups perceived that the physical characteristics of their maize grain were maintained during storage. Farmers in treatment groups managed sold their maize at a higher price, on average, compared to those in the control group. We also find that a significantly lower proportion of farmers who received hermetic bags used storage insecticides, compared to other groups, although they also invested more in controlling rodents (to prevent rats from making holes in the bags). This enabled them to significantly cut down the cost of storage protection. We observe that a higher proportion of farmers in the treatment groups adopted post-harvest loss mitigating practices compared to those in the control group. This adoption, plus the use of the hermetic bag itself, may explain the success of the intervention.

The cost-benefit estimations show that provision of training on post-harvest management is economically effective. Assuming that the effects of the training last for five years, the internal rate of return of this intervention is 14 percent. The use of hermetic bags together with training on post-harvest losses is also economically effective, with an internal rate of return of 35 percent over the investment horizon of three years, which is the lifetime of hermetic bags. Results suggest that training farmers on good post-harvest management practices can be economically effective in helping them reduce PHL. It is also economically feasible for smallholder farmers to adopt hermetic bags for maize storage; accompanying such adoption with training on post-harvest management provides better outcomes.

The **third paper**, *'Intimate Partner Violence and Food Insecurity'*, investigates gender-related violence within households as a crosscutting issue in addressing food insecurity.

The food security status of a household depends, among other things, on the well-being of those who produce and organize the preparation of that food. Women play an important role in food production, processing, marketing and other parts of the food chain (Doss, 2014; FAO, 2011). Traditionally, women bear the primary responsibility for preparing meals and caring for children and other family members within the household, especially in Africa. So, gender differences in roles, rights, resources and bargaining power, particularly those related to achieving food security for and within the household and those related to responsibilities for food provisioning, may limit the achievement of household food security (FAO, 2013). Grossman's human capital model of health demand (Grossman, 1972) proposes that ill-health reduces the amount of time available for production activities, thus hindering productivity. Empirical studies have shown that partner violence has adverse effects on women's physical, reproductive and mental health (Golding, 1999; Huang, et al. 2011; Aizer, 2011). This may in turn affect the productivity of women who are involved in food production by reducing the amount of time they spend and the effort they exert in production. It may also affect women's capacity to organize and prepare food for the family even when they are not per se involved in production of that food.

This study seeks to test the hypothesis that intimate partner violence correlates with household food insecurity. To test the hypothesis, I use violence data from the first wave of the Tanzania national panel survey and food security data from the second wave. To my knowledge, this is the first study to analyse the relationship between intimate partner violence and food security in the context of a developing country, where the rates of prevalence of

IPV affecting women are high; where most women are not formally employed, but are rather engaged in subsistence production of household food; and where the rate of food insecurity is higher. I do not find strong empirical evidence of the effect of abuse of women on household food security in either rural or urban areas. These results suggest that future studies on IPV and food security can explore within-household food heterogeneities and possible coping mechanisms by abused women; expand the time span; and address endogeneity issues.

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Paper I

Post-Harvest Losses Reduction by Small-Scale Maize Farmers: The Role of Handling Practices

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Abstract

Concerns about food insecurity have grown in Sub-Saharan Africa due to rapidly growing population and food price volatility. Post-harvest Losses (PHL) reduction has been identified as a key component to complement efforts to address food security challenges and improve farm incomes, especially for the rural poor. Effective investment in PHL mitigation requires a clear knowledge of the magnitudes of the losses, the drivers of these losses at each stage, and the cost of mitigation. This study quantifies PHL experienced by maize farmers; analyses the role of post-harvest handling practices in PHL reduction; and conducts a cost-benefit analysis of adopting good PH handling practices. The study finds that maize farmers lose about 11.7 percent of their harvest in the post-harvest system. About two-thirds of this loss occurs during storage. The study also shows that good post-harvest handling practices are highly correlated with lower PHL. The cost-benefit analysis indicates that the adoption of most of the good practices is on average economically beneficial. The study discusses the puzzle of why some farmers still do not adopt them and points out some policy implications.

JEL Classification: Q18 · Q16 · Q12 · D61 · C25

Keywords: post-harvest losses · post-harvest management · small-scale farmers · cost-benefit analysis · fractional response model

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1 Introduction

Sub-Saharan Africa (SSA) remains highly dependent on agriculture in terms of its share of total GDP and employment[1] (International Monetary Fund, 2015). It is estimated that crop production accounts for about 70 percent of typical incomes in this region, of which 37 percent is from grain crops (World Bank, 2011). However, according to the same World Bank report, 10-20 percent of the total grain produced in SSA suffers post-harvest physical losses. This loss is valued at USD 4 billion[2] annually, which is equivalent to the annual calorific requirement of 48 million people (at 2,500 kcal per person per day). Food losses in developed countries are as high as in developing countries. However, in the latter, the largest proportion of food is lost before reaching the consumer, during post-harvest processes and storage stages, while in the former the food losses occur mostly at retail and consumer levels (FAO, 2011). These scenarios suggest that reduction of Post-Harvest Losses (PHL) can complement efforts to address food security challenges and improve farm incomes, especially for the rural poor.

Investing in PHL reduction, like any other investment, will be undertaken if the benefits outweigh the costs. To avoid policy errors and sub-optimal choices of mitigation approaches, a precise knowledge of the magnitudes of the losses, the drivers of the losses at each stage, and the net benefits of adopting mitigation practices is important (Affognon et al., 2015). While the empirical literature seems to concur that the total PHL in cereals in SSA are high[3] and are concentrated in the handling and storage stages (Affognon et al., 2015; FAO, 2011; World Bank, 2011), studies analysing the factors driving PHL at different stages of the post-harvest system and economic assessment of PHL mitigating practices are scarce (Borgemeister et al., 1998; Kaminski and Christiaensen, 2014; Komen et al., 2006; Meikle et al., 1998; Rugumamu, 2009).

This paper aims to identify and quantify PHL experienced by maize farmers at different stages in the post-harvest system; examine the role of post-harvest handling practices in PHL reduction; and conduct a cost-benefit analysis of investing in PHL mitigation. To the best of my knowledge, this is the first study to assess the economic feasibility of post-harvest handling practices (apart from storage methods) in mitigating PHL among small-scale farmers in a developing country.

[1] The share of agriculture in SSA is about 20-35% and it employs 60-70% of the population on average.

[2] This is out of an estimated annual value of grain production of USD 27 billion (estimated average annual value of production for 200507). Qualitative post-harvest losses are also significant because they reduce revenues due to losses in quality and market opportunities and impact on the nutritional value of the grain (FAO-World Bank, 2010).

[3] The variation that may be observed across studies may be due to the metrics used (for example, calories versus weight), type of crop, and the stage in the food chain (Kaminski and Christiaensen, 2014).

PHL reduction got considerable attention following the food crisis in the mid-1970s,[4] but by the late 1980s it seemed to have been forgotten (Kaminski and Christiaensen, 2014). Recent concerns about food insecurity in SSA, due to the greater demands from an increasing and more affluent population, as well as food price volatility, have encouraged a critical review of all the food supply and demand components, including physical and economic post-harvest losses (FAO, 2011; Kaminski and Christiaensen, 2014). Over the past decade, substantial efforts and resources[5] have been channeled toward increasing agricultural output and productivity in SSA. Nonetheless, the expansion of food production faces challenges such as limited land and water resources, increased weather variability, and difficulty in adapting to climate change (Aulakh and Regmi, 2013). This has raised the profile of PHL reduction as one of the means to reduce tensions between the necessary increase in food demand and the challenges in increasing production fao2011state,hodges2011postharvest.

The key question is why farmers tolerate PHL. Lipton (1982) posited that it is because PHL are actually not that high. A traditional neo-classical economist would assume that farmers are rational profit maximisers and the levels of PHL observed are optimal. In that case, trying to intervene is merely imposing distortions. Other studies attribute the low responses to interventions to lack of economic incentives to reduce PHL, credit constraints (including high initial costs of PH technologies adoption), and social/cultural factors (Kadjo et al., 2013; World Bank, 2011).

Several factors may limit profitable investments in agricultural technologies including PHL reduction: information asymmetry; behavioral biases such as time inconsistency (Duflo et al., 2011) and risk and loss aversion (Kadjo et al., 2013); and failure to account for externalities. Farmers may not be fully aware of the factors driving PHL, the magnitude of the marginal effects of the drivers, and/or the marginal cost of mitigation. This uncertainty may deter risk-averse farmers from investing in PHL mitigation. In the case of externalities, the social and private optimal levels of mitigation will be different. PHL impact the environment and accelerate climate change because land, water, and non-renewable resources such as fertilizer and energy used to produce, process, handle, and transport food end up being lost and not consumed by anyone (Aulakh and Regmi, 2013; World Bank, 2011). Production of food that will not be consumed results in unnecessary greenhouse gas emissions and exacerbates resource scarcity (FAO, 2011).

[4] This food crisis exploded in 1973 and 1974 and was characterised by rapid food price increases in the West and by famines in Africa and Asia. The main causes were bad weather, rising agricultural input prices, grain export bans and hoarding of food purchases

[5] These include development of new hybrid seeds and the use of fertilisers.

We use survey data collected from 420 maize[6] farmers in a rural district in Tanzania. We collected information on household socioeconomic characteristics, maize production practices, post-harvest losses and post-harvest handling practices in one agricultural season. PHL information was collected in three stages: between harvesting and storage, during storage, and during marketing. This disaggregation enabled us to collect reliable loss estimates by vetting with cross-checking questions at each stage. We analyse the role of post-harvest handling practices in PHL reduction and do a cost-benefit analysis of adopting 'good' practices for mitigating the losses.

We find that, first, the levels of PHL experienced by maize farmers are 11.7 percent of the amount harvested. This includes 2.9 percent lost during the processes before storage, 7.8 percent during storage and 1.0 percent during marketing. The value of the losses is estimated to be USD 64.4 per household, which is about 1.2 times the median household monthly income. These losses are also negatively correlated with household food security. Second, our results show that 'good' post-harvest handling practices are highly correlated with low levels of PHL. Finally, the cost-benefit analysis shows that the adoption of most of the good practices is on average economically beneficial. The study discusses the puzzle as to why some farmers still do not adopt PHL mitigation practices and points out some policy implications.

The rest of the paper is organised as follows: Section 2 presents an overview of post-harvest losses; Section 3 provides the conceptual framework of the relationship between post-harvest handling practices and losses; Section 4 describes the data; Section 5 describes the estimation strategy and presents the results; and Section 6 is the conclusion.

2 Post-Harvest Losses

Post-harvest loss is defined as measurable food loss in the post-harvest system (Hodges et al., 2011). Post-harvest system refers to a chain of interconnected activities from the time of harvest to the time the food reaches the end consumers (World Bank, 2011). In the case of cereal, the chain comprises activities such as harvesting, shelling, drying, storage, packaging, transportation, milling and marketing. In our case, we study the losses during pre-storage processes (shelling, drying and transportation), storage, and marketing.

Quantitative PHL is defined as reduction in the physical weight of food available for human consumption and other utilization (FAO, 1980). Quantitative losses are due to spillage,

[6] We focus on maize because it is by far the most important crop in SSA. Out of a total annual grain production in SSA of 112 million tons, maize contributes 40% (World Bank, 2011).

grain breakage, rodent and pest damage, and spoilage due to temperature changes, chemical changes and humidity content (Aulakh and Regmi, 2013). The reduction in weight due to shrinkage of food grain after drying to allow for storage for a longer period is not counted as a loss because it does not involve any food loss (FAO, 1980). Similarly, losses due to theft are also not recorded as quantitative post-harvest losses. Qualitative PHL refer to loss in the nutritional value, edibility, caloric value, acceptability or other intrinsic feature of the food (FAO, 1980; World Bank, 2011). The sources of qualitative PHL include contamination by microorganisms, pest and rodent attacks, humidity content, chemical changes, broken grain, contamination by poisonous fungi, and pesticide residues. If qualitative deterioration of food makes it unfit for human consumption, leading to eventual rejection, this will be counted as a quantitative loss (FAO, 1980).[7] In this study, we will analyse quantitative PHL.

Maize, our focus crop, is the main staple food for most of SSA, including Tanzania. It is the basis for food security and is vital for the income of the majority of the people. In Tanzania, the area planted with maize occupies about 47% of the total area planted with annual crops, which is equivalent to 70% of the total area planted with cereal, and maize is grown by 60% of the households (TNBS, 2012). Maize also comprises about 72% of total cereals production in the country. The crop is an important component of the diet in Tanzania, contributing about 3436 percent of the daily caloric intake. Higher PHL in maize therefore imply that a significant amount of food in the country is lost, a notable amount of resources directed toward production is wasted, and households' a high degree. So, by focusing on maize, we capture a large proportion of planted area, food production, and sources of rural household income.

African Post-Harvest Losses Information System[8] estimates that PHL of maize (from harvesting to marketing) in SSA has been around 18% in the period between 2009 and 2013. In Tanzania, according to Tanzanian Markets-PAN (2013) PHL in maize was on average 15.5% of the total production of maize between 2003 and 2007. The study by Alliance for a Green Revolution in Africa (AGRA)[9] in 2013 show that maize losses in Tanzania differ

[7]However, it is worth acknowledging that it is still difficult to ensure perfect uniformity in PHL measurements across countries or regions, even with the use of these definitions. Along the postharvest system, what might be regarded as leftovers or damaged food to discard in one region can still be counted as fit for consumption somewhere else. In other cases, leftovers from processing or a particular kind of damage to food may make it unfit for human consumption but it may be utilized for other purposes, such as feeding livestock. This kind of loss may be recorded up to a certain limit.

[8]The African Postharvest Losses Information System was created within the framework of the project 'Postharvest Losses Database for Food Balance Sheet Operation' initiated and financed by the European Commission's Joint Research Centre led by the national natural esources experts

[9]AGRA is an organization dealing with improving agricultural products and supporting local farm owners and labour in Africa. It is funded by the Bill and Melinda Gates Foundation as well as the Rockefeller Foundation.

between large and small farmers, with losses experienced by large farmers recorded at 6% and those by small farmers at 11%. The level of storage losses in maize also depends on whether or not the area is infested with the large grain borer (LGB).[10] Reported storage loss figures for areas infested with maize LGB are double those of areas without LGB (Hodges, 2012).

The high level of PHL is of great relevance to SSA because the production per capita is very small. The wastage in food in these countries therefore not only means a big monetary loss but also a decline in the already low nutritional levels and a threat to economic development.

3 Conceptual Framework

The farmer is faced with a choice of whether and to what extent she should apply PH handling practices that will reduce post-harvest losses. Each of the handling practices carries an economic cost, either explicitly or implicitly. So, a farmer faces a tradeoff between incurring additional costs to mitigate PHL or risking PHL. A farmer could, for example, risk getting her maize infested by pests by letting it dry in the field, or she could incur more cost to harvest the maize timely and transport it immediately for drying at the homestead, reducing the risk of pest contamination and thereby reducing PHL. This stylized example builds the conceptual framework where farmers may rationally incur optimal levels of positive PHL. Farmers will invest in mitigating PHL if there is an economic motivation to do so. Other things remaining the same, reducing PHL increases the quantity of the crop available for sale and consumption. Thus, the quantity of the crop saved by reducing PHL and the cost of mitigating the losses play a crucial role in the farmer's decision. The literature in agricultural science provides the theoretical links between post-harvest practices and PHL. Below, we explain those links which we will test in this study.

Crop variety

The level of PHL may be partly determined as early as the time of choice of the crop type or variety. In some areas of eastern and southern Africa, it has been found that high-yielding varieties of maize are more susceptible to pest attacks before harvest, due to incomplete sheath cover, and after harvest, due to softer, more easily eaten grain (Meikle et al., 1998; World Bank, 2011). In most cases, smallholder farmers mix local and improved varieties in

[10]The larger grain borer (Prostephanus Trancatus) is a devastating storage pest introduced into Africa from Central America in the late 1970s. It is now widely recognised as the most destructive pest of stored maize and dried cassava in Africa and has been associated with a significant increase in storage losses since its introduction (Boxall, 2002).

their plots. To minimise losses in storage and to meet the urgent need for cash after the harvest, very often the crops from these high-yielding varieties are sold soon after the harvest (World Bank, 2011). We will compare traditional and hybrid varieties to find out how maize variety may influence PHL.

Weather at harvesting

Unfavourable weather conditions during harvesting and drying can dampen the matured crop, resulting in mould growth. This may later reduce the grain quality, causing some of the grain to be discarded, and may increase the associated risk of attacks by storage pests, aflatoxin or other mycotoxin contamination, which are harmful to human health (Hodges et al., 2011; USAID Rwanda, 2012).Climate change may bring about unstable weather, including unseasonal rains, leading to damper or cloudier conditions during harvesting and drying, which may increase PHL (Hodges et al., 2011; World Bank, 2011).

Crop stage at harvest and immediate handling

Leaving maize in the field for extended periods after physiological maturity[11] may favour insect infestation and fungal infections and may reduce grain quality. The losses are mainly due to a serious build-up of insect pests and mould months after maturity, which are carried over into storage and cause more damage (African Post-Harvest Losses Information System, 2015; Borgemeister et al., 1998). Similarly, early harvested maize is more prone to infestation and fungal growth because of higher grain moisture content at harvest (Borgemeister et al., 1998).

Piling up maize cobs in their stalks to dry in the field, heaping the cobs in a room or yard after reaping them from their stalks, and storing maize in sacks immediately after harvesting increase the chances of grain damage. Doing so exposes uncontaminated grain to insect infestation from infested grain, especially if the grain is not sorted, and allows moisture and higher temperature to build up, favouring the growth of fungi (African Post-Harvest Losses Information System, 2015; World Bank, 2011). Therefore, harvesting at the right time, and efficiently handling the crop immediately after harvest, by sorting out the infested cobs and spreading the cobs on the floor instead of heaping them, are critical to avoid losses down the chain.

Maize shelling

There are different techniques for shelling maize, including hand shelling, beating the maize in a sack, and using a mechanical hand sheller or a motorised sheller. Hand shelling normally involves more attention and less mechanical damage, but it takes longer, which increases losses in turn. Beating in a sack saves time and manpower but may result in more physical

[11] The maize crop is physiologically mature when the plant has become straw colored, the grain is hard and some of the cobs droop downward.

damage, which makes maize more vulnerable to insect pests, moulds and damage due to microorganisms (USAID Rwanda, 2012). Machine shelling is quicker but more expensive. Whether machine shelling leads to lower losses, compared to hand shelling or otherwise, depends on the quality of the machine and how careful the machine operators are relative to the farmers doing it themselves.

Drying

The moisture content of the grain is a key factor in grain deterioration during storage; generally, the faster the grain can be dried, the (Stathers et al., 2013). Drying makes the grain harder and reduces the chances of damage by pests. Taking moisture out of the grain minimises the growth of fungi and consequent risks of mycotoxin contamination. However, drying maize for too long may unnecessarily expose the grain to pest infestation, birds, animals, theft, and too much heat may damage the viability of grain for use as seed (USAID Rwanda, 2012). The drying period depends on the time of harvest, requirements of the other crops, labour availability, the time until the next rains, the moisture content of the grain at harvest, and its drying rate (Stathers et al., 2013). Experienced farmers can tell when maize is dry enough by biting or pinching it, or by the different sounds it makes when pouring or rattling it (USAID Rwanda, 2012). However, these techniques are subjective and may not work for farmers who are not experienced. The use of a moisture meter is an objective and accurate measure that can be used to test whether the level of drying is suitable, but this equipment is not always available to small-scale farmers and may not be affordable.

Drying technique is also important in determining PHL. Some drying practices such as drying on the ground without sheeting, outside on a platform without a roof, or suspended from sticks and uncovered, may expose the grain to moisture, dirt and insects (USAID Rwanda, 2012).

Maize storage and use of storage protectants

In the past, small-scale farmers in Africa used traditional methods that are well adapted to the prevailing climate, but skills for constructing the traditional woven and mud-plastered granaries are gradually being lost. Nowadays, polypropylene sacks are increasingly popular for maize storage for both consumption and marketing, because they are more portable, take up less space, and are easier to monitor and protect. These storage methods, which have a reasonable degree of sealing but are not fully airtight (hermetic), are a fairly effective barrier to pest attacks, but may require more action, such as using chemical protectants, to kill any pests that are in the grain at the time of loading and may not offer protection against moist external surroundings (World Bank, 2011). Adoption of airtight storage technology can improve the quality of grain and reduce PHL (De Groote et al., 2013).

Storage protectants are used to prevent damage by maize storage insect pests. This may not reduce PHL if applied after grains are seriously damaged (Kaminski and Christiaensen, 2014). Chemical protectants are expensive and so many resource-poor households may instead use traditional grain protection practices, including ashes, plants and herbs, vegetable oil, etc. The economic damages by insect pests usually start being experienced 3-4 months after storage, so farmers may sometimes sell maize early within three months of harvest as a technique to avoid losses (USAID Rwanda, 2012). In this case, they receive low market prices for their maize because they sell when the market is flooded. In addition, they may be forced to buy grain for consumption at a higher price just a few months after harvest, when their stock is exhausted.

4 Data and Descriptive Statistics

Our data was collected from the Kilosa district in the Morogoro region located in Eastern Tanzania, which is among the six biggest maize producing regions in Tanzania. Maize is the main food and income generating crop in Kilosa and the district is always a surplus producer of maize. The district is characterised by a semi-humid tropical climate. Its mean annual rainfall ranges between 800mm and 1400mm (Kajembe et al., 2013). The district receives long-term rainfall from March to early June and 'short rains' from November to January. The district experiences a long dry season between June and October. The temperature ranges from 18 to 30 degrees Celsius, depending on the altitude. These conditions offer a typical climate for maize production and a suitable case study area. Although Kilosa district has two rainy seasons, the pattern and amount of rainfall allow for only one harvest of the main staples per cropping season (MOVEK Development Solution, 2008).

The sample frame consisted of 420 households in 21 villages, located in nine wards (an administrative unit larger than a village but smaller than a district) in the Kilosa district. The sampling process involved two steps of randomization. First, we obtained a list of villages in Kilosa district which met two criteria: (1) maize is the main crop produced by the villagers and (2) maize is the main staple food in the village.[12] Then we randomly selected 21 villages from this list. Second, we randomly selected 20 maize farming households from the household roster in the village office.[13] The data collection process was done in June and July 2015, which is close to the end of the maize farming season in the district.

[12] This information was obtained by consulting the district administrative secretary and the district agricultural officer.

[13] In case no one eligible for the survey was found or the household had not grown maize in that season, then another household would be randomly chosen to replace it.

We collected self-reported information on PHL in the previous harvesting season[14] at three stages: between harvesting and storage, during storage, and during marketing. Specifically, we asked the following questions:
(i) How much was the loss from the time you harvested to storage time (taking into account all losses during transporting, drying, shelling and winnowing)?
(ii) How much was the loss between the time you stored the maize and the moment you used it for consumption or took it for sale?
(iii) How much was the loss at the marketing stage (taking into account all the stages from taking the maize from storage, weighing and transporting it)?

The farmers reported the loss at each stage in terms of quantities in kilograms, buckets or bags. We then converted all the quantities into kilograms.[15] Self-reported estimates of post-harvest losses are subjective and thus prone to measurement errors, but they reveal losses that farmers deem important (Kaminski and Christiaensen, 2014). Self-reported estimates are relevant indicators of demand for better storage and handling techniques and so are arguably the relevant metric when assessing likely adoption of better PHL handling techniques (World Bank, 2016).

To ensure reliable estimates of the losses experienced by farmers, a thorough study of the maize post-harvest system in the study area was conducted, and enumerators were educated about the system. First, field visits were made, village agricultural extension officers were consulted, and focus group discussions and interviews were held with farmers and village leaders. Second, enumerators were well trained to understand the maize post-harvest system, and effective ways of conducting the survey were tested off the field and again in the field. Third, a pilot study was conducted to test the questionnaire and the capacity of the enumerators to execute it. Fourth, during data collection, careful and thorough interviews were done to capture the PHL by taking respondents step-by-step along the post-harvest processes, with indirect cross-checking questions for more robustness. We collected detailed information on the socio-demographic characteristics of the households, social networks, maize farming practices, post-harvest activities (including storage and marketing), and food security.

Due to missing information for some of the variables for a few respondents and after dropping one household which was an outlier and did not fit as a small-scale farmer, we

[14] The previous harvesting season took place in August 2014, so for some questions farmers had to make a recall of 10 months. The timeline covering the recall period to the interview is shown in Figure A1 in the appendix.

[15] In each village, we explored the weights of maize when put in different vessels used by farmers in carrying maize. We also probed whether farmers knew how much maize weighs when put in those vessels. In most cases, their responses were the same as our measurement.

ended up with a sample of 415 respondents for the analysis..

Table 1 reports definitions and descriptive statistics of the key variables used in our analysis.

Farmers experienced on average about 2.9% loss of their maize from the time they harvested to when they stored it. This includes losses during transportation from the farm to the homestead, shelling, winnowing and drying. About 17% of the respondents reported not experiencing this type of loss and the maximum loss experienced was 12% of the total harvest. Losses during storage were on average about 7.8% of the total harvest. The main causes of storage losses reported were insects, rats, and rotting due to moisture (see Table A1 in the appendix). About 20% of the respondents did not experience any loss during storage, but the maximum loss was as high as 52% of the amount of maize stored. Marketing losses were about 1% of the total harvest.

The majority of the households are male-headed, with the average age and years of schooling for the head of households being 47 and 7, respectively. Seven years of schooling is equivalent to completion of primary school education. Household sizes are large and just over half of the members are active workers. Most of the households have much experience in maize production on average, 19 years. Households used, on average, 2.6 hectares of land for agriculture in the agricultural season preceding the survey, with a few outlier farmers cultivating more than 7 hectares. About 72% of the land farmed was used for maize. Most of the respondents' maize farms are on one or two plots; the average number of plots is 1.4. The usage of certified or improved seeds is low, at about 17%. Most farmers use traditional seeds or seeds retained from a previous harvest. There is a wide variation in the total amount of maize harvested among farmers, from the lowest (29 kilograms) to as high as 23 tons, with the average around 2.75 tons. The average yield is 1.7 t/ha, which is above the national average of 1.3 t/ha and above the district average of 0.98 t/ha in 2007, reported in the Tanzania Agricultural sample survey, 2007/08[16]

Most of the farmers do not harvest their maize in time when it is mature; most leave the matured crop to dry in the field, and only 19% harvest at maturity. A few farmers, 29%, practiced proper immediate handling[17] maize after harvest by spreading the maize on the floor or on a platform, instead of heaping it in rooms or keeping it in bags, and about

[16]The large variation in yield observed across time may be due to variations in weather conditions across years. It could also be because the sample is representative of a typical maize farming smallholder who mainly relies on maize for food and income; not all maize farming households are included in calculating the figure in the agricultural survey. Still, this yield is below the potential rain-fed maize yield in Tanzania, which is estimated to be 4t/ha (Mourice et al., 2015).

[17]This involves spreading maize on the ground or floor as opposed to heaping it or putting it into bags immediately

Table 1: *Summary statistics*

Variable	Obs	Mean	Std. Dev.	Min	Max
Dependent variables					
Pre-storage loss: % of total harvest	415	.029	.022	0	.119
Pre-storage loss [Kgs]	415	87.83	128.6	0	1080
Storage loss: % of total harvest	415	.078	.056	0	.515
Storage loss [Kgs]	415	198.0	229.1	0	1350
Marketing loss: % of total harvest	415	.010	.013	0	.087
Marketing loss [Kgs]	415	33.91	54.88	0	378
Total PHL: % of total harvest	415	.117	.691	0	.553
Socioeconomic variables					
Sex of Head of Hh [Male=1]	415	.853	.355	0	1
Age of Head of Hh [Years]	415	46.59	12.30	19	81
Years of schooling of Head of Hh	415	7.087	2.914	0	18
Log wealth	415	15.17	1.306	10.24	18.74
No of active workers	415	3.000	1.574	1	10
Household size	415	5.402	2.113	1	13
Farming characteristics and harvesting practices					
Hh years of Experience-Maize prod.	415	18.51	12.22	1	62
Area of land for agric [acres]	415	2.581	2.217	.245	17.15
Area of land for maize [acres]	415	1.647	1.432	.245	14.7
Number of maize plots	415	1.366	.743	1	8
Percentage of hybrid seeds used	415	.165	.363	0	1
Weather at harvest [Sunny=1]	415	.817	.387	0	1
Harvest at maturity [Yes=1]	415	.188	.391	0	1
Amount harvested [Kgs]	415	2749	2723	29	23100
Yield [Kgs/acre]	415	1700	841	39	5942
Pre-storage handling practices					
Proper immediate handling [Yes=1]	415	.292	.455	0	1
Maize sorted after harvesting [Yes=1]	415	.518	.500	0	1
Drying period [days]	415	4.836	10.45	0	60
% of maize shelled by hand	415	.103	.298	0	1
% of maize shelled by machine	415	.538	.497	0	1
% shelled by beating maize in sacks	415	.358	.476	0	1
Storage practices					
Amount stored [Kgs]	415	2601	2555	28	22400
% stored for food purpose	415	.452	.263	0	1
% stored for sale	415	.532	.266	0	1
% stored for other purposes	415	.016	.073	0	.667
Maize stored for food per capita	415	214.4	218.2	0	3119
Main storage method: Sacks	415	.783	.413	0	1
Main storage method : traditional	415	.195	.397	0	1
Main storage method : airtight storage	415	.022	.146	0	1
Storage facility disinfected [Yes=1]	415	.455	.499	0	1
Used storage protectants [Yes=1]	415	.793	.406	0	1
% sold 3 months after harvest	415	.289	.192	0	0.852
Marketing characteristics					
Time to the nearest main road [minutes]	415	21.77	33.23	0	240
Time to the nearest market [minutes]	415	42.69	57.58	0	540
Number of maize transactions	371	2.121	1.670	1	20
Farmer transported maize to sale [Yes=1]	371	.067	.251	0	1

51% sorted the infected and rotten maize from the good maize before storage. For shelling, farmers use mostly shelling machines or beating in the sacks. Very few use hands only for shelling because it is labourious. The drying period varies a lot among farmers; the average number of days is four, which is relatively short, probably because most farmers let the maize dry in the field before harvesting

The farmers in the survey area use their maize mainly for consumption and sale, and are mostly surplus producers of maize. On average, about 53% of maize is stored for sale and 45% for own-consumption. Households store on average 214 kilograms of maize for food per capita, which is high for the area. The use of polypropylene sacks is the main storage method for most of the farmers (78%), whereas 19% use traditional storage methods such as reed cribs and bamboo granaries, and only 2% use modern storage such as silos or airtight drums. About 46% of the farmers store their maize in facilities that are disinfected before storage and 80% use different maize treatment techniques to protect their stored maize. These practices are used to reduce storage losses but they are also costly.

Of the maize that is harvested, 29% is sold within three months after harvesting. Marketing at this period is considered to be too early and is normally associated with low prices because of high supply of maize during the harvest period; however, it might be used as a technique to get rid of excess maize in case storage facilities are not adequate to avoid storage losses. In marketing their maize, farmers on average carry out two transactions. Normally the middlemen will come and buy from their homes; only 7% of those who sold maize transported it to the market themselves.

We next quantify the post-harvest losses in monetary terms. Post-harvest losses reduce the amount of crop available for sale or consumption. We assume that the monetary cost of this loss equals the market value of this maize if it were sold at the market or bought from the market. We therefore multiply the average amount of maize lost by the average price of maize[18] to get the value of the loss, as presented in Table 2.

TABLE 2: *Monetary costs of Post-Harvest Losses to the farmer*

Production(Kg)	**Price (USD)**	**Value (USD)**	**Loss(%)**	**Loss(Kg)**	**Value of Loss (USD)**
2749	0.2	550	11.7	322	64.4
Yield(Kg/Ha)	**Price (USD)**	**Value(USD)/Ha**	**Loss(%)**	**PHL(Kg)/Ha**	**Value of Loss/Ha**
1700	0.2	340	11.7	199	39.8

The amount of maize produced by farmers in our sample is worth, on average, USD

[18]The price figure is the average price of maize that farmers will get in the market during the normal time (neither lean nor harvest season) in the survey area.

550 per year. On average, 11.7% of the production, which is equivalent to 322 kg, is lost. This PHL is valued at USD 64.4. This loss is more than the median monthly income of the sample households, which is USD 50. So, on average, more than a month's income is lost as post-harvest losses in maize (based on a yearly harvest), which is a significant loss to a poor small-scale agricultural household. Another way of looking at this is to express it as cost per hectare. The cost of the mean amount of PHL per hectare per season is USD 40. This is similar to the cost of applying recommended maize top dressing fertilizer to one hectare for a season, which could increase the net maize returns by 15-27 percent over a season (Duflo et al., 2011).

5 Empirical Strategy and Estimation Results

5.1 Empirical Strategy

This section analyses the role of post-harvest handling practices in quantitative PHL of maize. We measure PHL experienced by farmers at different stages in the PH system: during the processes between harvesting and storage, during storage, and during marketing. We express PHL at each stage as a proportion of the total amount available at the beginning of each stage. Thus, pre-storage losses are expressed as a proportion of the amount of maize harvested; storage losses as a proportion of the amount stored; and marketing losses as a proportion of amount sold. So, the main outcome variables forming the dependent variables will be a fraction bounded by 0 and 1, inclusive.

Linear estimation methods such as OLS are not suitable to estimate fractional dependent variables. Bounded dependent variables often exhibit non-constant responses (slope) to changes in the explanatory variables, while linear models imply constant marginal effects, regardless of the initial value of the explanatory variable. Linear models may also produce predictions that lie outside the unit interval. Alternatively, nonlinear approaches such as logit and probit transformations have been established to curb the shortcomings of linear regressions. However, these approaches are not suitable in settings where a substantial portion of the observations are at the boundaries. In the logit transformation, for example, neither zeros nor ones can be included because the distribution is not defined for those values; this implies dropping the observations with values of zero or one, which would create a truncation problem, or coding them with some arbitrary values (Baum et al., 2008; Gallani et al., 2015). Another remedy could be using models that estimate bounded continuous dependent variables, such as censored and truncated regressions for example, tobit estimation. However, in the case of proportional data, the values outside the unit interval are not censored; rather, they are not feasible (Baum et al., 2008).

Papke and Wooldridge (1996) proposed a fractional response model (FRM) for handling outcome variables measured as proportions. The model they propose synthesizes and extends the generalized linear models (GLM) and quasi-likelihood methods to a class of functional forms with satisfying properties that overcome most of the known limitations of the other conventional econometric models for bounded dependent variables. The FRM takes into account the continuous and bounded nature of the dependent variable from both above and below, predicts response values within the interval limits of the dependent variable, and captures the nonlinearity effect of the predictors, thus producing a better fit than linear estimation models (Gallani et al., 2015)). Moreover, the FRM permits a direct estimation of the conditional expectation of the dependent variable, allowing zeros and ones as well as intermediate values to appear, and does not require ad-hoc transformations to handle data at the boundary values of zero and one (Baum et al., 2008; Gallani et al., 2015).

Papke and Wooldridge (1996) considered the following model for the conditional expectation of the fractional response variable:

$$E(y_i \mid x_i) = G(x_i\theta), i = 1, 2, ..., N \tag{1}$$

where $0 \leq \text{y}_i \leq 1$ denotes the dependent variable and (1 x k row vector) x_i represents the explanatory variables for observation i. $G(\cdot)$ is a known function satisfying $0 \leq \text{G}(\cdot) \leq 1$. A typical choice for $G(\cdot)$ is a cumulative distribution function, most popularly a logistic distribution $G(z) \equiv \text{exp}(z)/(1 + exp(z))$ directly estimated using nonlinear techniques.

The estimation procedure proposed by the authors is a particular quasi-maximum likelihood (QML) method based on a Bernoulli log-likelihood function, given by:

$$LL_i(\theta) = y_i Log[G(x_i\theta)] + (1 - y_i)[1 - G(x_i\theta)] \tag{2}$$

Because the Bernoulli distribution is a member of the linear exponential family (LEF), the QML estimator of θ, defined by:

$$\theta = \underset{\theta}{\text{argmax}} \sum_{n=1}^{N} LL_i(\theta) \tag{3}$$

is consistent and asymptotically normal, regardless of the true distribution of y_i conditional on x_i; and y_i could be a continuous variable, a discrete variable, or have both continuous and discrete characteristics. This method generates consistent and robust methods for estimation and inference of the model's parameters under general linear model conditions (Papke and Wooldridge, 1996)[19].

For the main regression analysis, we use the logit Quasi Maximum Likelihood estimation to estimate the fractional response model:

$$E(LOSS|x) = G(\alpha_0 + \alpha_1 PostHarvest + \gamma.VILLAGE) \tag{4}$$

where $LOSS$ is the proportion of loss experienced at different stages in the post-harvest system; $PostHarvest$ is a vector of post-harvest practices which include pre-storage handling practices and storage practices; and $VILLAGE$ is the vector of dummies for the villages.

The cross-sectional nature of the data does not allow us to determine whether the correlations we estimate are causal. There might be observable and unobservable differences across households that affect both the PHL and the PH handling practices. So, the PH handling practice variables may be endogenous because of omitted variables. Howevere, the richness of our data allows us to control for many observable farming and socioeconomic characteristics which might be driving both the PHL and the PH handling practices, which minimises the possible bias due to omitted variables. So, we estimate the model below:

$$E(LOSS|x) = G(\alpha_0 + \alpha_1 PostHarvest + \alpha_2 Farm + \alpha_3 SC + \gamma.VILLAGE) \tag{5}$$

where $Farm$ is a vector of farming characteristics and SC is a vector of socioeconomic characteristics.

We still cannot control for unobservable variables such as maize self-consumption pattern, thus we cannot rule out completely the possibility of endogeneity. We also do not have a credible instrument to enable us to use an instrumental variable strategy to solve the endogeneity problem. Nevertheless, the correlations between PH handling practices and PHL are still interesting for the discussion on PHL mitigation

[19]A concern arises about proportions data containing zeros or ones if these extreme values were generated by a different process. In this context, the GLM approach, while properly handling both zeros and ones, does not allow for an alternative model of behaviour generating the limit values (Baum et al., 2008). For example, a farmer with zero amount of maize sold may have made a discrete choice. If different factors generate the observations at the limit points, a sample selection issue arises. We cannot find any reason in this study that a different behaviour would generate zero losses among the maize farmers

5.2 Results

In Tables 3-5, we report the marginal effects from the estimation of the fractional response model for the effect of post-harvest handling practices on quantitative PHL at the pre-storage, storage, and marketing stages. In Column [1] of all the tables, only post-harvest handling practices are included as explanatory variables. The differences in post-harvest handling practices may, however, be due to observable characteristics across households that may also affect PHL. So, in Column [2] of Tables 3-5, we expand the specification by adding farming and socioeconomic characteristics to minimise the bias.

Table 3 presents the results of regressing the proportion of pre-storage losses on the post-harvest handling practices. Column [1] of the table shows that most of the 'good' post-harvest handling practices statistically significantly correlate with lower losses at the pre-storage stage. After including farming and socioeconomic characteristics in Column [2], the marginal effects of the post-harvest handling practices slightly decrease, but the significance or insignificance of the variables remains stable. So the interpretation will be based on the results in Column [2].

Sunny weather during harvesting significantly correlates with lower pre-storage losses by 0.7 percentage points compared to damp weather. If weather conditions during harvesting are rainy or cloudy, the moisture content of the grain is likely to be high, causing grain rotting and fungi growth. Harvesting maize immediately when it matures is significantly associated with 0.92 percentage points lower pre-storage losses compared to leaving matured maize to dry in the field or harvesting before full maturity. Immature maize is soft and has high moisture content, and thus is vulnerable to pests; maize left to dry in the field is exposed to infestation by insect pests and damage by birds and wild animals. Proper immediate handling after harvesting, which involves spreading harvested maize on a floor or platform, significantly correlates with lower pre-storage losses by 1.1 percentage points, compared to piling maize up or putting it directly into the sacks. Sorting out damaged and infested maize from the good maize is not significantly associated with lower losses at this stage. Sorting prevents exposure of uncontaminated grain to dirt and infestation, thus reducing losses. But the act of sorting itself means noticing the damaged grain and discarding it before the succeeding stage. So the two opposing effects may offset each other at this stage. We do not observe any significant differences in pre-storage losses associated with different methods used for maize shelling.

We also find that having a larger maize land area and more maize plots is significantly correlated with more pre-storage losses. This may be due to the increased logistic cost of dealing with bulky production and multiple plots. A greater number of active workers in

Table 3: *Pre-storage losses and post-harvest handling practices*

Dep. variable: Pre-storage losses as a proportion of total harvest [mean=0.029]	[1]	[2]
Post-harvest handling practices		
Weather at harvest [Sunny=1]	-0.0099***	-0.0069***
	[0.0018]	[0.0014]
Harvest at maturity	-0.0125***	-0.0092***
	[0.0026]	[0.0024]
Proper immediate handling [Yes=1]	-0.0125***	-0.0110***
	[0.0024]	[0.0017]
Maize sorted after harvesting	-0.0030*	-0.0019
	[0.0016]	[0.0013]
Drying period [days]	-0.0014**	-0.0012**
	[0.0006]	[0.0006]
Drying period squared	0.0000	0.0000
	[0.0000]	[0.0000]
% of maize shelled by machine	0.0052	0.0025
	[0.0040]	[0.0035]
% shelled by beating maize in sacks	0.0023	-0.0022
	[0.0043]	[0.0038]
Farming characteristics		
Hh years of Experience-Maize prod.		0.0001
		[0.0001]
Number of maize plots		0.0021*
		[0.0012]
% planted Hybrid varieties		-0.0011
		[0.0026]
Area planted maize		0.0018***
		[0.0007]
Socioeconomic variables		
Sex of Head of Hh [Male=1]		0.0045
		[0.0040]
Age of Head of Hh [Years]		0.0000
		[0.0001]
Years of schooling of Head of Hh		-0.0029***
		[0.0004]
Log value of assets		0.0007
		[0.0007]
Number of active workers		-0.0015**
		[0.0007]
Village Fixed Effects	YES	YES
Observations	415	415

Clustered standard errors in brackets
Pre storage losses are calculated as proportion of total amount of maize harvested.
*** p<0.01, ** p<0.05, * p<0.1

a household significantly correlates with lower losses. This is because most of the handling activities after harvesting require manual labour. Higher education of the head of household is significantly associated with lower pre-storage losses. More education may contribute to more effective and possibly safer application of post-harvest procedures, which may reduce PHL.
Next we analyse the drivers of storage losses.

Table 4 presents the correlations between post-harvest handling practices and quantitative storage losses. Column [1] of Table 4, which presents the model with only post-harvest handling practices as explanatory variables, shows that most of these practices are statistically significantly associated with lower storage losses. In Column [2], the farming and socioeconomic characteristics are added into the model specification. The marginal effects of the post-harvest handling practices decrease very slightly but their significance does not change. We carry on with further interpretation and discussion based on the results in Column [2].

Harvesting when the weather is sunny correlates with lower storage losses by 1.8 percentage points, compared to when it is cloudy and rainy. Damp conditions lead to high grain moisture content, which favours fungi growth and may cause grain rotting. Harvesting immediately when maize matures is significantly associated with lower storage losses by 2.4 percentage points, compared to late or too early harvesting.

Proper immediate handling after harvesting, by spreading harvested maize on a floor or platform rather than piling it up or keeping it in sacks, significantly correlates with lower losses during storage, by 2.2 percentage points. Sorting out dirty and infested maize grain from the uncontaminated grain significantly correlates with lower storage losses by 0.9 percentage points, compared to letting them mix. Drying period has a significant quadratic effect on storage losses. Specifically, drying maize longer is associated with storage losses, but drying beyond 26 days leads to more storage losses. Drying drives moisture out of the maize grain and makes the grain harder, which minimises the chances of fungi growth and rotting, and makes the grain less vulnerable to insect damage. But too much drying exposes the grain to outdoor pests. Methods used for maize shelling do not significantly drive storage losses.

We also do not find any significant difference in storage losses between the most popular method of storage (using sacks) and either traditional methods or modern airtight storage facilities. We do not find a significant effect from using airtight storage, probably because a very small proportion of households in the sample (2 percent) use them. Management of the storage facility and the stored product has a significant correlation with storage losses

Table 4: *Storage losses and post-harvest handling practices*

Dep. variable: Storage losses as a proportion of amount stored [mean=0.083]	[1]	[2]
Post-harvest handling practices		
Weather at harvest [Sunny=1]	-0.0202***	-0.0183***
	[0.0042]	[0.0038]
Harvest at maturity	-0.0258***	-0.0244***
	[0.0068]	[0.0068]
Proper immediate handling [Yes=1]	-0.0239***	-0.0220***
	[0.0055]	[0.0054]
Maize sorted after harvesting	-0.0099***	-0.0093***
	[0.0030]	[0.0036]
Drying period [days]	-0.0038***	-0.0040***
	[0.0010]	[0.0011]
Drying period squared	0.0001***	0.0001***
	[0.0000]	[0.0000]
% of maize shelled by machine	-0.0040	-0.0018
	[0.0086]	[0.0091]
% shelled by beating maize in sacks	-0.0103	-0.0126
	[0.0092]	[0.0090]
Storage method [base: Storage in Sacks]		
Store using traditional storage	0.0010	-0.0009
	[0.0072]	[0.0068]
Store using modern storage	-0.0120	-0.0090
	[0.0177]	[0.0187]
Storage facility disinfected [Yes=1]	-0.0316***	-0.0308***
	[0.0062]	[0.0069]
Used storage protectants [Yes=1]	-0.0219***	-0.0257***
	[0.0048]	[0.0056]
% sold 3 months after harvest	-0.0365***	-0.0354***
	[0.0131]	[0.0125]
Farming characteristics		
Hh years of Experience-Maize prod.		-0.0002
		[0.0002]
Number of maize plots		-0.00123
		[0.0033]
% planted Hybrid varieties		0.0000
		[0.0064]
Area planted maize		-0.0049***
		[0.0014]
Socioeconomic variables		
Sex of Head of Hh [Male=1]		0.0106
		[0.0093]
Age of Head of Hh [Years]		-0.0000
		[0.0002]
Years of schooling of Head of Hh		-0.0036***
		[0.0010]
Log value of assets		0.0031
		[0.0021]
Number of active workers		0.0007
		[0.0015]
Village Fixed Effects	YES	YES
Observations	415	415

Clustered standard errors in brackets
Storage losses are calculated as proportion of amount stored for those who stored maize
*** p<0.01, ** p<0.05, * p<0.1

reduction. Disinfecting the storage facility before storing the harvest and protecting the stored products (using chemical protectants and ashes for storage pests, and poisons and traps for rats) significantly correlate with lower storage losses, by 3.1 percentage points and 2.6 percentage points, respectively. Selling a large proportion of maize within three months after harvesting is also associated with lower storage losses. This result is intuitive as economic damages by storage pests normally start being experienced after three months..

We do not find a significant correlation between the proportion of hybrid maize seeds used and the storage losses. This is good news because the hybrid seeds are intended to increase maize yield. A larger amount of land farmed with maize is associated with lower storage losses. This might reflect the importance of maize to the household and the attention provided to reduce stored maize loss. Of the socioeconomic characteristics, only education is significant. Education of the head of household is a significant factor for lower storage losses. Education influences the choice of good practices and effectiveness in their implementation.

Lastly, we analyse the determinants of losses during maize marketing. There is no substantial difference between the parsimonious model in Column [1] of Table 5 and the model in Column [2] that includes socioeconomic characteristics, in terms of the marginal effects and significance of marketing factors.

We find that farmers experience more marketing losses if they transport maize themselves during marketing and if they carry out many transactions. One more transaction increases the marketing losses by 0.3 percentage points, and transporting maize for sale by one's self leads to greater losses by 1.6 percentage points. We do not find significant effects on marketing losses of the distance to the nearest main road or distance to the nearest market on marketing losses. This may be due to the fact that, in the study area, farmers sell maize to agents who come to collect it from their home. Marketing losses are thus mainly driven by the logistical processes involved.

5.3 Robustness check

In this section, we check the robustness of our main results to alternative model specifications or estimations. In particular, we undertake robustness checks using the following specifications:

i. To check whether the results are sensitive to the outlier producers, we first exclude observations falling outside one standard deviation from the mean of land area used for maize production. Second, we exclude the observations falling outside one standard deviation from the mean of the amount of maize harvested. For the case of estimation

Table 5: *Determinants of quantitative marketing losses*

Dep. variable: Marketing losses as a proportion of amount sold [mean=0.0185]		
	[1]	[2]
Time to nearest main road	0.0000	0.0000
	[0.0001]	[0.0001]
Time to nearest market	0.0000	0.0000
	[0.0000]	[0.0000]
Number of transactions	0.0034***	0.0034***
	[0.0007]	[0.0007]
Farmer transported maize to sale	0.0140***	0.0158***
	[0.0014]	[0.0021]
Sex of Head of Hh [Male=1]		-0.0079***
		[0.0016]
Age of Head of Hh [Years]		0.0000
		[0.0001]
Years of schooling of Head of Hh		-0.0002
		[0.0003]
Log wealth		-0.0006
		[0.0009]
Number of active workers		0.0015***
		[0.0005]
Hh years of Experience-Maize prod.		0.0001
		[0.0001]
Area planted maize		0.0013**
		[0.0005]
Village Fixed Effects	YES	YES
Observations	371	371

Clustered standard errors in brackets
Marketing losses are calculated as proportion of total amount of maize sold.
*** p<0.01, ** p<0.05, * p<0.11

of determinants of marketing losses, we exclude the observations falling outside one standard deviation from the mean amount sold.

ii. Because we have a small number of clusters (20), using standard cluster-robust standard errors can over-reject the null of zero effect (Cameron et al., 2008). We therefore check the robustness of our inferences by estimating an Ordinary Least Square model and using a wild-cluster bootstrap-t procedure.[20]

The robustness check results for drivers of pre-storage losses, storage losses and marketing losses are shown in Tables A2, A3 and A4 respectively in the appendix. For comparison, Columns [1] in all these tables present the full specification estimation results[21] obtained using the fractional response model which we have discussed in the main results section.

Columns [2] of Tables A2 and A3 present the results for drivers of pre-storage losses and storage losses after excluding observations with outliers in maize land size. We observe that the significance, sign and size of the marginal effects are robust, except for the effect of maize land size, which becomes insignificant in some cases. We also check the sensitivity with regard to the total amount of maize harvested by excluding the outliers. The results are shown in Columns [3] of Tables A2 and A3. Again, the results are robust, except for maize land size in the storage losses model, which becomes insignificant. So, the effect of maize land size that we observe is mainly driven by the outliers. For drivers of marketing losses in Table A4, after excluding the outliers in terms of quantity sold, the results remain robust.

Because of the fractional nature of the dependent variables, we estimated a fractional response model using logit QML and standard cluster-robust errors. For our second robustness check, we estimate the linear model and use the wild-bootstrap cluster-t procedure. The results for pre-storage losses and storage losses are shown in Columns [4] of Tables A2and A3 in the appendix and those of sales losses are shown in Column [3] of Table A4 in the appendix. These results are qualitatively and quantitatively consistent with the main estimations in Columns [1].

[20]See Cameron et al. (2008) for the discussion on small number of clusters. We used the Stata code cgmwildboot.ado, available at https://sites.google.com/site/judsoncaskey/data, which reports the OLS estimation coefficient as well as the p-values of tests of the null that the coefficient is 0, computed using the wild-bootstrap cluster-t procedure.

[21]That is columns [2] of Tables 3- 5 are used as baselines.

5.4 Post-Harvest Losses and Food Security

Post-harvest losses reduce the amount of crop available for consumption. Thus they may impact the food security status of the household. We used the third version of the Household Food Insecurity Access Scale (HFIAS) questionnaire [22] to measure household food insecurity status. The questions were asked with a recall period of four weeks.

This food insecurity questionnaire consists of nine 'yes or no' occurence questions representing a generally increasing level of severity of food insecurity, and nine 'frequency-of-occurrence' questions. The respondent is first asked whether the condition occured at all in the past four weeks. If the respondent answers 'yes' to an occurrence question, a frequency-of-occurrence question, scored 1-3, is asked to determine whether the condition happened 1=rarely (once or twice), 2=sometimes (three to ten times) or 3=often (more than ten times) in the past four weeks. The questions range from inquiring about the respondents' *perceptions* of food vulnerability or stress (e.g., did you worry that your household would not have enough food?) to the respondents' *behavioral responses* to insecurity (e.g., did you or any household member have to eat fewer meals in a day because there was not enough food?). The questions address the situation of all household members without distinguishing adults from children (Coates et al., 2007).

From responses to the nine questions we constructed a food insecurity scale for the household. If the response to the question on occurrence was 'No' we assigned that response a score of 0; if the response was 'Yes' (and therefore the respondent proceeded to answer the frequency-of-occurrence question) we gave that response a score between 1 and 3 according to the frequency. Then the total food insecurity scale for each household was calculated by adding the scores from all nine questions. Thus the most food-secure household would receive a score of 0 on the food insecurity scale and the most food-insecure household would receive a score of 27. On average the food insecurity score from our sample was 6.6 with a minimum of 0 and a maximum of 26. This implies that the sampled households were, on average, moderately food insecure during the recall period.

We now analyse the effect of post-harvest losses on food security. The outcome variable is the food insecurity scale score, which takes the value of a whole number between 0 and 27. We control for other factors that might also affect household food security, such as agricultural land area, which can proxy for the amount of food produced by the household; amount of maize stored for food, which captures the consumption plan; and socioeconomic

[22] The questionnaire was developed by the U.S. Agency for International Development (USAID) Bureau for Global Health, through the Food and Nutrition Technical Assistance Project (FANTA) for measurement of household food access.

variables such as wealth (measured by value of assets owned by the household), household size, etc., which affect households' food decisions. However, we do not claim causality because of the possible endogeneity problem due to omitted variables, such as household consumption pattern, which affect both post-harvest losses and the household food situation. Because of the count data nature of the outcome variable, we estimate the following equation using Poisson regression:

$$FoodInsecurity = \alpha_0 + \alpha_1 PHL + \alpha_2 SC + \alpha_3 FarmFoodBehvr + \alpha_4 VILLAGE + \epsilon \quad (6)$$

where $FoodInsecurity$ is the food insecurity scale score of the household; PHL is the total maize post-harvest losses experienced by the household as a percentage of the amount of maize harvested; SC is a vector of socio economic characteristics; $FarmFoodBehvr$ is a vector of farming and food storage behavior of the household; $VILLAGE$ is a vector of dummies for the villages; and ϵ is the error term.
The marginal effects from the Poisson model estimation for food insecurity are presented in Table 6.

TABLE 6: *Correlation of Post-Harvest Losses and Food insecurity*

Dependent variable: Food insecurity scale score [Mean=6.6]	
Post-Harvest Loss (%)	0.0980***
	[3.7670]
Sex of Head of Hh [Male=1]	-0.0333
	[0.5360]
Age of Head of Hh [Years]	-0.0207
	[0.0190]
Years of schooling of Head of Hh	-0.1990*
	[0.1020]
Log value of assets	-1.0150***
	[0.1620]
Household size	0.2780*
	[0.1460]
Area of agricultural land cultivated	-0.3130*
	[0.1670]
Maize stored for food per capita	-0.0035**
	[0.0017]
Village FE	YES
Observations	415
Pseudo R-squared	0.172
Clustered Standard errors in brackets	
*** p<0.01, ** p<0.05, * p<0.1	

Table 6 shows that maize post-harvest losses have a positive and significant correlation with household's food insecurity. A percentage point increase in PHL in maize is associated with an increase of 0.1 of the food insecurity. To put this into context, a 10 percentage points increase in PHL in maize is associated with a movement of a moderately food insecure household form eating a limited variety of foods due to a lack of resources once or twice a month to limiting the food variety three to ten times a month. This correlation is big enough to draw attention to the importance of mitigating PHL. Other factors, such as the amount of maize stored for food purposes per capita, the amount of agricultural land cultivated, wealth and education, display significant correlations with low food insecurity.

5.5 Cost-Benefit Analysis of Post-Harvest Losses Mitigation

We have found that most of the 'good' post-harvest handling practices are statistically significantly correlated with lower PHL, and their marginal effects are large. A puzzling question is: Why are these practices not adopted by some farmers? It might be that the cost of reducing PHL is too high. In this section, we carry out a cost-benefit analysis of PHL mitigation to solve the puzzle.

We consider the mitigation of PHL in the first two stages of the PH system in our analysis: pre-storage and storage. First, we find the total marginal effect of each post-harvest handling practice in the pre-storage stage and the storage stage, obtained in the regressions (as presented in Column [1] of Table 7). Then, we find the value per ton of maize saved by employing each practice.[23]

To determine the additional cost of adopting each practice, we collected information from farmers on the hours of labour, amount of money, or both, required to adopt each of the practices. Next, we converted the labour hours into monetary term by multiplying by the labour cost per hour[24] in the study area. The monetary costs of adopting a mitigation practice are shown in Column [6]. Then, in Column [7], we present the net benefit of employing each post-harvest handling practice.

The results in Column [7] of Table 7 show that, on average, it is economically beneficial to invest in some practices, namely: timely harvesting, proper immediate handling (i.e., spreading maize after harvesting), maize sorting, and disinfecting the storage facility. Drying maize for an extra day and protecting stored maize are not economically beneficial.

[23]We obtain this value by calculating the amount of maize saved in kilograms, then multiplying it by the average price of maize, which is USD 0.2 per kilogram.

[24]We calculated the average labour cost per hour in the study area from different farm activities; it is about USD 0.5 per hour.

Table 7: *Cost benefit analysis of PHL mitigation*

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
	Benefit from mitigation			**Cost of mitigation**			
	Total marginal effect	Amount mitigated per ton (kg)	**Value of maize saved per ton (USD)**	Labor hours of mitigation per ton	Monetary cost of mitigation per ton (USD)	**Monetary cost of mitigation per ton(USD)**	**Net mitigation benefit per ton (USD)**
Harvest at maturity	0.034	33.63	**6.73**	8.93		**4.46**	**2.26**
Proper immediate handling	0.033	33.00	**6.60**		6.37	**6.37**	**0.23**
Sorting Maize	0.011	11.22	**2.24**	3.59		**1.80**	**0.45**
Drying an extra day	0.005	5.00	**1.00**	3.35		**1.68**	**-0.68**
Disinfect store facility	0.031	30.80	**6.16**	2.10	4.26	**5.31**	**0.85**
Protect stored maize	0.026	25.70	**5.14**	1.35	4.47	**5.17**	**-0.01**

So, why do farmers still not adopt the practices with positive net benefits? One explanation is that the average net gains we observe are small.[25] Therefore, compared to alternative investments, it might be profitable not to invest in PHL mitigation. Another possible explanation is that farmers know the cost of mitigating PHL but they are uncertain about the actual benefits of adopting the good practices. Thus, risk aversion may deter them from adopting good practices. It might also be the case that farmers are stuck to traditional ways that increase PHL and are not aware of the PHL mitigating practices.[26] In that case, training might improve their decision making. But this requires more analysis.

6 Conclusion

In recent years, concerns about food insecurity have heightened in SSA due to the rapidly growing population and the frequent increases in food prices (FAO, 2011). Many efforts to increase food production may be constrained by limited resources such as agricultural land and water, as well as by climate variation. PHL reduction has been identified as a key component to complement efforts to address food security challenges and improve farm incomes, especially for the rural poor (World Bank, 2011).Effective investment in PHL reduction requires clear knowledge of the magnitudes of the losses, the drivers of the losses at each stage, and the opportunity cost involved in mitigating the losses (Affognon et al., 2015).

[25]Only one of them, timely harvesting, saves more than a dollar per ton.

[26]During focus group discussion, it was revealed that most farmers let maize dry on the field, which is the traditional way of drying cereal crops, and did not know that it is not a good practice.

This study contributes to the initial steps of addressing PHL by (i) measuring quantitative PHL experienced by maize farmers at three stages: during processes between harvesting and storage, during storage, and during marketing; (ii) analysing the role of post-harvest handling practices in PHL reduction; and (iii) carrying out a cost-benefit analysis of adopting good PH handling practices

We find that maize farmers experience 11.7 percent quantitative PHL. Of these losses, 2.9 percent is lost during the processes after harvesting until just before storage; 7.8 percent is lost during storage; and 1.1 percent is lost during marketing. The value of this quantitative PHL is estimated to be USD 64.4 per household, which is about 1.2 times the median household monthly income. This loss value is too high to ignore, and should be considered as the lower boundary. Qualitative losses have not been considered in this study but are also of significance, because they reduce revenues due to lost market opportunities and impact on the nutritional value of the grain. We also find that PHL negatively affect the food security status of the household. These findings imply that reducing PHL can potentially improve farmers' income and food security.

In analysing the role of post-harvest handling practices in PHL reduction, we potentially face an endogeneity problem. Observable and unobservable differences across households may be driving both the PHL and the PH handling practices. The cross-sectional nature of our data and lack of credible instrumental variables, which would enable us to use IV techniques, constrain us from establishing causality. To minimise the bias, we control for most of the observable farming and socioeconomic characteristics which might affect both the decision to adopt the practices and the PHL. Our empirical analysis shows that adoption of good post-harvest handling practices significantly and sizably correlates with low levels of PHL. We also find that education of the head of household correlates strongly with lower losses. Education might lead to more effective implementation of PHL mitigation strategies. The results are robust after the exclusion of outliers in terms of the amount of land used for maize and the amount of maize harvested, for the case of pre-storage and storage losses, and the amount of maize sold, for the case of marketing losses.

We went a step further to analyse why some farmers do not adopt these good post-harvest handling practices despite their large marginal effects. It is clear that farmers will invest in mitigating PHL if there is an economic motivation to do so. We conduct a cost-benefit analysis of adopting the post-harvest practices. The results show that most of the practices are on average economically beneficial. However, the average net gains per ton of maize are small, except for one practice: harvesting at maturity. This may explain why some farmers do not adopt these practices. Some farmers might actually be facing negative net benefits. It could also be the case that farmers do not know the actual benefits of adopting the good practices. So, even if they are aware of how much it might cost them to adopt the practice, they cannot risk doing so because they do not know what the returns will be. Other practices which have not been included in our analysis may also be imposing costs, such as the health effects from chemical residues due to storage disinfectant and insecticides. Farmers may be taking these costs into consideration.

We point out some policy implications from our study, although these require more analysis too. First, investment in technologies that lower the cost of adopting good practices may increase the adoption of good practices. Second, extension services and training to provide awareness of the potential benefits of good post-harvest practices may reduce the uncertainty about possible economic gains, which may make the farmers more likely to adopt.

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Appendix A

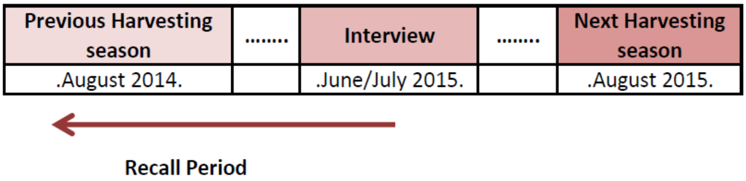

Figure A1: Timeline for the interviwews and recall period

TABLE A1: *Main causes of Storage Losses*

Main Cause of the loss	**Frequency**	**Percent**
Insects	138	41
Rodents	159	48
Moisture and Rotting	27	8
Others	9	3
Total	**333**	**100**

Table A2: *Robustness check: Determinants of Pre-storage Losses*

Dep. variable: Pre storage loss as a proportion of total harvest[mean=0.029]				
	[1]	[2]	[3]	[4]
	Main Result	Outliers: maize land area	Outliers: Amount harvested	OLS: wild bootstrap cluster-t
Post-harvest handling practices				
Weather at harvest [Sunny=1]	-0.0069***	-0.0078***	-0.0074***	-0.0096***
	[0.0014]	[0.0016]	[0.0016]	
Harvest at maturity	-0.0092***	-0.0093***	-0.0101***	-0.0056**
	[0.0024]	[0.0028]	[0.0024]	
Proper immediate handling [Yes=1]	-0.0110***	-0.0116***	-0.0114***	-0.0091***
	[0.0017]	[0.0018]	[0.0019]	
Maize sorted after harvesting	-0.0019	-0.0017	-0.0008	-0.0015
	[0.0013]	[0.00158]	[0.00167]	
Drying period [days]	-0.0012**	-0.0012*	-0.0014**	-0.0010
	[0.0006]	[0.0007]	[0.0006]	
Drying period squared	0.0000	0.0000	0.0000	0.0000
	[0.0000]	[0.0000]	[0.0000]	
% of maize shelled by machine	0.0025	0.0027	0.0026	0.0025
	[0.0035]	[0.0034]	[0.0035]	
% shelled by beating maize in sacks	-0.0022	-0.0026	-0.0026	-0.0015
	[0.0038]	[0.0039]	[0.0038]	
Farming characteristics				
Hh years of Experience-Maize prod.	0.0001	0.0001	0.0001	0.0001
	[0.0001]	[0.0001]	[0.0001]	
Number of maize plots	0.0021*	0.0008	0.0010	0.0016*
	[0.0011]	[0.0018]	[0.0019]	
% planted Hybrid varieties	-0.0011	-0.0008	-0.0008	-0.0014
	[0.0026]	[0.0026]	[0.0029]	
Area planted maize	0.0018***	0.0033	0.0037***	0.0025***
	[0.0007]	[0.0021]	[0.0014]	
Socioeconomic variables				
Sex of Head of Hh [Male=1]	0.0045	0.0036	0.0041	0.0046
	[0.0040]	[0.0041]	[0.0039]	
Age of Head of Hh [Years]	0.0000	0.0001	0.0001	0.0000
	[0.0001]	[0.0001]	[0.0001]	
Years of schooling of Head of Hh	-0.0029***	-0.0028***	-0.0031***	-0.0028***
	[0.0004]	[0.0004]	[0.0004]	
Log value of assets	0.0007	0.0003	0.0004	0.0005
	[0.0007]	[0.0007]	[0.0007]	
Number of active workers	-0.0015**	-0.0013*	-0.0017**	-0.0014**
	[0.0007]	[0.0007]	[0.0008]	
Village Fixed Effects	YES	YES	YES	YES
Observations	381	381	372	415
R-squared				0.4269
Clustered standard errors in brackets				
*** p<0.01, ** p<0.05, * p<0.1				

Table A3: *Robustness check: Determinants of Storage Losses*

Dep. variable: Storage loss as a proportion of amount stored [mean=0.083]	[1]	[2]	[3]	[4]
	Main Result	Outliers: maize land area	Outliers: Amount harvested	OLS: wild bootstrap cluster-t
Post-harvest handling practices				
Weather at harvest [Sunny=1]	-0.0183***	-0.0194***	-0.0197***	-0.0235***
	[0.0038]	[0.0039]	[0.0045]	
Harvest at maturity	-0.0244***	-0.0270***	-0.0256***	-0.0180***
	[0.0068]	[0.0070]	[0.0075]	
Proper immediate handling [Yes=1]	-0.0220***	-0.0205***	-0.0236***	-0.0199***
	[0.0054]	[0.0056]	[0.0050]	
Maize sorted after harvesting	-0.0093***	-0.0084**	-0.0063*	-0.0080**
	[0.0036]	[0.0037]	[0.0033]	
Drying period [days]	-0.0040***	-0.0037***	-0.0037***	-0.0032***
	[0.0011]	[0.0011]	[0.0011]	
Drying period squared	0.0001***	0.0001***	0.0001***	0.0001***
	[0.0000]	[0.0000]	[0.0000]	
% of maize shelled by machine	-0.0018	-0.0034	-0.0035	-0.0034
	[0.0091]	[0.0095]	[0.0091]	
% shelled by beating maize in sacks	-0.0126	-0.0128	-0.0136	-0.0155
	[0.0090]	[0.0093]	[0.0093]	
Storage method [base: Storage in Sacks]				
Store using traditional storage	-0.0009	0.0012	0.0010	-0.0030
	[0.0068]	[0.0064]	[0.0071]	
Store using modern storage	-0.0090	-0.0157	-0.0292	-0.0000
	[0.0187]	[0.0212]	[0.0275]	
Storage facility disinfected [Yes=1]	-0.0308***	-0.0303***	-0.0293***	-0.0297***
	[0.0069]	[0.0066]	[0.0067]	
Used storage protectants [Yes=1]	-0.0257***	-0.0245***	-0.0229***	-0.0333***
	[0.0056]	[0.0056]	[0.0050]	
% sold 3 months after harvest	-0.0354***	-0.0382***	-0.0330***	-0.0353**
	[0.0125]	[0.0123]	[0.0119]	
Farming characteristics				
Hh years of Experience-Maize prod.	-0.0002	-0.0001	-0.0002	-0.0001
	[0.0002]	[0.0002]	[0.0002	
Number of maize plots	-0.0012	-0.0042	-0.0028	0.0003
	[0.0033]	[0.0047]	[0.0047]	
% planted Hybrid varieties	0.0000	0.0006	-0.0019	-0.0059
	[0.0064]	[0.0069]	[0.0068]	
Area planted maize	-0.0049***	-0.0035	-0.0026	-0.0048***
	[0.0014]	[0.0043]	[0.0024]	
Socioeconomic variables				
Sex of Head of Hh [Male=1]	0.0106	0.0110	0.0105	0.0114
	[0.0093]	[0.0095]	[0.0092]	
Age of Head of Hh [Years]	0.0000	-0.0000	-0.0001	0.0000
	[0.0002]	[0.0002	[0.0002]	
Years of schooling of Head of Hh	-0.0036***	-0.0034***	-0.0043***	-0.0033***
	[0.0010]	[0.0011]	[0.0012]	
Log value of assets	0.0031	0.0025	0.0034	0.0026
	[0.0021]	[0.0022]	[0.0022]	
Number of active workers	0.0007	0.0005	0.0002	0.0004
	[0.0015]	[0.0018]	[0.0016]	
Village Fixed Effects	YES	YES	YES	YES
Observations	415	381	372	415
R-squared				0.591
Clustered standard errors in brackets				
*** p<0.01, ** p<0.05, * p<0.1				

Table A4: *Robustness check: Marketing Losses*

Dep. variable: Sales losses as a proportion of amount sold [mean=0.0185]	[1]	[2]	[3]
	Main Result	Outliers: Amount harvested	OLS: wild bootstrap cluster-t
Time to nearest main road	0.0000	0.0000	0.0000
	[0.0001]	[0.0001]	
Time to nearest market	0.0000	-0.0000	0.0000
	[0.0000]	[0.0000]	
Number of transactions	0.0034***	0.0032***	0.0082***
	[0.0007]	[0.0007]	
Farmer transported maize to sale	0.0158***	0.0173***	0.0190***
	[0.0021]	[0.0027]	
Sex of Head of Hh [Male=1]	-0.0079***	-0.0083***	-0.0050**
	[0.0016]	[0.0019]	
Age of Head of Hh [Years]	0.0000	-0.0000	-0.0001
	[0.0001]	[0.0001]	
Years of schooling of Head of Hh	-0.0002	-0.0001	-0.0003
	[0.0003]	[0.0003]	
Log wealth	-0.0006	-0.0004	-0.0003
	[0.0009]	[0.0009]	
Number of active workers	0.0015***	0.0013**	0.0013**
	[0.0005]	[0.0006]	
Hh years of Experience-Maize prod.	0.0001	0.0001	0.0001
	[0.0001]	[0.0001]	
Area planted maize	0.0013**	0.0027***	0.0006
	[0.000518]	[0.000758]	
Village Fixed Effects	YES	YES	YES
Observations	371	338	371
R-squared			0.554
Clustered standard errors in brackets			
*** p<0.01, ** p<0.05, * p<0.1			

Paper II

How economically effective are hermetic bags in maize storage?: A RCT with small scale farmers

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Abstract

Uncertainty about possible economic gains from technology to reduce post-harvest losses may hinder adoption and lead to inefficient choices and a suboptimal level of losses. This study analyses the impact and the economic effectiveness of two randomised interventions with small-scale maize farmers in rural Tanzania on post-harvest loss reduction. Farmers in the first treatment group were given training on post-harvest management practices; those in the second treatment were given the same training and were in addition provided with hermetic (airtight) bags for storing maize. We show that both interventions had a significant effect in reducing storage losses but not pre-storage losses. The intervention with hermetic bags improved the quality of maize grain as perceived by farmers, increased the market price of maize, and reduced the cost of storage protection using insecticides. We show that both interventions are economically feasible. We suggest provision of training on post-harvest management practices and motivation to use hermetic bags as policy options to reduce post-harvest losses among small-scale farmers.

JEL Classification: C93 · Q18 · Q16 · Q12 · D61

Keywords: randomised controlled trial · post-harvest losses · training · hermetic bags · small-scale farmers · cost-benefit analysis

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1 Introduction

Post-harvest losses (PHL) of food constitute one of the largest factors contributing to food insecurity, poor nutrition, hunger, and low incomes, directly impacting the lives of millions of poor, smallholder farming households (Costa, 2015; FAO, 2011; World Bank, 2011). It is estimated that, in Sub-Saharan Africa (SSA), post-harvest physical grain losses range from 10 to 20 percent of the total grain production, at a value of USD 4 billion per year (World Bank, 2011).[1] Reducing PHL provides an important avenue for combating hunger, improving food security and nutrition, and raising income in SSA (Affognon et al., 2015; FAO, 2011). FAO estimates that about half of the USD 940 billion needed for investment to eradicate hunger in SSA by 2050 should be geared toward reduction of post- harvest losses by investing in cold and dry storage, rural roads, rural and wholesale market facilities, and first stage processing (FAO-World Bank, 2010).[2]
In this study, we conduct a randomised controlled trial to examine the economic effectiveness of a newly introduced hermetic bags technology for maize storage among smallholder farmers.

Different PHL reduction technologies have been developed and promoted in various SSA countries.[3] Despite the potential gains from PHL reduction, the adoption of these technologies, especially among smallholder farmers, is puzzlingly low (World Bank, 2011). Non-adoption of seemingly profitable technologies has been a subject of interest in economics and numerous studies have been conducted to explain the puzzle. First, the technology may be physically or financially inaccessible to farmers. Second, it has been established that low adoption may be a reflection of the (observable and unobservable) heterogeneity in the costs and benefits that farmers accrue when using the technology (Suri, 2011). So, the technology will be adopted by the farmers with high net returns, while those with low returns will not do so. Once the heterogeneity is taken into account, there is no puzzle. Third, farmers may fail to adopt because of behavioral biases due to time inconsistency or risk preferences (Duflo et al., 2011; Liu, 2013). Fourth is that, while most technologies may seem to provide good returns when tested on experimental farms, the net returns in real-world situations might be different (Duflo et al., 2008).

These explanations motivate our study from three angles. First, those introducing PHL reduction technology may not know the characteristics of the farmers, which may affect their

[1]The estimates are according to the African Postharvest Losses Information System (APHLIS), reported in the World Bank's 2011 report *Missing Food: The Case of Postharvest Grain Losses in Sub-Saharan Africa*.

[2]Estimates made in 2006

[3]Technology in a wider sense means the relationship between inputs (knowledge, skills, materials, or processes) and outputs (Flor et al., 2010). So, adoption of new technologies means both the use of new mappings between inputs and outputs and the corresponding allocation of inputs that exploit the new mappings (Foster and Rosenzweig, 2010).

adoption behavior. Second, farmers may be uncertain about the true marginal benefit and cost of adopting the technology; in an environment characterised by risk and loss aversion, most of them might be reluctant to adopt (Kadjo et al., 2013). This may lead to inefficient choices and suboptimal levels of PHL. Third, to fully realise the benefits from technology adoption in the real world, adoption may need to be accompanied by other supporting practices (Baoua et al., 2014).

Studies on hermetic bags conducted on experimental farms have shown that the bags are effective in controlling insects and are economically beneficial if they last three years (Baoua et al., 2014; De Groote et al., 2013). The field experiment study on hermetic bags by Ndegwa et al. (2016) found that hermetic bags become potentially profitable, under basic price and loss assumptions, if farmers use hermetic bags for storage for at least four months per season, and if the bags last at least four seasons.

We contribute to the literature on adoption of storage technologies, specifically hermetic bags, by studying the impact of two interventions: (1) training on post-harvest management practices; (2) provision of hermetic bags bundled with such training. Our study differs from the previous studies in the following ways. (i) We provide hermetic bags as well as training on supporting post-harvest handling practices. It has been argued that efficient use of hermetic bags should go along with the application of appropriate post-harvest handling practices (Baoua et al., 2014). Most importantly, maize stored in hermetic bags should be well dried and clean, and separated from the chaff and all other dirt particles, which limits the risk of fungi contamination. (ii) We consider benefits beyond PHL reduction, including perceived quality of maize, market price of maize, and reduced use of insecticides in protecting stored maize, as well as the costs of supporting practices that come along with the adoption of hermetic bags. (iii) Our analysis covers almost the entire period from when maize is harvested to just a month before the next harvesting season, which enables us to capture the full benefits and costs incurred by, the farmer in the post-harvest system.

We take into account that the farmers poor knowledge and skills on post-harvest management may also be largely responsible for the food losses (Meikle et al., 2002); and that increasing farmers knowledge on post-harvest management could reduce food losses (Abass et al., 2014). It could be the case that, once farmers are well informed about loss mitigation practices, then they can make efficient choices and there would be no need of other interventions to reduce PHL. Thus, we use a separate treatment which provides training only, without hermetic bags.

Our results indicate that both interventions had significant effects in reducing storage losses but not on pre-storage losses. The intervention with hermetic bags improved the quality of maize as perceived by farmers and the market price of maize, and also reduced the cost of storage using insecticides. We also find that both interventions are economically feasible and suggest that training on post-harvest management practices and motivation to use hermetic bags should be considered as policy options to reduce post-harvest losses among small-scale farmers.

The paper proceeds as follows: Section 2 presents an overview of efforts to reduce post-harvest losses; Section 3 presents the experimental design; Section 4 describes the data; Section 5 describes the estimation strategy; Section 6 presents the results; Section 7 provides the cost-benefit analysis for the economic effectiveness of the interventions; and Section 8 is the conclusion.

2 An Overview of efforts to reduce PHL

Interest in PHL reduction started back in the mid-1970s after the food crisis.[4] The United Nations declared that PHL reduction in developing countries should be undertaken as a matter of priority (World Bank, 2011). Initially, considerable investments were made on PHL reduction in grains and, in later years, the coverage extended to roots, tubers, fruits and vegetables (Affognon et al., 2015). In SSA, food losses at the post-harvest handling and storage stages are high relative to the distribution and consumption stages, due to inadequate handling, poor storage facilities and lack of infrastructure (Costa, 2015; FAO, 2011). This led to interventions taking a producer perspective, putting more efforts toward improving harvest techniques, farmer education and storage facilities (Affognon et al., 2015).

After food prices stabilised, and due to low adoption of the PHL technologies promoted in various SSA countries, the importance of PHL in the African grain sector was downsized. International programs such as FAO's Prevention of Food Losses Program and the Global Postharvest Forum (PhAction) became dormant (World Bank, 2011). In recent years, food security concerns have increased following the 2008 surge in food prices, variability in climate, and rapid population growth. This has reignited an interest in PHL reduction.

Maize is the staple food crop in most of SSA countries. In Tanzania, maize comprises about 72 percent of total cereals production in the country (TNBS, 2012). Maize contributes about 35 percent of the daily calorific intake in Tanzania. Its production is highly seasonal, whereas its consumption over the year is relatively constant in Eastern and Southern Africa

[4] This food crisis exploded in 1973 and 1974 and was characterised by rapid food price increases in the West and by famines in Africa and Asia. The main causes were bad weather, rising agricultural input prices, grain export bans and hoarding of food purchases

(Gitonga et al., 2013). Maize storage is therefore important for food security because it smooths the supply throughout the year, as well as stabilizing prices, which plummet during the peak season and surge during the lean season (Proctor, 1994).

In the past, maize farmers in Africa have used traditional methods and structures such as woven, mud-plastered granaries and house roofs to store maize. These methods were effective at the time, but the recent changes in climatic conditions and the introduction of the Larger Grain Borer (LGB)[5] into East Africa necessitated improvement in post-harvest management and storage of maize (Gitonga et al., 2013; Ndegwa et al., 2016). Pest attacks on maize not only cause grain weight losses but also increase the risk of mycotoxin[6] contamination and poisoning. Mycotoxin contamination makes grain unsafe as food, thus adversely affecting food safety (Hoffmann and Gatobu, 2014). Traditional storage practices in East African countries therefore no longer ensure proper protection for stored maize over an adequate length of time (Tefera et al., 2011).

Currently in Tanzania, the use of polypropylene bags (sacks) is popular among small-scale farmers. These sacks are cheap; portable in case of emergencies (e.g., floods, fires); make it easy to monitor quality; can be kept within the house after loading, serving as a protection against spillage and theft; take up less space in the room (as opposed to a large woven granary that fills a whole room, whether empty or full); and are always ready for marketing in case of need for emergency or opportunistic sales (Ndegwa et al., 2016; World Bank, 2011). However, these sacks do not provide protection against moisture and storage pests. To limit storage pests infestation, farmers apply several methods, such as the use of pesticides, insecticidal plants and ashes (Farrell and Schulten, 2002). The efficacy of these methods, their accessibility and their economic effectiveness is highly variable. Meikle et al. (2002) found that use of maize storage chemicals was not economically viable. Moreover, use of pesticides can have negative impacts on the environment, and can be hazardous for human health (FAO-WHO, 2016; Kumari et al., 2012)

To avoid high losses due to lack of suitable grain storage structures and absence of storage management technologies, smallholders tend to sell their maize immediately after harvest. Consequently, they receive low market prices for their maize because they sell when

[5]The larger grain borer (*Prostephanus Trancatus*), is a devastating storage pest introduced into Africa from Central America in the late 1970s. It is now widely recognised as the most destructive pest affecting stored maize and dried cassava in Africa. It is associated with a significant increase in storage losses after its introduction (Boxall, 2002).

[6]The most common and most dangerous mycotoxin is aflatoxin (poisonous and cancer-causing chemicals produced by *Aspergillus flavus* and *Aspergillus parasiticus*, which grow in grains, soil, and decaying vegetation). Production of aflatoxin is facilitated by excessive heat, drought stress and pest attacks during crop development, and inadequate drying and poor storage conditions after harvest (Hell et al., 2008; Wilson and Payne, 1994).

the market is flooded. In addition, they may be forced to buy grain for consumption at a higher price just a few months after harvest, when their stock is exhausted. They also lose an opportunity to use their harvest as collateral to access credit (Abass et al., 2014; Kimenju et al., 2009).

Improved storage technologies, mainly hermetic storage methods, have been developed in response to those storage challenges. These include metal silos and hermetic bags. Metal silos are airtight and have proven to be effective in protecting the maize grains from both storage insects and rodent pests (Fao, 2008). They kill insect pests that are inside the silos, without the use of pesticides, by suffocating them (De Groote et al., 2013; Tefera et al., 2011). Though metal silos could potentially reduce post-harvest losses and allow storage for a longer period, they are expensive. A 100-kg, one-ton and three-ton metal silo costs around USD 35, 210 and 375 respectively (Ndegwa et al., 2016; Tefera et al., 2011). The high start-up cost makes them unaffordable to most small-scale farmers. Moreover, the metallic structure means that they permanently occupy space, whether they are used or not, and that they cannot be easily stored in the bedroom to prevent theft during food shortage periods. The effectiveness of metal silos may also decrease when grain is removed because oxygen levels are likely to increase.

Hermetic storage bags offer a recently developed technology. These bags have two or more layers. The outer layer is the normal sack (polypropylene bag) and the inner layers are special plastic (high density polyethylene) linings, which are air-proof. They are cheap, at a cost of about USD 2 for a 100-kg bag.[7] These bags are accessible and affordable to farmers. In addition, they are easier to use. Hermetic bags kill storage pests by depriving them of oxygen. Once some grains are off-loaded from the bag, the bags can easily be tightened again to keep them airtight and reduce the oxygen level to prevent insect pests from surviving.

3 Experimental design

3.1 Study Area

The study was conducted in Kilosa district in the Morogoro region in the eastern side of Tanzania. According to the 2012 population census, the district had a population of 438,175. The district offers a variety of agro-ecological conditions for cultivation of different crops, such as maize, rice, millet, cassava, beans, bananas and cowpeas (Kajembe et al., 2013).

[7]For an hourly agricultural wage of USD 0.50 in the study area; the price of one 100-kg hermetic bag, USD 2, is equivalent to a wage for four hours.

Crop farming is the main economic activity for 55% of the households in the district (TNBS, 012b).Maize is the main food crop in Kilosa and, in a normal year, the district is a surplus producer of maize.

Kilosa district receives an average annual rainfall of 800-1400 mm (Kajembe et al., 2013). It experiences two rain seasons: the short rains between November and January and the long rains between March and early June. The district experiences a long dry season from June to October. Despite having two rain seasons, the pattern and amount of rainfall in the district allow for only one harvest of the main staples per cropping season (MOVEK Development Solution, 2008). The climatic condition of Kilosa district is a typical one for maize production.[8] Kilosa district has been identified by the Southern Agricultural Growth Corridor of Tanzania (SAGCOT)[9] as one of the districts with high potential to increase maize production. This study uses Kilosa district as a case study; generalization of the results may not apply to other districts.

Despite efforts to increase production, the goals of improving food security, reducing rural poverty and ensuring environmental sustainability may be constrained by post-harvest losses. Results from the baseline survey show that post-harvest losses in maize are significantly correlated with household food insecurity and lead to income losses equivalent to a month of household income per year (Chegere, 2017). The hermetic bags were developed as an affordable technology that small-scale farmers can use to reduce storage losses caused by insect infestation and rotting, and to preserve grain quality without using chemical protectants. This study provides evidence on the economic effectiveness of the use of hermetic bags for maize storage in Kilosa.

3.2 Sample Selection

The sampling framework comprised households in villages which met two criteria (1) Maize is the main crop produced by the villagers and (2) maize is the main staple food in the village. The selection of these villages was done after consulting the district administrative secretary and the district agricultural officer and then confirmed by respective village leaders and

[8] Because many maize growing districts in Tanzania and other Sub-Saharan African countries are similar in terms of climate, production scale and technology, as well as types of maize pests and diseases, the findings from this study will also be relevant to other parts of Tanzania and other Sub-Saharan African countries.

[9] SAGCOT was initiated at the World Economic Forum (WEF) Africa Summit 2010 with the support of the Government of Tanzania and private sector companies. Its objective is to foster inclusive, commercially successful agribusinesses that will benefit the regions small-scale farmers, and, in so doing, improve food security, reduce rural poverty and ensure environmental sustainability. The risk-sharing model of a public-private partnership (PPP) approach has been demonstrated to be successful in achieving these goals and SAGCOT marks the first PPP of such a scale in Tanzanias agricultural history.

village agricultural officers. This selection was important to ensure that our interventions were targeted to the most relevant group of farmers. We used a two-stage sampling process to recruit participants in our survey. In the first stage, we randomly selected 21 villages from the list of villages which met the above criteria. In the second stage, we randomly selected 20 maize-farming households from each village from the household roster obtained from the village office. So, the total sample consisted of 420 households in 21 villages.

3.3 Implementation

During April and May 2015, prior to the main baseline survey, we conducted preliminary fact finding. This involved consultation with village agriculture extension officers and focus group discussions and interviews with farmers and village leaders in two villages in Kilosa district that were not included in the main survey. The preliminary study enabled us to thoroughly understand the maize production cycle and post-harvest systems in the study area. We learnt when farmers plant and harvest, how they carry out the processes from harvest until storage, how they store, what losses they experience post-harvest, and how they protect their stored grain. The responses show that they normally plant one crop of maize per year and that most of them use propylene sacks for maize storage. They were not aware of the hermetic bags technology for maize storage. Farmers experience post-harvest losses and have to spend a good deal of money on protecting the stored grain. We also conducted a pilot survey to test our questionnaire with 20 households in one village that was not included in the main survey.

We conducted the main survey between the last week in June and mid-July in 2015.[10] In each household, we interviewed either the head of household or the spouse. The baseline questionnaire collected information on demographic and other socio-economic characteristics, household food security, maize production practices, and post-harvest losses and post-harvest management practices in the previous agricultural season. Because the survey was conducted close to the end of the maize farming season in the district, the loss figures reported covered almost the entire post-harvest period for grain.

By the end of July 2015, we implemented the intervention. The aims of the intervention were to improve post-harvest management practices, introduce the hermetic bags storage technology to some of the treated villages, and then measure the impact of doing so on PHL reduction. We worked in collabouration with an agronomist in providing the training on post-harvest management practices and with two companies manufacturing hermetic bags to distribute the bags and explain their usage. During the baseline period, only 22 percent

[10]The timeline of the events is shown in Figure A1 in the appendix

of the farmers reported ever having attended training on post-harvest losses, and none of them had ever used hermetic bags.

In order to minimise spill-over effects from treatment groups to the control group, we assigned treatments at village level. We randomly assigned the villages to the two treatment groups Bags and Training (6 villages) and Training only (6 villages) and the control group (9 villages). Figure A2 in the appendix show the map of the study area and the distribution of villages according to experimental groups.

In the first treatment group, 120 farmers in 6 villages were given training on maize post-harvest handling and storage techniques. Then, they were provided hermetic bags and trained on how to use them. We will refer to this group as the 'training and hermetic bag' treatment. The training was designed and conducted by agronomists who are specialised in maize production and post-harvest management and have field experience in working with farmers. The content and material for the course were gathered from various sources, including maize harvesting and post-harvest management guidelines from the ministries and departments of agriculture in East Africa, consultation with NGOs working with maize farmers and dealing with post-harvest losses, researchers and academic articles, and field experience.[11]

The topics covered included: time to harvest; requirements during the harvesting process; harvesting; drying; shelling; storage and storage structures; and losses due to poor storage. The training sessions in each village lasted about one and a half to two hours. In each village, farmers were trained in either one or two groups depending on convenience. One trainer conducted the training on maize post-harvest management in all villages and another trainer did so for the use of hermetic bags. Farmers were given the training guide to read and follow and had the chance to ask questions and seek clarification as much as they wished during the training session and at the end

Then the farmers in this 'training and hermetic bag' treatment were trained on using the new storage technology of hermetic bags. They were also given a two-page leaflet that explained what hermetic bags are, how hermetic bags are used, the benefits of using hermetic bags, and things to consider when using the bags. The benefits of using hermetic bags include killing insects by suffocation and being able to store maize without using insecticides; the possibility of storing for a longer period; and being able to use the bag for up to three seasons. Farmers were also informed about the adverse effects that can happen if the bags are not used properly. For example, storing maize with high moisture content in the hermetic

[11]We consulted Alliance for a Green Revolution in Africa (AGRA) and NAFAKA project, NGOs which work closely with maize farmers. We also consulted maize and crop protection researchers at Sokoine University of Agriculture in Tanzania

bags can cause fungal growth and rot all the grain in the bag; also, if a bag is perforated by rodents, then it loses its air-proof quality. It was important that the intervention with hermetic bags was bundled with training because getting good outcomes with bags requires farmers to have followed good practices prior to storage, especially in drying.

At the end of the session, each farmer received the hermetic bags. In the baseline survey, we had asked farmers how many acres of land they had planted in maize during the prevailing season and how much maize they expected to harvest. We gave them the number of bags that would store about 60% of their expected harvest. This was done for three reasons. First, farmers tend to be optimistic about the amount they can harvest and thus the expected harvest would in most cases be larger than the true amount harvested. Secondly, it is recommended that, once the grains are stored in hermetic plastic bags, the bag should remain sealed for at least six weeks to stop oxygen from entering the bag, which could revive the pests that were dying of suffocation. Thus, some of the maize, which would be used for food or sales within six weeks after storage, would not be stored in the hermetic bags. Thirdly, this was intended to minimise the chances that some farmers would end up with excess bags and decide to sell them, which could contaminate our experiment.

Farmers were asked to use the hermetic bags solely for maize storage and were asked not to give or lend them to other farmers. To facilitate this, we asked them to inform their neighbors and relatives that they were in agreement with the researchers from the University of Dar es Salaam to use all the bags themselves, and that the researchers would be checking periodically to assess their use. In November and December 2015, a random physical visit to about 50 percent of the farmers who received the bags was made at their homes to observe whether the bags were used and whether the farmers had any challenges in using them. The feedback was very good, in that the farmers did not experience any challenges in using the bags and they used the bags that were given to them

In the second treatment group, which we will refer to as the ‘training only’ treatment, 120 farmers received the same training on maize harvesting and post-harvest handling, including the benefits of effective storage in reducing PHL and various technologies available to achieve them, but were not given hermetic bags. In both treatment groups, subjects were given the training manuals and a leaflet with verbal and pictorial explanations and illustrations about post-harvest technologies.

Although one of the advantages of using hermetic bags is being able to store grain for a longer period, farmers in the treatment groups were not instructed to commit themselves to store any particular amount of maize for any period. This is because asking farmers to commit themselves might have hindered them from making the best decisions for themselves,

such as selling at a time when the prices were good or when they could benefit from lower transactional costs. This was also done to avoid having farmers completely exclude themselves from participating due to fear of losing freedom over their harvest.
The control group consisted of 180 farmers from 9 villages, who continued with business as usual.

4 Data and Descriptive Statistics

The data used in this study was collected in two separate household surveys. The baseline survey was conducted June-July 2015 and the follow-up survey was carried out in June 2016. In the baseline, the questionnaire was administered to the heads of households or their spouses or any other adult in the household who was involved in maize farming decisions. The follow-up survey interviewed the same person. The baseline consisted of 420 households. During the follow-up and in several attempts thereafter, 22 households could not be induced to respond to the survey. One household was dropped from the analysis because it was an outlier, operating on a large scale and not representing the smallholder. Overall, the data consists of 397 observations, although there are sometimes missing items on single questions.

In the baseline and follow-up surveys, we collected information on PHL experienced after the previous harvest at three stages: between harvesting and storage, during storage, and during marketing. The information was self-reported and involved a recall period of about ten months. The farmers reported the loss at each stage in terms of kilograms, number of buckets, or number of bags, depending on what they found easier to estimate. All the quantities were then converted into kilograms.[12] We asked the following questions to elicit the losses:
(i) How much was the loss from the time you harvested to storage time (taking into account all losses during transporting, drying, shelling and winnowing)?
(ii) How much was the maize loss between the time you stored and the moment you used it for consumption or took it for sale?
(iii) How much was the loss at the marketing stage (taking into account all the stages from taking the grain from storage to weighing and transporting it)?

To minimise recall bias in estimates of the losses experienced by farmers, the losses were assessed step-wise with indirect cross-checking questions for greater robustness. Enumerators were also well trained and tested off the field and on the field during the pilot, to ensure

[12] In each village, we explored the weights of maize when put in different vessels used by farmers in carrying maize. We also probed whether farmers knew how much maize weighs when put in those vessels. In most cases, their responses were the same as our measurements.

effective collection of data. After the baseline data collection, we also instructed farmers to keep an account of the amount of maize they harvested, consumed and sold, at least at the end of each month, to be used in the follow-up. We also collected information on maize farming practices, post-harvest activities (including storage and marketing), and food security, during both baseline and follow-up surveys. The information on the socio-demographic characteristics of the households and social networks was collected in the baseline only.

Table 1 presents selected summary statistics measured at the baseline for the 397 households, together with tests for balance across treatment groups. The majority of the heads of households are male (86%) and they were 47 years old on average. The average number of years of schooling of the household head is 7.1 years which is similar to completion of primary school.[13] The households are fairly large, with 5.4 members; on average, 3 of them are active workers.[14] The households mean annual income is USD 1053, which translates to approximately USD 0.60 per person per day.[15] Their stock of assets is valued on average at USD 4289. The income and stock of wealth figures imply that the households are relatively poor, but with considerable variation within the sample, as shown by the standard deviations.

The subjects have on average 19 years of experience with maize farming, which implies that maize has been part and parcel of their lives for a long time. Most of their agricultural land is devoted to maize production, which is planted on 1.7 hectares of their 2.6 hectares of agricultural land, on average. They harvested about 2.8 tons of maize in the 2014 season, which implies a yield of about 1.6t/ha, which is above the national average of 1.3 t/ha and above the district average of 0.98 t/ha in 2007, reported in the Tanzania Agricultural sample survey, 2007/08.[16] Most of the households (89%) sold some of their maize from the 2014 harvest season; the amount of maize sold was on average 1.9 tons for those who sold.[17] The remaining amount was mostly used for food at homes and seeds for the next planting season. About 29% of maize produced is sold within three months after harvesting. This is done essentially to meet the pressing demand for cash and as a technique to avoid storage losses.

[13]Primary school education in Tanzania is seven years.

[14]Active workers were defined as those household members who are between the ages of 15 and 64 and who have no health or physical impediment to working.

[15]It is important to point out that most of these households live at the subsistence level and normally grow their own food.

[16]The large variation in yield observed across time may be due to variations in weather conditions across years. It could also be because the sample is representative of a typical maize-farming smallholder who relies mainly on maize for food and income, while all maize-farming households are included in calculating the figure in the agricultural survey. Still, this yield is below the potential rain-fed maize yield in Tanzania, which is estimated to be 4t/ha (Mourice et al., 2015)

[17]This is on average 51% of the amount of maize produced for the whole sample.

Table 1: *Baseline Summary statistics and Randomization tests*

Variable	Obs	ALL Mean	ALL Stdv	1-CONTROL Mean	1-CONTROL Stdv	2-TRAINING Mean	2-TRAINING Stdv	3-TRAIN+BAGS Mean	3-TRAIN+BAGS Stdv	[1 - 2] Diff	[1 - 3] Diff	[2 - 3] Diff
Socioeconomic characteristics												
Sex	397	0.86	0.35	0.84	0.37	0.87	0.33	0.87	0.34	-0.035	-0.030	0.004
Age	397	46.9	12.1	48.6	11.6	46.6	11.4	44.7	13.1	1.95	3.88**	1.93
Years of schooling	397	7.06	2.81	7.16	3.11	6.65	2.59	7.32	2.51	0.516	-0.154	-0.67*
Number of active workers	397	3.03	1.57	3.06	1.66	3.11	1.72	2.91	1.27	-0.051	0.146	0.197
Household size	397	5.45	2.07	5.61	2.19	5.50	2.17	5.14	1.75	0.113	0.472**	0.360
Yearly Income (USD)	397	1053	1278	1060	1117	1019	1614	1077	1145	41.0	-17.7	-58.7
Value of assets (USD)	397	4289	7030	4742	7361	4407	6809	3487	6710	335.0	1254.8	919.8
Maize farming practices												
Maize experience (Years)	397	19.0	12.2	19.7	12.6	18.0	11.2	18.9	12.4	1.728	0.877	-0.851
Got PH training before	397	0.22	0.42	0.21	0.41	0.24	0.43	0.24	0.43	-0.028	-29	-0.000
Area of Land for agric (ha)	397	2.62	2.24	2.65	2.49	2.56	2.29	2.61	1.76	0.089	0.040	-0.050
Area of Land for maize (ha)	397	1.67	1.45	1.75	1.70	1.67	1.34	1.55	1.11	0.075	0.193	0.119
Number of maize plots	397	1.37	0.74	1.35	0.66	1.33	0.88	1.43	0.72	0.025	-0.077	-0.103
Amount harvested (Kgs)	395	2803	2766	2874	2912	2817	3104	2683	2148	56.6	191.2	134.6
Amount of maize stored (Kgs)	394	2645	2597	2749	2824	2618	2771	2510	2012	131.3	239.2	107.9
Sold maize (Yes=1)	395	0.89	0.31	0.87	0.33	0.90	0.30	0.92	0.27	-0.027	-0.049	-0.022
Amount sold (Kgs)	353	1872	2234	1925	2423	1845	2457	1821	1688	80.6	104.2	23.6
Amount sold within 3 months (Kgs)	395	855	1049	860	1090	907	1227	797	769	-47.4	62.1	109.6
% sold in 3 months	395	0.29	0.19	0.28	0.21	0.29	0.18	0.30	0.18	-0.006	-0.018	-0.012
Average price per ton (USD)	351	179.4	43.74	178.6	45.66	180.7	49.06	179.5	35.19	-2.091	-0.968	1.123
Weather at harvest(Sunny=1)	393	0.81	0.39	0.80	0.40	0.86	0.35	0.78	0.42	-0.061	0.022	0.084
Harvest at maturity [Yes=1]	394	0.19	0.39	0.18	0.39	0.19	0.40	0.19	0.40	-0.011	-0.012	0.000
Proper immediate handling [Yes=1]	397	0.29	0.45	0.31	0.46	0.30	0.46	0.25	0.44	0.006	0.052	0.046
Maize sorted (Yes=1)	395	0.51	0.50	0.51	0.50	0.53	0.50	0.51	0.50	-0.026	-0.003	0.023
Number of days maize dried	397	4.77	10.48	4.82	10.06	4.78	10.56	4.68	11.12	0.039	0.137	0.098
Store disinfected (Yes=1)	394	0.45	0.50	0.47	0.50	0.44	0.50	0.45	0.50	0.025	0.014	-0.011
Used any means to protect (Yes=1)	394	0.80	0.40	0.76	0.43	0.79	0.41	0.86	0.35	-0.027	-0.097**	-0.069
Used chemical protectants	394	0.60	0.49	0.60	0.49	0.61	0.49	0.60	0.49	-0.016	0.013	-0.003
Used traps and poisons	394	0.17	0.38	0.17	0.38	0.18	0.39	0.16	0.37	-0.009	0.015	0.024
Protections costs per ton (USD)	394	4.88	3.89	4.65	3.94	5.12	4.29	4.68	3.38	-0.470	-0.325	-0.145
Post-Harvest Losses												
Pre-storage losses	395	0.029	0.022	0.028	0.021	0.029	0.019	0.030	0.025	-0.001	-0.002	-0.001
Storage losses	395	0.079	0.057	0.084	0.061	0.077	0.051	0.074	0.053	0.007	0.010	0.003
Marketing losses	395	0.010	0.013	0.011	0.015	0.009	0.011	0.010	0.011	0.003*	0.001	-0.001
Total Losses	395	0.118	0.069	0.124	0.071	0.115	0.065	0.114	0.071	0.008	0.010	0.001

Different maize harvesting and post-harvest management practices are variably employed by households. Most of them, 81%, harvested when the weather was mainly sunny, as compared to when it was cloudy and rainy. Only 19% and 29% of the households harvested the maize immediately when it matured and spread the maize after harvesting, respectively. The common practice in the sample area is to leave maize in the field to dry while on the stalks and, once the harvest has taken place, to heap the maize in small piles to dry more. However, these practices are not recommended because they increase the risk of pest infestation. About half (51%) of the households sorted the good maize cobs or grains from the dirty and infected ones after harvesting, to avoid contamination. The farmers dry maize for 4.7 days on average. 45% and 80% of the households disinfected their stores and used other means to protect their stored crops, respectively. These practices may help to reduce storage losses but may also be an indication of the significance of storage losses the farmers face.

The post-harvest losses figures were self-reported by the subjects. They were divided into three stages: the losses occurring between harvesting and storage (referred as pre-storage losses in this study); storage losses, which occurred during storage until the time of consumption or sales; and marketing losses, which occurred in the process of selling maize. On average, farmers experienced a total of 11.7% post-harvest losses relative to the quantity harvested. Of the three stages, farmers experienced the most losses during storage, averaging 7.9% of the amount harvested. The main stated causes of storage losses were rodent attacks, insect infestations, moisture and rotting. Pre-storage losses were on average 2.9%, occurring mainly during shelling, drying and transporting to the homestead. Marketing losses were low, about 1%, as most farmers sell their maize to agents who collect them from their homes.

Balance tests were carried out to check how successful the randomization was in forming treatment and control groups with households with similar baseline characteristics. The mean values of the selected key variables were compared across the groups and the null hypotheses that the differences in means are not statistically significantly different from zero were tested. For most of the variables, the differences in means were not statistically significantly different from zero. Out of the 84 mean values that were compared, only 5 were statistically different from zero at the 10% level of significance. These pre-intervention differences are minor and are not expected to bias the results. However, results with control variables are also presented for a robustness check, and results seem to be insensitive to the control variables.

Attrition was not a big problem in this experiment, in that 94.7% of the households in the baseline were found in the follow-up survey. Attrition was slightly different across the experimental groups. It was 3.9% in the control group, 7.6% in the 'training only' treatment and 5% in the 'training and hermetic bag' treatment. The main reason given for not finding households during the follow-up was migration to towns or other villages. We examine the characteristics of the attritors and non-attritors for the whole sample and for the experimental groups; results are reported in the appendix Table A1). Generally, attritors have fewer years of experience with maize, are relatively poor, and experienced lower post-harvest losses in the previous season. Attritors in the control group tend to be those with more education and more post-harvest losses. Attritors in the training treatment are those who are relatively poor and have fewer years of experience in maize farming. Attritors in the training and bags treatment are those who are less educated and have less years of maize farming experience. The factors driving attrition are consistent with the reasons for the absence of most of the attrited households because poor households and those less experienced in maize farming tend to shift more, seeking opportunities for other activities.

5 Estimation strategy

Because the treatments were randomly assigned at village level, the average observable and unobservable characteristics of the households should be similar across the experimental groups at the baseline. The baseline statistics shown in Table 1 verify that there were no significant differences in observable mean characteristics of the households across the experimental groups. Thus, the impact of the interventions can be identified by simple mean comparison across the groups. Using a simple regression framework, for each outcome, the estimation equation is:

$$Y_{iv} = \alpha + \gamma.B_v + \sigma.T_v + X'_{iv}\beta + \epsilon_{iv} \tag{1}$$

where Y_{iv} is the outcome variable of interest for household i in village v. B_v is an indicator variable equal to 1 if the village received training on post-harvest management and hermetic bags for maize storage. T_v is an indicator variable equal to 1 if the village received training on post-harvest management only. For each outcome, regressions were run both with and without the household level socio-economic controls, X_{iv}. The inclusion of controls improves efficiency if they predict variance in the dependent variable (Mutz and Pemantle, 2011). $\epsilon_i v$ are the error terms. The coefficient measures the effect of training on post-harvest management and the effect of using hermetic bags for maize storage on the outcome of interest. The effect of training on maize post-harvest management training only is measured by .

The dependent variables of interest are PHL at pre-storage and storage stages; maize grain qualities; use of storage protectants; maize price; and household food insecurity index.

We also considered the issue of statistical inference in our case, where we have few (21) clusters. With a small number of clusters, the usual techniques for calculating cluster-robust standard errors based on asymptotic theory provide downward-biased standard errors. So, with few clusters, the standard asymptotic tests tend to over-reject the null of no effect (Bertrand et al., 2004; Cameron et al., 2008). We use the wild cluster bootstrap approach proposed by Cameron et al. (2008) for making inferences.[18] In the estimation results tables, we report the p-values of tests of the null that the coefficient is 0, computed using the wild-bootstrap cluster-t procedure. Clustering is done at village level.

We also estimate the impact using Difference-in-Differences (DID) specifications to check how robust the results are. DID removes biases in follow-up comparisons between the treatment groups and the control group if there were unobservable permanent differences between experimental groups. It also removes the bias from comparisons over time that are due to trends. We estimate the DID for the balanced and unbalanced panel. We estimate the following DID model.

$$Y_{iv} = \alpha + \gamma.B_v + \sigma.T_v + \theta.t + \phi.(B_v * t) + \omega.(T_v * t) + X'_{iv}\beta + \epsilon_{iv} \tag{2}$$

This model has three more terms thano the model in (1): t which is the time dummy equal to 1 for the follow-up period. $(B_v * t)$ which is the interaction between the 'training and hermetic bag' treatment and the follow-up dummy; and $(T_v * t)$ is the interaction between the 'training only' treatment and the follow-up dummy. The coefficients γ and σ capture possible differences between the treatment and control groups prior to the interventions. The coefficient θ captures changes in the outcome variable between the two periods even in the absence of the interventions. ϕ and ω are the coefficients of interest which capture the effects of the interventions.

6 Results

This section describes the impact of training and hermetic bags interventions on post-harvest losses and assesses the economic effectiveness of hermetic bags in maize storage.

[18]We used the Stata code cgmwildboot.ado, available on Judson Caskeys website https://sites.google.com/site/judsoncaskey/data, which reports the OLS estimation coefficient as well as the p-values of tests of the null that the coefficient is 0, computed using the wild-bootstrap cluster-t procedure.

6.1 Impact on Post-harvest Losses

We first examine the impact of the interventions on quantitative post-harvest losses at two stages: between harvesting and storage (pre-storage) and during storage (storage losses), as presented in Table 2. Columns [1] and [3] in Table 2 represent the results of estimation models without socioeconomic controls, whereas Columns [2] and [4] include socioeconomic controls.

Table 2: *Impact on Post-harvest Losses*

	[1]	[2]	[3]	[4]
VARIABLES	Pre-storage losses		Storage losses	
Mean of Dep. Variable	0.0292	0.0292	0.0926	0.092
Training + Bags	-0.0046	-0.0046	-0.0670***	-0.0676***
	(0.4970)	(0.4609)	(0.0040)	(0.0040)
Training Only	-0.0063	-0.0064	-0.0277**	-0.0283**
	(0.2886)	(0.2846)	(0.0120)	(0.0240)
Sex		-0.0098*		0.0063
		(0.0601)		(0.4890)
Age		-0.0002		-0.0002
		(0.2886)		(0.6773)
Years of schooling		0.0001		0.0007
		(0.9259)		(0.6533)
No. of active workers		0.0004		0.0037
		(0.7214)		(0.4128)
Wealth (USD)		0.0000		-0.0000
		(0.1924)		(0.7575)
Maize farming experience (years)		-0.0003		-0.0002
		(0.1884)		(0.6974)
Got PH Training before		-0.0506		-0.0137
		(0.2725)		(0.2084)
Constant	0.0292***	0.0490***	0.0926***	0.0864**
	(0.0000)	(0.0020)	(0.0000)	(0.0296)
Observations	395	395	390	390
R-squared	0.008	0.045	0.109	0.120

Wild-cluster bootstrap-t p-values in parentheses.
Pre storage losses are calculated as proportion of total amount of maize harvested.
Storage losses are calculated as proportion of amount stored for those who stored maize
*** p<0.01, ** p<0.05, * p<0.1

With respect to pre-storage losses, the 'training and hermetic bags' treatment had a positive but insignificant effect, as shown in Column [1] of Table 2. The intervention reduced pre-storage losses by 0.46 percentage points, which is equivalent to a 16% decrease in pre-storage losses. As for storage losses, Column [3] of Table 2 suggests that the training and hermetic bags intervention reduced such losses by 6.7 percentage points, which is a 73% reduction in storage loss. This effect is statistically significant at 1%. Not surprisingly, the results are substantially the same after the inclusion of socioeconomic controls, because of the random assignment of villages to experimental groups (Table 2, Columns [2] and [4]).

The results in Columns [1] and [3] indicate that training on post-harvest management helped farmers reduce pre-storage and storage losses. Farmers who received training experienced lower pre-storage losses, by 0.64 percentage points (a 22% reduction in losses), compared to those in the control group. However, this effect is not statistically significant. Post-harvest management training led to a 2.8 percentage point reduction (30% reduction) in storage losses. The effect is statistically significant at the 1% level.
The impacts of both interventions remain the same after including the socio-economic control in Columns [2] and [4].

The DID estimation results for the effect of the interventions on PHL for the balanced and unbalanced panel are reported in Table A2 in the Appendix. The marginal effects of both interventions on pre-storage losses increase slightly, while the effects on storage losses decrease slightly. This implies that there was a small bias which has been corrected. The significances of the marginal effects remain stable.

We also explore the heterogeneous effect of the interventions across income groups. In particular, in Table A3, we look at the effects of the interventions on PHL for the lower and the upper income quartiles and for the bottom and top half of income. We find that the results are similar to the main results. So the effect of the interventions was similar across the income groups.

6.2 Impact on the qualitative characteristics of stored maize grain, sales behavior and maize price

Physical quality of the grain is important for maize marketing as well as for consumption. It is used to signify the nutrient content of the maize grain. Farmers were asked if the size and shape, aroma, and taste and color of the maize grain were maintained after being stored. They responded whether they greatly agree=4, agree=3, disagree=2 or greatly disagree=1 with the statement.

They were also asked to compare the degree of maize infestation and rotting before and after storage, to which they responded that it remained the same=1, increased=2 or increased greatly=3. We also asked them the amount of maize they sold three months after harvesting. Using that information, we calculated the proportion sold three months after harvest relative to the total amount of maize harvested. We asked farmers who sold maize the highest and the lowest price they obtained in their transactions, then calculated the mean value to obtain the average price of maize. We estimate the impacts of the interventions on those qualitative outcomes and on sales price for those who sold maize.

Columns [1]- [4] of Table 3 show that both 'training and hermetic bags' and 'training only' treatments have positive impacts on the physical characteristics of the stored maize grain. However, only the effects of 'training and hermetic bags' on size and shape of maize and maize aroma are significant, at 5% and 10%, respectively. The use of hermetic bags seems to add more to the qualitative characteristics of the maize grain when bundled with training. These results imply that better management combined with hermetic technologies can potentially increase the market value of maize. We also find that there were statistically significantly lower degrees of pest infestation and rotting of maize after storage in the 'training and hermetic bags' treatment compared to the control group (Columns [5] and [6] of Table 3). The degrees of pest infestation and rotting of maize were also lower in the 'training only' treatment, but the effects are not statistically significant.

Column [7] of Table 3 shows that the farmers in the treated groups sold 4.8 and 2.2 percentage points less in the first three months in the training and hermetic bags group and training only group, relative to the control. However, the effects are not statistically significant. Because hermetic bags reduce the risk of storage losses, they may allow farmers to store grain for a longer period and make opportunistic sales. Column [8] indicates that households in 'training and hermetic bags' and 'training only' treatments sold their maize at USD 13.0 (equivalent to 5.8%) and USD 6.5 (equivalent to 3%) more per ton respectively compared to those in the control group. The effect is statistically significant at 5% for the 'training and hermetic bags' intervention but insignificant for the 'training and only' intervention. The higher price may be due to higher quality of maize, as we have observed, or because of opportunistic sales.

Table 3: *Impact on the qualitative characteristics of stored maize grain, sales behavior and price*

VARIABLES	[1] Size and shape	[2] Aroma	[3] Taste	[4] Color	[5] Pest infestation	[6] Rotting	[7] Prop sold 3 months after harvest	[8] Average maize price obtained
Mean of dept. variable	3.45	3.41	3.43	3.51	1.29	1.24	0.18	USD 221.8
Training+Bags	0.4923**	0.4540*	0.4114	0.3370	-0.3107**	-0.2370**	-0.0483	12.983**
	(0.0240)	(0.0801)	(0.1403)	(0.1403)	(0.0120)	(0.0160)	(0.1924)	(0.0281)
Training Only	0.2238	0.2024	0.2209	0.1771	-0.1516	-0.0847	-0.0223	6.4583
	(0.2405)	(0.4088)	(0.3848)	(0.3768)	(0.1362)	(0.3046)	(0.6693)	(0.3367)
Sex	-0.1752	-0.0858	-0.06523	-0.1036	0.0517	0.0134	0.0376	3.5763
	(0.1963)	(0.4289)	(0.6012)	(0.2886)	(0.4930)	(0.8818)	(0.3327)	(0.7255)
Age	-0.0047	-0.0059	-0.0040	0.0000	-0.0028	-0.0015	-0.0011	-0.4480
	(0.3647)	(0.2926)	(0.3968)	(1.0000)	(0.2405)	(0.6493)	(0.2365)	(0.2485)
Years of schooling	-0.0133	0.0073	0.0000	0.0035	-0.0217*	-0.0069	-0.0007	1.2550
	(0.4930)	(0.6733)	(0.9820)	(0.9218)	(0.0721)	(0.5050)	(0.9218)	(0.1603)
No. of active workers	-0.0108	-0.0415*	-0.0258	-0.0135	0.0348	0.0072	-0.0081	0.8237
	(0.7735)	(0.0921)	(0.2766)	(0.6453)	(0.1643)	(0.7856)	(0.2445)	(0.5210)
Wealth (USD)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006
	(0.1242)	(0.5010)	(0.7134)	(0.8297)	(0.4409)	(0.3126)	(0.8657)	(0.2445)
Years of experience	0.0052	0.0079	0.0049	0.0037	-0.0014	-0.0006	0.0000	-0.0656
	(0.2806)	-1723	(0.3607)	(0.2766)	(0.7054)	(0.7615)	(0.9579)	(0.8457)
Got PH Training before	-0.0181	0.0581	0.0495	0.1165	-0.0229	-0.0604	-0.0141	3.0410
	(0.9299)	(0.53301	(0.5731)	(0.1764)	(0.8016)	(0.3126)	-6212	(0.4810)
Constant	3.615***	3.463***	3.458***	3.372***	1.576***	1.418***	0.252***	220.59***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Observations	390	390	390	390	390	390	397	312
R-squared	0.084	0.073	0.060	0.050	0.075	0.041	0.017	0.070

Wild-cluster bootstrap-t p-values in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

We therefore run an estimation of the average price of maize received by farmers on the index of maize quality[19] and proportion of maize sold within three months after harvesting plus other controls. The results presented in Table A4 in the appendix show that opportunistic sales play a significant role compared to quality in getting a higher price.

6.3 Impact on maize protectants use and cost of protection

One of the advantages of using hermetic bags is that it kills pests by depriving them of oxygen. This means a farmer will have a reduced need to use insecticides and thus will save money, as well as avoiding the negative health effects of pesticide residues. Column [1] of Table 4 shows that the proportion of farmers who protected[20] their stored crops was significantly lower for those who received the hermetic bags compared to other groups. Specifically, a significantly lower proportion of farmers in the 'training and hermetic bags' treatment group used chemical protectants compared to other groups (Column [2]). However, a significantly higher proportion of those in the 'training and hermetic bags' treatment used rat traps and poisons compared to those in other groups (Column [3]). This is intuitive because an attack by rodents on the hermetic bags will perforate them and render them useless as airtight storage.

An estimation of the total cost of protecting stored maize in Column [4]) shows that farmers in the 'training and hermetic bags' treatment group spent USD 2.63 less to protect a ton of stored maize compared to those in the control group. There are no significant differences between the 'training only' treatment and the control group in any of those aspects.

Tables A3 and A4 in the Appendix present the DID estimation results of the impact of the interventions on maize protectants use and cost of protection for the unbalanced and balanced panels respectively. The results are similar to the baseline results.

6.4 Mechanism

We have shown the effects of the 'training and hermetic bags' and 'training only' interventions on PHL reduction and on the physical qualities of maize grain. We now examine whether the interventions led to adoption of the 'good' post-harvest management practices which were presented in the training. Table 5 presents the DID estimation with an unbalanced

[19]The index was constructed using the principal component analysis.

[20]This includes those who applied at least one technique of protection, such as using chemical protectants, ashes, plants, herbs, rat traps and rat poisons.

Table 4: *Impact on maize protectants use and cost of protection*

VARIABLES	[1] Protected stored maize (YES=1)	[2] Used chemical Protectants (YES=1)	[3] Used rats traps and poisons (YES=1)	[4] Cost of protection (Per 1 Ton)
Training + Bags	-0.1725**	-0.3604***	0.1115*	-2.5935***
	(0.0361)	(0.0040)	(0.0841)	(0.0040)
Training Only	-0.0402	0.0171	0.0028	0.8960
	(0.6533)	(0.8898)	(1.0000)	(0.5451)
Sex	0.0846	0.0880**	0.0200	2.2680***
	(0.1042)	(0.0481)	(0.6453)	(0.0000)
Age	0.0003	-0.0033	-0.0005	-0.0635**
	(0.8657)	(0.1563)	(0.8697)	(0.0160)
Years of schooling	0.0081	-0.0008	0.0086	-0.0652
	(0.4770)	(0.8697)	(0.3607)	(0.6052)
No. of active workers	0.0078	0.0039	0.0120	-0.2700
	(0.6493)	(0.7816)	(0.3928)	(0.2926)
Wealth (USD)	0.0000	0.0000	0.0000	0.0003**
	(0.9339)	(0.7575)	(0.5370)	(0.0361)
Years of experience	0.0025	0.0031	-0.0010	0.0473
	(0.2244)	(0.2725)	(0.7014)	(0.1202)
Got PH Training before	-0.0108	0.0099	0.0080	-1.2070
	(0.8216)	(0.9339)	(0.8497)	(0.1924)
Constant	0.617***	0.627***	0.100	5.338***
	(0.0000)	(0.0000)	(0.4649)	(0.0040)
Observations	390	390	390	395
R-squared	0.042	0.114	0.027	0.137

Wild-cluster bootstrap-t p-values in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

panel[21] of the effect of the interventions on five post-harvest management practices: harvest at maturity; spreading maize after harvesting; sorting maize after harvesting; number of days maize was dried; and whether maize storage was cleaned and disinfected.

TABLE 5: *DID estimation of the effect of interventions on post-harvest management practices*

VARIABLES	[1] Harvested immediately when matured (Yes=1)	[2] Maize spread after harvest (Yes=1)	[3] Maize sorted (Yes=1)	[4] Number of days maize dried	[5] Store disinfected (Yes=1)
(Training + Bags) * Wave2	0.0759	0.2036*	0.1179	1.0930	0.0138
	(0.3888)	(0.0681)	(0.2485)	(0.3527)	(0.8657)
(Training Only)* Wave2	0.0653	0.1110	0.1328	1.2950	0.0216
	(0.3808)	(0.3407)	(0.2886)	(0.4810)	(0.7816)
Training + Bags	-0.0077	-0.0611	0.0083	0.1920	-0.0155
	(0.7776)	(0.4770)	(0.8737)	(0.9218)	(0.8497)
Training Only	-0.0046	-0.0002	0.0255	0.0062	-0.0286
	(0.8938)	(0.9579)	(0.6693)	(1.0000)	(0.7134)
Wave2	-0.0224	0.0552	0.0672	-0.6400	-0.1104**
	(0.6573)	(0.4850)	(0.3527)	(0.2765)	(0.0200)
Constant	0.191***	0.311***	0.508***	4.733***	0.469***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Observations	811	814	812	814	806
R-squared	0.004	0.033	0.030	0.003	0.011

Wild-cluster bootstrap-t p-values in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

The results of this exercise show that, although more farmers in the treatment groups adopted 'good' post-harvest management practices compared to those in the control group, the differences are not statistically significant. There might be some constraints to adoption, such as the cost of adoption of each practice relative to the conventional practices[22] and the possible side effectss[23] of the practices.

[21]The results with a balanced panel are shown in Table A7 in the Appendix and are similar.
[22]For example, in the study area the conventional way is to let maize dry while on the stalks in the field after maturity.
[23]For example, pesticide residues might cause health problems.

7 Analysis of the economic effectiveness of the interventions

We found that the interventions reduced PHL, increased market price of maize, and saved money from not using storage insecticides. To conduct the analysis of the economic effectiveness of training on post-harvest management practices and the use of hermetic bags, we use the marginal effects from different models we have estimated and other information collected from the field. The details of the calculations are presented in appendix B.

We calculate the net benefits and internal rates of return (IRR) for both interventions relatives to the control group. Our analysis shows that, on average, the farmers in the 'training only' and 'training and hermetic bag' treatments earned net benefits of USD 9.74 and USD 33.87 respectively, for one season. Taking into account the investment cost in training and assuming that the effects of the training last for five years, the IRR of 'training only' is 14%. Considering the costs of training and that of hermetic bags and assuming that the bags last for three years, the IRR of 'training and hermetic bags' is 35%. Further analysis shows that the use of hermetic bags breaks even after just the first season, considering all the benefits (PHL reduction, increase in maize quality and value, and costs saved from less use of insecticides), net of the costs of other practices involved.

8 Conclusion

There has been a longstanding puzzle as to why farmers do not adopt technologies that seem to be economically beneficial. Among the arguments for the observed phenomenon is that the benefits observed in the trial field do not reflect the real-world and/or that there is actually no puzzle when heterogeneity among the potential adopters of the technology is considered. In this paper, we examine the impact of post-harvest management and hermetic bag technologies on PHL reduction and the economic effectiveness of these technologies for small-scale farmers.

We find that both interventions had significant effects on reducing storage losses but not on pre-storage losses. In both interventions, a greater proportion of farmers perceived that the physical characteristics of their maize grain were maintained during storage, and they sold their maize at a higher price on average, compared to those in the control group. We also find that a significantly lower proportion of farmers who received hermetic bags used storage insecticides, compared to other groups. Although they also invested more in controlling rodents, they significantly reduced the net cost of storage protection. We observe that higher proportions of farmers in the treatment groups adopted post-harvest loss mitigating practices, compared to those in the control group. This adoption, plus the use of the hermetic bag itself, may explain the success of the intervention.

Our cost-benefit estimations show that provision of training on post-harvest management is economically effective if the effects of the training last for at least five years. There are reasons to believe that the effects can last longer. First, the more farmers use the adopted techniques, the more they become familiar with them, and thus can implement them at a lesser cost. Second, through social networks, more farmers might adopt due to learning from early adopters about the suitability, profitability, and methods of using the new technology, as documented in literature on technology adoption (Maertens and Barrett, 2013; Magnan et al., 2015).

The use of hermetic bags together with training on post-harvest losses is also economically effective. Investment in hermetic bags will break even after just the first season of using them. This is different from other studies which show that hermetic bags will not be economically feasible if they last one season (Baoua et al., 2014; De Groote et al., 2013; Ndegwa et al., 2016).This is probably because, in this study, we have considered other benefits such as gain from the market value of the grain and savings from not using insecticides, which have not been considered in other studies.[24] The training we have provided on post-harvest management, alongside provision of bags, might also have improved efficiency in the use of the hermetic bags, thus reaping more benefits.

The findings from this study have direct policy implications. Training farmers on good post-harvest management practices can help them reduce PHL, and this can be done economically effectively. However, not all farmers adopt the good practices at once. What impedes others from adopting is an area worthy of further investigation. It is also economically feasible for smallholder farmers to adopt hermetic bags for maize storage even if they last ony one season. For better outcomes the introduction of hermetic bags should be accompanied with training on post-harvest management.

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[24]There are, of course, other costs involved in implementation of the interventions which have also been taken into account.

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Appendix

A

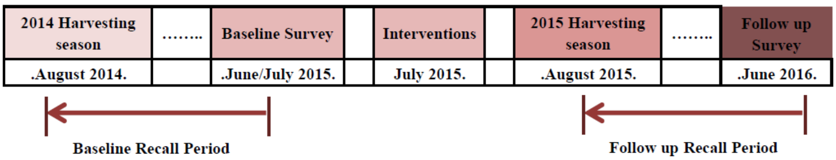

Figure A1: Timeline of field events

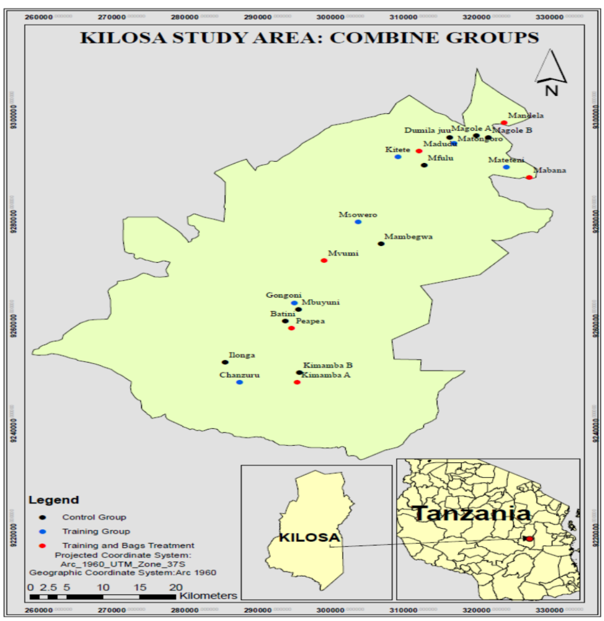

Figure A2: A map of the study area showing the distribution of villages according to experimental groups

Table A1: *Attrition between Baseline and Follow up survey*

	[1]	[2]	[3]	[4]
	ALL	CONTROL	TRAINING	TRAIN+BAGS
Dependent variable Dummy=1 if household was available during follow up survey				
Training + Bags	-0.0039			
	(0.7856)			
Training Only	-0.0280			
	(0.1122)			
Sex	0.0079	0.0005	-0.0302	0.0305
	(0.7976)	(0.9739)	(0.8938)	(0.5571)
Age	-0.0005	0.0003	0.0019	-0.0016
	(0.7695)	(0.6854)	(0.8417)	(0.5611)
Years of schooling	0.0005	-0.0118	-0.0061	0.0308**
	(0.8096)	(0.1883)	(0.6092)	(0.0281)
No. of active workers	0.0035	-0.0080	0.0228	-0.0057
	(0.5932)	(0.3808)	(0.3527)	(0.7375)
Wealth (USD)	0.0000**	0.0000	0.0000*	0.0000
	(0.0361)	(0.1042)	(0.0842)	(0.5130)
Years of experience	0.0030**	0.0011	0.0036	0.0055
	(0.0120)	(0.2565)	(0.2725)	(0.1403)
Total PHL	0.2921*	0.4330*	0.0980	0.0899
	(0.0962)	(0.0721)	(0.5611)	(0.7735)
Constant	0.855***	0.965***	0.743***	0.678***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Observations	417	179	118	120
	0.049	0.106	0.107	0.151

Wild-cluster bootstrap-t p-values in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table A2: *Diff in Diff estimation of the Impact on PHL*

	[1]	[2]	[3]	[4]
	Unbalanced Panel		Balanced Panel	
VARIABLES	Pre-storage loss	Storage loss	Pre-storage loss	Storage loss
(Training + Bags) * Wave2	-0.0077	-0.0606***	-0.0063	-0.0557***
	(0.3327)	(0.0040)	(0.4689)	(0.0040)
(Training Only)* Wave2	-0.0084	-0.0224	-0.0073	-0.0189
	(0.2044)	(0.1122)	(0.2966)	(0.1844)
Training + Bags	0.0031	-0.0064	0.0017	-0.0090
	(0.2645)	(0.4609)	(0.5731)	(0.3647)
Training Only	0.0021	-0.0053	0.0009	-0.0073
	(0.4529)	(0.7094)	(0.7335)	(0.6092)
Wave2	0.0018	0.0062	0.0008	0.0012
	(0.6974)	(0.3487)	(0.8417)	(0.8096)
Constant	0.0274***	0.0864***	0.0284***	0.0893***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Observations	812	806	784	780
R-squared	0.009	0.086	0.009	0.089

Wild-cluster bootstrap-t p-values in parentheses.
Pre-storage losses are calculated as proportion of total amount of maize harvested.
Storage losses are calculated as proportion of amount stored for those who stored maize
*** p<0.01, ** p<0.05, * p<0.1

Table A3: *Heterogeneous effects of the interventions on PHL*

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Income group	Lower Quartile	Upper Quartile	Lower Half	Upper Half	Lower Quartile	Upper Quartile	Lower Half	Upper Half
VARIABLES	Pre-Storage losses				Storage losses			
Mean of Dep. Variable	0.0278	0.0312	0.0279	0.0303	0.1157	0.0930	0.0868	0.0992
Training + Bags	0.0034	-0.0007	-0.0066	-0.0044	-0.0886***	-0.0665***	-0.0648***	-0.0693***
	(0.7896)	(1.0000)	(0.2645)	(0.6173)	(0.0080)	(0.0040)	(0.0040)	(0.0040)
Training Only	-0.0097	-0.0098	-0.0096	-0.0056	-0.0458	-0.0341	-0.0279**	-0.0223
	(0.1483)	(0.3327)	(0.2285)	(0.3968)	(0.1683)	(0.1323)	(0.0361)	(0.1804)
Sex	-0.0143	-0.0033	0.0013	-0.0149	0.0189	-0.0006	0.0061	0.0126
	(0.1763)	(0.8377)	(0.7856)	(0.1162)	(0.4329)	(0.9820)	(0.5932)	(0.4008)
Age	-0.0003	-0.0005	-0.0004	-0.0000	0.0005	-0.0001	0.0003	-0.0008
	(0.2365)	(0.3166)	(0.1643)	(0.9900)	(0.6332)	(0.9419)	(0.6373)	(0.1403)
Years of schooling	-0.0017	0.0000	0.0001	0.0008	-0.0071	0.0010	0.0018	0.0007
	(0.3607)	(0.9980)	(0.9699)	(0.5531)	(0.1323)	(0.8136)	(0.3327)	(0.7695)
No. of active workers	0.0011	-0.0006	0.0011	-0.0001	0.0137*	0.0097	0.0012	0.0075
	(0.3126)	(0.7214)	(0.6413)	(0.9659)	(0.0802)	(0.1523)	(0.6894)	(0.2565)
Wealth (USD)	0.0000	0.0000	0.0000	-0.0000	0.0000	0.0000	0.0000	0.0000
	(0.6092)	(0.3607)	(0.2084)	(0.6613)	(0.9178)	(0.9018)	(0.5371)	(0.2846)
Maize farming experience (years)	-0.0006	-0.0001	-0.0001	-0.0003	-0.0024	-0.0007	-0.0010	0.0006
	(0.1122)	(0.8377)	(0.7054)	(0.1804)	(0.0321)	(0.4008)	(.1323)	(0.5291)
Got PH Training before	-0.0091	-0.0024	-0.0042	-0.0064	-0.0168	-0.0166	-0.0178	-0.0066
	(0.1283)	(0.7174)	(0.3527)	(0.2325)	(0.4409)	(0.3968)	(0.1002)	(0.6934)
Constant	0.0720***	0.0578	0.0454***	0.0452***	0.132***	0.0778	0.0699**	0.0959***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.1483)	(0.0240)	(0.0000)
Observations	100	99	195	200	99	98	194	196
R-squared	0.137	0.044	0.047	0.068	0.258	0.158	0.172	0.120

Wild-cluster bootstrap-t p-values in parentheses.
Pre storage losses are calculated as proportion of total amount of maize harvested.
Storage losses are calculated as proportion of amount stored for those who stored maize
*** p<0.01, ** p<0.05, * p<0.1

Table A4: *Effect of maize quality and opportunistic selling on maize price*

VARIABLES	Average maize price obtained
Quality Index	1.0383
	(0.4449)
% sold within 3 months	-67.261***
	(0.0040)
Sex	7.1990
	(0.4368)
Age	-0.5630
	(0.1122)
Years of schooling	1.1550
	(0.1643)
No. of active workers	0.4599
	(0.6693)
Wealth (USD)	0.0051
	(0.3647)
Years of experience	-0.0512
	(0.8577)
Got PH Training Before	1.8590
	0.5410
Constant	245.700***
	(0.0000)
Observations	310
R-squared	0.192

Wild-cluster bootstrap-t p-values in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A5: *DID estimation of the impact on maize protectants use and cost of protection (Unbalanced panel)*

	[1]	[2]	[3]	[4]
VARIABLES	Protected stored maize (YES=1)	Used chemical Protectants (YES=1)	Used rats traps and poisons (YES=1)	Cost of protection (Per 1 Ton)
(Training + Bags) * Wave2	-0.2747***	-0.3598***	0.1310*	-3.0200***
	(0.0040)	(0.0080)	(0.0521)	(0.0080)
(Training Only)* Wave2	-0.0797	-0.0193	0.0036	0.1980
	(0.3487)	(0.8417)	(0.9339)	(0.9058)
Training + Bags	0.1030*	0.0100	-0.0191	0.2860
	(0.0521)	(0.8737)	(0.6693)	(0.6293)
Training Only	0.0339	0.0405	-0.0008	0.6760
	(0.6492)	(0.7415)	(0.9098)	(0.4970)
Wave2	0.0693*	0.0311	0.0036	0.4170
	(0.0641)	(0.6493)	(1.0000)	(0.5491)
Constant	0.754***	0.587***	0.179***	4.605***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Observations	806	806	806	811
R-squared	0.022	0.059	0.011	0.031

Wild-cluster bootstrap-t p-values in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table A6: *DID estimation of the impact on maize protectants use and cost of protection (Balanced panel)*

	[1]	[2]	[3]	[4]
VARIABLES	Protected stored maize (YES=1)	Used chemical Protectants (YES=1)	Used rats traps and poisons (YES=1)	Cost of protection (Per 1 Ton)
(Training + Bags) * Wave2	-0.2720***	-0.3536***	0.1210*	-3.0540***
	(0.0040)	(0.0040)	(0.0601)	(0.0080)
(Training Only)* Wave2	-0.0662	0.0171	-0.0046	0.4667
	(0.4369)	(0.9459)	(1.0000)	(0.7896)
Training + Bags	0.0982*	-0.0006	-0.0161	0.2982
	(0.0721)	(1.0000)	(0.7174)	(0.6253)
Training Only	0.0288	0.0123	0.0081	0.4427
	(0.7054)	(0.9459)	(0.8697)	(0.5892)
Wave2	0.0623	0.0130	0.0080	0.3610
	(0.1122)	(0.8297)	(0.8818)	(0.5892)
Constant	0.760***	0.602***	0.175***	4.682***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Observations	780	780	780	784
R-squared	0.022	0.063	0.010	0.032

Wild-cluster bootstrap-t p-values in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table A7: *DID estimation of the effect of interventions on post-harvest management practices (Balanced panel)*

	[1]	[2]	[3]	[4]	[5]
VARIABLES	Harvested immediately when matured (Yes=1)	Maize spread after harvest (Yes=1)	Maize sorted (Yes=1)	Number of days maize dried	Store disinfected (Yes=1)
(Training + Bags) * Wave2	0.0461	0.1812*	0.1211	1.3849	0.0160
	(0.5331)	(0.0921)	(0.2485)	(0.2044)	(0.8577)
(Training Only)* Wave2	0.0495	0.1214	0.1350	1.3665	0.0217
	(0.4770)	(0.2846)	(0.2926)	(0.4970)	(0.7735)
Training + Bags	0.0134	-0.0475	-0.0043	-0.1515	-0.0107
	(0.5651)	(0.5972)	(0.9739)	(0.8697)	(0.9018)
Training Only	0.0114	-0.0105	0.0233	-0.0515	-0.0216
	(0.6653)	(0.8617)	(0.6934)	(0.9218)	(0.7495)
Wave2	-0.0107	0.0665	0.0736	-0.7480	-0.1070*
	(0.8216)	(0.3888)	(0.3527)	(0.2285)	(0.0601)
Constant	0.181***	0.304***	0.509***	4.877***	0.462***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Observations	784	784	784	784	780
R-squared	0.003	0.034	0.032	0.003	0.010

Wild-cluster bootstrap-t p-values in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Table A8: *Follow-up summary statistics and mean comparison across experiment groups*

		ALL		1-CONTROL		2-TRAINING		3-TRAIN+BAGS		[1 - 2]	[1 - 3]	[2 - 3]
Variable	Obs	Mean	Stdv	Mean	Stdv	Mean	Stdv	Mean	Stdv	Diff	Diff	Diff
Maize farming practices												
Area of Land for agric (ha)	397	2.19	1.70	2.17	1.66	2.05	1.72	2.35	1.75	0.121	-0.182	-0.303
Area of Land for maize (ha)	397	1.44	1.24	1.43	1.22	1.49	1.45	1.39	1.03	-0.054	0.040	0.094
Number of maize plots	397	1.35	0.61	1.34	0.59	1.25	0.55	1.44	0.67	0.086	-0.098	-0.184
Amount harvested (Kgs)	397	1944	2044	2028	2192	1853	2184	1904	1643	175	124	-51
Amount of maize stored (Kgs)	395	1811	1960	1874	2104	1777	2108	1749	1562	97	125	28
Sold maize (Yes=1)	394	0.79	0.41	0.77	0.42	0.75	0.43	0.87	0.34	0.015	-0.100**	-0.115**
Amount sold (Kgs)	312	1465	1928	1602	2142	1385	2074	1347	1445	217	255	38
Sold within 3 months (Kgs)	312	605	1107	740	1349	646	1024	390	723	93	350**	256
Prop sold in 3 months	397	0.18	0.22	0.19	0.24	0.18	0.23	0.15	0.20	0.019	0.042	0.023
Average price per ton (USD)	312	221.8	41.4	215.2	40.5	222.2	39.1	230.3	43.3	-7.011	-15.06***	-8.049
Weather at harvest(Sunny=1)	395	0.93	0.26	0.92	0.27	0.93	0.26	0.94	0.24	-0.008	-0.020	-0.012
Harvested at maturity(Yes=1)	395	0.21	0.40	0.17	0.38	0.23	0.42	0.24	0.43	-0.061	-0.068	-0.007
Maize spread after harvest (Yes=1)	395	0.44	0.50	0.37	0.48	0.48	0.50	0.51	0.50	-0.111*	-0.142**	-0.032
Maize sorted (Yes=1)	395	0.66	0.48	0.58	0.50	0.73	0.44	0.70	0.46	-0.158***	-0.126**	0.032
Number of days maize dried	395	4.82	5.93	4.09	4.72	5.39	6.09	5.38	7.20	-1.30*	-1.284*	0.017
Store disinfected (Yes=1)	390	0.36	0.48	0.36	0.48	0.35	0.48	0.36	0.48	0.007	0.002	-0.005
Used any means to protect (Yes=1)	390	0.76	0.43	0.82	0.38	0.78	0.42	0.65	0.48	0.046	0.172***	0.126**
Used chemical protectants	390	0.52	0.50	0.62	0.49	0.63	0.48	0.27	0.44	-0.021	0.350***	0.371***
Used traps and poisons	390	0.22	0.41	0.18	0.39	0.19	0.39	0.29	0.46	-0.003	-0.112**	-0.109*
Protections costs per ton (USD)	390	4.47	7.38	5.02	6.77	5.90	9.50	2.29	5.12	-0.875	2.734***	3.608***
Post-Harvest Loses												
Pre-storage loses	395	0.026	0.031	0.029	0.036	0.023	0.028	0.025	0.026	0.006	0.005	-0.002
Storage loses	395	0.060	0.079	0.084	0.091	0.061	0.078	0.024	0.037	0.023**	0.060***	0.037***
Marketing loses	395	0.005	0.008	0.004	0.008	0.004	0.007	0.005	0.008	0.001	-0.001	-0.001
Total Loses	395	0.091	0.089	0.118	0.098	0.088	0.092	0.053	0.049	0.030**	0.064***	0.035***
Attrition	419	0.053	0.223	0.039	0.194	0.076	0.266	0.050	0.219	-0.037	-0.011	0.026

Table A9: *Mean comparison of the baseline and follow-up across experimental groups*

Variable	ALL (Mean)			CONTROL (Mean)			TRAINING (Mean)			TRAIN+BAGS (Mean)		
	Rnd 1	Rnd 2	R1-R2	Rnd 1	Rnd 2	R1-R2	Rnd 1	Rnd 2	R1-R2	Rnd 1	Rnd 2	R1-R2
Area of Land for agric (ha)	2.62	2.19	0.43***	2.65	2.17	0.49***	2.56	2.05	0.52***	2.61	2.35	0.27**
Area of Land for maize (ha)	1.67	1.44	0.23***	1.75	1.43	0.31***	1.67	1.49	0.19*	1.55	1.39	0.16**
Number of maize plots	1.37	1.35	0.02	1.35	1.34	0.01	1.33	1.25	0.07	1.43	1.44	-0.01
Amount harvested (Kgs)	2803	1944	859***	2874	2028	846***	2817	1853	965***	2683	1904	779***
Amount of maize stored (Kgs)	2645	1811	834***	2749	1874	876***	2618	1777	841***	2510	1749	761***
Sold maize (Yes=1	0.89	0.79	0.10***	0.87	0.77	0.10***	0.9	0.75	0.15***	0.92	0.87	0.05*
Amount sold (Kgs)	1872	1465	407***	1925	1602	324***	1845	1385	460*	1821	1347	474***
Sold within 3 months (Kgs)	855	605	249***	860	740	120*	907	646	261**	797	390	407***
Prop sold in 3 months	0.29	0.18	0.11***	0.28	0.19	0.09***	0.29	0.18	0.11***	0.3	0.15	0.15***
Average price per ton (USD)	179.4	221.8	-42.4***	178.6	215.2	-36.6***	180.7	222.2	-41.5***	179.5	230.3	-50.8***
Weather at harvest(Sunny=1)	0.81	0.93	-0.11***	0.80	0.92	-0.12***	0.86	0.93	-0.06	0.78	0.94	-0.16***
Harvested at maturity(Yes=1)	0.19	0.21	-0.02	0.18	0.17	0.01	0.19	0.23	-0.04	0.19	0.24	-0.04
Maize spread after harvest (Yes=1)	0.29	0.44	-0.15***	0.31	0.37	-0.06	0.30	0.48	-0.18**	0.25	0.51	-0.25***
Maize sorted (Yes=1)	0.51	0.66	-0.14***	0.51	0.58	-0.07	0.53	0.73	-0.20***	0.51	0.70	-0.19***
Number of days maize dried	4.77	4.82	-0.05	4.82	4.09	0.73	4.78	5.39	-0.61	4.68	5.38	-0.69
Store disinfected (Yes=1)	0.45	0.36	0.10***	0.47	0.36	0.11**	0.44	0.35	0.09	0.45	0.36	0.09
Used any means to protect (Yes=1)	0.80	0.76	0.04	0.76	0.82	-0.06	0.79	0.78	0.01	0.86	0.65	0.21***
Used chemical protectants	0.60	0.52	0.08**	0.60	0.62	-0.012	0.61	0.63	-0.03	0.60	0.27	0.33***
Used traps and poisons	0.17	0.22	-0.05	0.17	0.18	-0.01	0.18	0.19	-0.001	0.16	0.29	-0.13***
Protections costs per ton (USD)	4.88	4.47	-0.41	4.65	5.02	-0.37	5.12	5.90	-0.78	4.68	2.29	2.39***
Pre-storage loses	0.029	0.026	0.003	0.028	0.029	-0.001	0.03	0.023	0.007*	0.029	0.025	0.005
Storage loses	0.079	0.06	0.019***	0.084	0.084	0	0.074	0.061	0.013*	0.077	0.024	0.054***
Marketing loses	0.01	0.005	0.005***	0.011	0.004	0.007***	0.01	0.004	0.006***	0.009	0.005	0.003***
Total Loses	0.118	0.091	0.028***	0.124	0.118	0.006	0.114	0.088	0.026**	0.115	0.053	0.062***

B Cost benefit analysis

We assume a hypothetical average farmer in a treatment group. We use the marginal effects obtained from the estimations, that is, the mean difference between losses experienced by the farmers in the treatment group and those in the control group. We find the total amount of maize loss abated by the hypothetical average farmer in a treated group by multiplying the marginal effects at each stage of the post-harvest system (harvest, storage and marketing) by the total amount available at the beginning of the stage.[25] Then we calculate the monetary value of the amount abated by multiplying the amount abated by the market price.

A farmer in a treatment group can also gain by using less insecticide or by selling maize at a higher price. We use the marginal effects obtained from regression results, that is, the mean difference between the cost incurred or price obtained by the farmers in the treatment group and the control group. Then we multiply these marginal gains by the total amount available at the beginning of the stage to get the total gain by the hypothetical average farmer in a treated group.

In the next step, we multiply the value of the loss abated (or incurred) at each stage (harvest, storage and selling) by the proportion of farmers who acted at that stage to get the total gain by the hypothetical average farmer in a treated group in the entire post-harvest system. Then we multiply the total gain of the hypothetical average farmer by the total number of farmers to get the total gains.

We start with the economic analysis of training on post-harvest management practices. Table B1 shows the calculation of the total value gained by a hypothetical average farmer in the 'training only' group, compared to the average farmer in the control group. This farmer will abate 13.6 Kgs of loss of maize at the pre-storage stage, and 33.6 Kgs at the storage stage, compared to the results if she were in the control group. These losses abated are valued at USD 2.72 and USD 6.72 (at the price of USD 0.2 per kg of maize). This farmer will also gain USD 9.00 from selling all the maize she brought to the market, compared to her sales if she were in the control group. So, in total, this farmer gains USD 16.15 compared to the case if she were in the control group.

In addition, farmers incurred more costs to adopt 'good' post-harvest management practices. We take these costs into account too and present them in Table B2. We collected information from farmers on the labour hours, amount of money, or both, required to adopt each of the practices. Then we converted the labour hours into monetary terms by multiply-

[25]For pre-storage loss abated, we multiply by the amount harvested; for the storage loss abated, we multiply by the amount stored; and, for gains at the marketing level, we multiply by the amount sold.

Table B1: *The marginal value gained by a hypothetical average farmer in the 'training only' treatment*

	Kgs			Marginal effects	Amount abated	Value gained($)
Amount harvested	1850	x	Marginal pre-storage loss abated	0.0073	= 13.6	= 2.72
Amount stored	1777	x	Marginal storage loss abated	0.0189	= 33.6	= 6.72
Amount sold	1385	x	Gain from selling at higher price	0.0065		= 9.00
Total value gained	=		2.72+108/109x6.72+82/109x9			**= 16.15**

ing by the labour cost per hour in the study area.[26] We obtain the total monetary costs of adoption of post-harvest management practices per ton of maize. We then multiply this cost by the average amount of maize harvested or stored depending on the stage at which the practice is done, and then multiply by the marginal effects to get the cost of adoption of each practice by a treated farmer relative to one in the control group.[27] In total, the hypothetical average farmer incurs USD 6.52 more in costs for adoption compared to a farmer in the control group.

Table B2: *The marginal cost of adoption by a hypothetical average farmer in the 'training only' treatment*

	[1]	[2]	[3]	[4]	[5]	[6]
	Labour hours per ton	Monetary cost per ton (USD)	Total Monetary cost per ton (USD) =0.5*[1]+[2]	Amount for average farmer(ton)	Marginal effect	Cost of adoption =[3]*[4]*[5]
Harvest at maturity	8.93		4.46	1.850	0.065	0.54
Proper immediate handling		6.37	6.37	1.850	0.111	1.31
Sorting maize	3.59		1.80	1.850	0.133	0.44
Drying an extra day	3.35		1.68	1.850	1.295	4.02
Disinfect store facility	2.10	4.26	5.31	1.777	0.022	0.20
					Total	**6.518**

Therefore, the total net benefit of a hypothetical average farmer in the 'training only' treatment is USD 9.63 (USD 16.15 minus 6.52) in one season. The total cost of providing

[26]We calculated the average labour cost per hour in the study area from different farm activities; it is about USD 0.50 per hour.

[27]Multiplying by the marginal effect captures the difference in adoption rate between the treated group and the control group.

this training for 120 farmers was USD 4000, which is equivalent to USD 33.33 per farmer.[28] Assuming that the effects of the training last five seasons and that the net benefits during that period are constant (USD 9.63) in every season, then, with the initial investment of USD 33.33, the internal rate of return (IRR) for this intervention is 14%.[29] It is important to note that in this case we have not considered the spillover effects of the training to other people in the village. We have also assumed that a session would cover only twenty people per village as we did, but in reality more than that can be covered at a very small additional cost.

TABLE B3: *The marginal value gained by a hypothetical average farmer in the 'training and hermetic bags' treatment*

	Kgs			Marginal effects	Amount abated	Value gained($)
Amount harvested	1900	x	Marginal pre-storage loss abated	0.0063	= 11.9	= 2.4
Amount stored	1750	x	Marginal pre-storage loss abated	0.0557	= 97.5	= 19.5
Amount stored	1750	x	Gain from not using insecticides	0.0026		= 4.6
Amount sold	1350	x	Gain from selling at higher price	0.0130		= 17.5
Total value gained	=		2.38+112/114(19.5+4.6)+98/114x17.5			**= 41.0**

Next, we conduct a similar analysis for the economic effectiveness of the training and use of hermetic bags intervention. Again, we assume a hypothetical average farmer in the 'training and hermetic bags' treatment. Table B3 shows that this farmer, compared to the case if she were in the control group, will abate a loss of 11.9 Kgs of maize during pre-storage, and 97.5 Kgs during storage. These losses abated are valued at USD 2.38 and USD 19.5. This farmer will also gain USD 4.6 and USD 17.5, respectively, for not using (or using less) storage insecticides and from selling all the maize she brought to the market, compared to the case if she were in the control group. After assigning weights, in total, this hypothetical average farmer in the'training and hermetic bags' treatment gains USD 41.0 more, compared to the case if she were in the control group.

The monetary costs of adoption of post-harvest management practices per ton of maize are presented in Table B4. The average farmer incurs USD 7.13 more cost for adoption compared to the farmer in the control group. Therefore, the net benefit of an average farmer in the 'training and hermetic bags' treatment is USD 33.87 (41 minus 7.13) compared to the

[28] The costs take into account trainers' fees, transport and other logistics to organise the training sessions.

[29] Internal rate of return (IRR) is a discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero. IRR calculations rely on the same formula as NPV does: $NPV = \sum_{t=1}^{T} B_t/(1+r)^t - C_0$ where B_t is the net flow of benefit at time t, C_0 is the initial cost at time zero, r is the discount rate, and t is number of time periods

farmer in the control group, in one season.

TABLE B4: *The marginal cost of adoption by a hypothetical average farmer in the 'training and hermetic bags' treatment*

	[1]	[2]	[3]	[4]	[5]	[6]
	Labour hours per ton	Monetary cost per ton (USD)	Total Monetary cost per ton (USD) =0.5*[1]+[2]	Amount for average farmer(ton)	Marginal effect	Cost of adoption =[3]*[4]*[5]
Harvest at maturity	8.93		4.46	1.9	0.076	0.643
Proper immediate handling		6.37	6.37	1.9	0.204	2.47
Sorting maize	3.59		1.80	1.9	0.118	0.40
Drying an extra day	3.35		1.68	1.9	1.093	3.49
Disinfect store facility	2.10	4.26	5.31	1.75	0.014	0.12
					Total	**7.13**

Again, the total cost of providing the post-harvest management training for 120 farmers was USD 4000, which is equivalent to USD 33.33 per farmer. On average, a farmer in the 'training and hermetic bags' treatment received 12 hermetic bags, which in total cost USD 24 (at a price of USD 2 per bag). So, the total initial investment is USD 57.33 (33.33+24). The hermetic bag lasts three seasons. Considering the investment horizon of three seasons and assuming the net benefits during that period are constant (USD 33.87) in every season, then, with the initial investment of USD 57.33, the internal rate of return (IRR) for this intervention is 35

One would also be interested to learn whether the use of hermetic bags is economically effective if they last for one season. To conduct the analysis, we make a simplifying assumption that the effects of the two interventions are additive. In that case, we can calculate the net gain of using hermetic bags by subtracting the 'training only' gains from the 'training and hermetic bags' gains. So the net gain of using hermetic bags only is USD 24.24 (33.87 minus 9.63) for an average farmer in the 'training and hermetic bags' treatment. On average, farmers were given 12 bags. Then the net gain per bag is USD 2.02 in one season. One hermetic bag costs about USD 2. thus the use of hermetic bags breaks even in one season.

Paper III

Intimate Partner Violence and Household Food Insecurity

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Abstract

Developing countries have high rates of intimate partner violence (IPV) against women. The human capital model of health demand predicts that, if IPV affects women's health, it will lower their health capital, which in turn will reduce their productivity, resulting in lower earnings and low production of commodities that enter their individual and household utility functions. In this study, I test the hypothesis that IPV affects household food insecurity in Tanzania. I use the violence data from the first wave of Tanzania's national panel survey, combined with food security data from the second wave. I do not find strong empirical evidence that abuse of women affects household food security in either rural or urban areas. The study suggests some further areas of research.

JEL Classification: J12; J24; Q18

Keywords: intimate partner violence; productivity; food security

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1. Introduction

Domestic violence against women has been acknowledged worldwide as a violation of basic human rights (United Nations General Assembly, 1991). According to a World Health Organization report (2013), about 35 percent of women have experienced violence in their lifetime, most of which is intimate partner violence (IPV). The rate of violence against women is higher in developing countries, compared to developed countries (Garcia-Moreno et al., 2006). The effect of IPV on the economic well-being of employed women is well documented, particularly on employment stability, productivity, and earnings (Lloyd, 1997; Smith, 2001; Tolman and Wang, 2005; Crowne et al., 2011; Adams et al., 2013; Vyas, 2013; Farmer and Tiefenthaler, 2015). An extensive strand of this literature has explored the effect of IPV in the workplace, particularly on absenteeism and distraction (Rothman and Corso, 2008; Reeves and O'Leary-Kelly, 2009). Very little, however, has been done to explore the effect of IPV on economic well-being involving women not employed outside the home and on the household in general. In this study, I examine the effect of IPV on one particular aspect of well-being: household food security for the case of a developing country.

The Food and Agricultural Organization's recent estimates indicate that 12.5 percent of the world's population (868 million people) is undernourished in terms of energy intake (FAO, 2013). This is due to both food shortages and low nutritional value of food. Malnutrition imposes a cost to the global economy as a result of lost productivity and direct health care costs, which is estimated to account for as much as 5 percent of the global GDP, equivalent to USD 3.5 trillion per year or USD 500 per person (FAO, 2013). In Tanzania, the level of food insecurity is high and persistent. Between 2009 and 2011, the proportion of Tanzanian households classified as highly food energy deficient increased from 24 percent to 29 percent (WFP, 2013).

Food insecurity occurs in both rich and poor countries but it is more prevalent in poor countries, because of the strong correlation between income and food insecurity. At the household level, a critical factor for food security is access to food. Access to food refers to the ability of households to produce or purchase sufficient food for their needs. Little attention has been paid to other causes of food insecurity at the household level, apart from income and poverty. When it comes to health events in particular, the fundamental literature has implicitly assumed that food insecurity has an influence on health outcomes. Gundersen et al. (2011) argue that causation might often run in both directions and that research on the impact of health limitations on food insecurity would be of interest in terms of delineating the causes of food insecurity.

Food security status of a household that produces its own food will depend, among other things, on the well-being of those who produce and organise the preparation of that food. According to the human capital model of health demand by Grossman (1972), ill-health reduces the amount of time available for production activities and thus hinders productivity. Empirical studies have shown that partner violence has adverse effects on women's physical, reproductive and mental health (Golding, 1999; Campbell, 2002; Coker, et al., 2002; Huang, et al., 2011; Aizer, 2011). This may in turn affect the productivity of women who are involved in subsistence food production, by reducing the amount of time they spend and the effort they exert in production. It may also affect women's capacity to organise and prepare food for the family, even when women are not directly involved in production of that food. Thus, this study seeks to analyse whether IPV inflicted on women jeopardises household food security in Tanzania.

In this paper, I make two contributions to the existing literature. First, I analyse the effect of IPV on food insecurity, an aspect of economic well-being which has been given little attention in previous studies compared to other aspects such as labour participation, employment stability, and earnings. To the best of my knowledge, there are only three studies that analyse the effect of domestic violence on food security: Chilton et al. (2013), Hernandez et al. (2014), and Riberio-Silva et al. (2016), which were all conducted in developed economies. I use four binary measures of food insecurity: food uncertainty, reduction in food intake, change of diet to less-preferred food, and food shortage. These measures enable me to capture different aspects that manifest the household food insecurity situation.

Second, I do the analysis in the context of a developing country. The socioeconomic environment of developed and developing countries is different, and the prevalence of IPV toward women is higher in developing countries. The Tanzania Demographic and Health Survey (TDHS) report of 2010 shows that 44 percent of ever-married women have experienced physical or sexual violence by their current/most recent partner, at least once. Moreover, in developing countries, most women are not formally employed, but rather are engaged in subsistence production of household food and are the ones responsible for almost all household chores. Therefore, the costs of IPV in developed countries may not exactly reflect those in developing countries.

I use data on IPV toward women from the first wave of nationally representative data from the Tanzania National Panel Surveys (TNPS), collected in 2008/09, and match it with food insecurity data from the second wave of TNPS, collected in 2010/11. I also control for other socioeconomic characteristics of the man and the woman, and that of the households, using the first wave data. I find a positive but insignificant effect of IPV on most measures of food insecurity. These results suggest future studies on IPV and food security should explore household food heterogeneities, expand the time span, and address the endogeneity issues.

The rest of the paper is organised as follows: Section 2 provides the background and a survey of existing literature on the determinants and consequences of IPV and discusses the conceptual framework linking IPV and food security; Section 3 describes the data and empirical estimation strategies and presents the results; and Section 4 is the conclusion.

2. Conceptual Framework

Agriculture is the main economic activity of 79 percent of women in developing countries (Doss, 2014). When a household is engaged in production of both food and cash crops, women are more likely than men to engage in production of food crops (World Bank, 2009). Women also dedicate a substantial share of their labour and non-labour income to food and family well-being (Hoddinott and Haddad, 1995; FAO, 2006) and are most responsible for processing and preparing food at home.

Despite their role in food production, the productive potential of women is not fully realised, for several reasons. One of the reasons is the asymmetries in ownership of and access to agricultural inputs (World Bank, 2009; Deere and Doss, 2006). A second reason is violence against women, which may reduce their productivity and capacity to maintain work (Browne et al., 1999; Swanberg et al., 2005). A third is prevention of women from working (Pearson et al., 1999) or interference with work effort (Tolman and Rosen, 2001). The failure to realise the full potential of women in production puts the food security status and welfare of the household at risk.

The link between IPV and food security can be explained by the human capita model of health demand developed by Grossman in his 1972 paper. According to human capital theory, increases in an individual's stock of knowledge and 'good' personal attributes raise her productivity in the market sector of the economy, where she produces money earnings, and in the nonmarket or household sector, where she produces commodities that enter her utility function (Grossman, 2000). Health capital as a component of human capital determines the total amount of time available for market and nonmarket activities and the efficiency in doing those activities (Grossman, 1972). The human capital theory therefore predicts that, if IPV affects women's health, it will lower their health capital, which in turn will reduce their productivity, resulting in lower earnings in the market sector and low production of commodities (in this case, food), which enter their individual and household utility functions.

The negative effects of partner violence on women's physical and mental health have been well documented. Empirical studies have provided evidence that IPV has significant negative effects on employment stability and productivity. Women who experience physical IPV sustain employment for a significantly shorter period (Browne et al., 1999; Adams et al., 2013) and work for significantly fewer hours per year (Tolman and Wang, 2005), compared to those who have not been abused. Furthermore, it has been shown that IPV leads to lower earnings by abused women (Meisel et al., 2003; Adams et al., 2013; Vyas 2013; Farmer and Tiefenthaler, 2015). The link between IPV and low productivity is mediated by depression, decreased self-esteem, low concentration, chronic pain, overweight, obesity, and permanent disability (Browne et al., 1999; Tolman and Wang, 2005). These symptoms are associated with physical and cognitive fatigue or inability and feelings of being overwhelmed by productive tasks, which may impact women's motivation and ability to work to earn money, produce food, or organise food preparation (Chilton et al., 2014; Hernandez et al., 2014; Noonan et al., 2014).

3. Data, Empirical Estimation Strategy and Results

3.1 Description of Data

To estimate the impact of violence toward women on food security, I use data from the first and second waves of the Tanzania National Panel Survey. The first wave, collected in 2008-2009, contains information on self-reported experience of IPV by women aged 15-50 years. The violence questions are a subset of the Conflict Tactics Scale developed by the World Health Organization. The section on violence against women asked the following questions:

Has your current partner or any partner ever....

a) Slapped you or thrown something at you that could hurt you?

b) Pushed you or shoved you?

c) Hit you with his fist or with something else that could hurt you?

d) Kicked you, dragged you, or beaten you up?

e) Choked or burnt you on purpose?

f) Threatened to use or actually used a gun, knife, or other weapon against you?

g) Physically forced you to have sexual intercourse when you did not want to?

h) Did you ever have sexual intercourse you did not want because you were afraid of what he might do?

For each type of violent incident, a woman would respond either YES or NO. If a respondent reported that she had ever experienced any of these acts, she was then asked if it had happened in the past 12 months. In this study, I considered a woman to have experienced violence if she responded YES to at least one of the eight violent incidents. A class of binary measures of IPV was constructed in the following manner: 'Lifetime IPV' was identified if a respondent reported to have ever experienced at least one of the violent incidents. 'Current IPV' is classified if at least one violent incident was experienced in the past 12 months before the survey. 'Severe violence' was identified if a woman reported any of the violent incidents c) to f), and could be either lifetime or current.

The measure of violence from individual survey data may suffer from self-reporting bias. However, the interview process tried to minimize this risk by making the interview private, ensuring that no other man or woman was present in the same interview room at the same time. The interviewees were ensured of the confidentiality of their responses in the sense that no one would learn about their answers, and no one would ever talk to their husbands, boyfriends or parents about what they said in this interview. This included the assurance that their responses would not incriminate anyone. The fact that the interviewer was a government agent unknown to them and not from their community increased the confidentiality.

Food security data is obtained from the second wave of the National Panel Survey of Tanzania, collected in 2010-2011. The food security questions were directed to one member of the household who is mainly involved in making decisions on food and preparing it. In Tanzania, it is women who are mostly in charge of the food preparation at home. Eight types of questions were asked about food security. I classified the responses to these questions into five binary measures of food security by grouping together the responses which relate to one of the following aspects of food insecurity: (i) Experienced food uncertainty if in the past seven days there was concern that the household would not have enough for at least one day; (ii) Experienced undesired diets if in the past seven days the household had to rely on less-preferred foods or limit the variety of food on at least one day; (iii) Experienced reduced food intake if in the past seven days the household limited portion size at meal-times; reduced the number of meals eaten in a day; or restricted consumption by adults so that small children could eat; (iv) Experienced lack of food if in the past seven days the household borrowed food, or relied on help from a friend or relative; had no food of any kind in the household; or went a whole day and night without eating anything for at least one day; (v) Experienced food insecurity if in the past seven days the household experienced any of the above incidents of food insecurity.

In addition, we include other variables: (i) Women's socio-demographic variables: age, years of schooling; whether a woman owns land; marital status; and whether the woman's occupation is the same as her partner's; (ii) The male partner's characteristics: age, years of schooling and whether a man consumed alcohol in the past seven days; and (iii) Household characteristics: years of schooling of the most educated member of the household, whether the household grows its own staple food, value of agricultural assets, and per capita expenditure per month.

Table 1: Summary statistics

Variable	[1]	[2] Mean	[3]	[4] Difference
	ALL	RURAL	URBAN	Rural -Urban
Food Insecurity				
Food uncertainty	0.32	0.33	0.28	0.05**
Undesired diet	0.30	0.32	0.27	0.05**
Reduced intake	0.26	0.28	0.22	0.06***
Lack of food	0.12	0.13	0.09	0.03**
Food shortage	0.18	0.20	0.15	0.05**
Intimate Partner Violence				
Lifetime IPV	0.29	0.32	0.22	0.11***
Current IPV	0.17	0.18	0.13	0.05***
Lifetime Severe IPV	0.15	0.17	0.10	0.06***
Current Severe IPV	0.08	0.09	0.05	0.04***
Women' Characteristics				
Age	33.0	33.0	33.0	-0.05
Years of schooling	5.51	4.67	7.18	-2.51***
Own land	0.26	0.34	0.11	0.24***
Monogamy	0.76	0.74	0.78	-0.03
Polygamy	0.12	0.14	0.06	0.09***
Cohabiting	0.13	0.11	0.17	-0,06***
Same occupation	0.63	0.82	0.25	0.57***
Justify violence	0.60	0.63	0.53	0.10***
Male partner's characteristics				
Male age	40.9	41.0	40.81	0.17
Male years of schooling	6.36	5.48	8.11	-2.63***
Male takes alcohol	0.13	0.13	0.12	0.01
Household characteristics				
Highest education	7.77	6.92	9.46	-2.53***
Household size	5.75	6.00	5.26	0.75***
% of Hh in working age (15-64 yrs)	0.55	0.52	0.62	-0.10***
Grows staple food	0.55	0.74	0.19	0.55***
Log value of agric assets	6.84	9.08	2.40	6.68***
Log expnd. per capita	13.20	12.98	13.64	-0.65***
Observations	1704	1133	571	

The final sample used in this study consists of 1704 currently partnered women who live in the same household as their partners, where both partners were interviewed and the woman responded to questions on violence.[2] 1133 of these women are from rural areas and 571 from urban areas.

Table 1 presents sample means for the data, divided between the rural and urban areas. From the full sample, 32% of the respondents were worried that their households would not have enough food. Almost the same figure had to depend on less preferred foods or limit the variety of foods eaten. 26% had to reduce their food intake in various forms, whether by limiting meal size, reducing the number of meals in a day, or restricting adults' consumption. About 12% lacked food and had to either borrow or go without food altogether at least once in the past seven days. In the last 12 months, 18% of the respondents' households were faced with a situation in which they did not have enough food to feed the household. Households in rural areas are significantly more food insecure in all four aspects compared to those in urban areas.

29% of women have experienced IPV and 17% experienced violence in the 12 months prior to the survey. The levels of violence are higher in the rural areas compared to the urban areas. 32% of women in rural areas have experienced IPV in their lifetime, compared to 22% in urban areas. Similarly, 18% of women in rural areas experienced IPV in the 12 months prior to the survey, compared to 13% in urban areas. These figures are very high when compared to those in developed countries. For example, according to Aizer (2010), only two percent of women in the US suffer IPV annually.

The summary statistics show that women are younger and less educated compared to their male partners. About a quarter of the women (most of them in the rural areas) own land. A majority of women, 60%, accept that a man is justified to beat his wife under certain circumstances.[3] Generally, I observe that the rural and urban samples differ significantly in many variables. So, I will conduct separate estimations for the rural and urban areas.

[2] The initial sample consisted of 3616 women who responded to the violence questions. Those who were not partnered, and those whose partner was not living in the same household or was not interviewed, were dropped.

[3] These circumstances include: she goes out without telling him; she neglects the children; she argues with him; she refuses to have sex with him; there are problems with his or her family; there are money problems; there is no food at home; and other reasons.

3.2 Empirical Estimation Strategy and Results

3.2.1. Analysis of the factors driving intimate partner violence

First, I present the probit regression estimates for factors driving IPV episodes (for violence ever experienced and violence experienced in the previous year). I analyse separate estimations for the rural and urban samples because the two seem to be different and, therefore, the marginal effects of the explanatory variables may differ between the two areas.

A probit model on the factors determining IPV is given by:

$$IPV = 1[F\alpha + M\beta + H\delta + \varepsilon > 0]$$

IPV is a binary indicator equal to one if a woman has experienced IPV and zero otherwise. F is a vector of the woman's characteristics. M is a vector of the male partner's characteristics. H is a vector of household characteristics. α, β *and* δ are vectors of parameters to be estimated and ε is the error term, which is normally distributed.

Table 2 reports the marginal effects from the probit estimates of the factors determining IPV against women.

The results suggest that, in both rural and urban areas, IPV is mainly driven by male factors. IPV is significantly negatively correlated with age of the male partner. The younger the male partner, the higher the probability that the female partner will experience IPV in both rural and urban areas. In rural areas, the more the male is educated, the more likely the female partner will experience IPV; in the urban areas, this effect of the male partner's education on IPV is negative. This may imply that, while more years of schooling in urban areas means understanding the vices of violence and thus stopping it, in rural areas it could be a tool to increase the men's relative power and abuse. Men who take alcohol are more likely to abuse their female partners in both rural and urban areas.

Polygamy is positively associated with a higher likelihood of experiencing IPV at least once in a lifetime, in both rural and urban areas, whereas cohabiting tends to increase the likelihood of experiencing lifetime and current IPV in urban areas. The higher the education of the family member with the highest level of education, the lower the likelihood of a woman in the household experiencing IPV in the rural areas. Whereas income in rural areas is associated with less likelihood of women experiencing IPV, in urban areas it is positively associated with IPV.

Table 2: Factors associated with IPV in rural and urban Tanzania

VARIABLES	[1]	[2]	[3]	[4]	[5]	[6]
	Lifetime IPV			Current IPV		
	All	Rural	Urban	All	Rural	Urban
Woman's characteristics						
Age	0.0097*	0.0087	0.0128	-0.0015	0.0010	-0.0075
	[0.0056]	[0.0074]	[0.0108]	[0.0072]	[0.0095]	[0.0110]
Years of schooling	0.0192	0.0229*	0.0202	0.0184	0.0200	0.0197
	[0.0125]	[0.0137]	[0.0155]	[0.0152]	[0.0171]	[0.0231]
Owns land	0.1280	0.0573	0.3560**	0.1230	0.0692	0.3820
	[0.1190]	[0.1240]	[0.1800]	[0.1370]	[0.1390]	[0.3120]
Polygamy	0.4370***	0.4310***	0.3640*	0.1500	0.1080	0.3450
	[0.1150]	[0.1100]	[0.1980]	[0.1190]	[0.1270]	[0.2270]
Cohabiting	0.2090*	0.1330	0.3880***	0.2750***	0.2370*	0.3790**
	[0.1080]	[0.1170]	[0.1400]	[0.0938]	[0.1330]	[0.1570]
Same occupation	0.0469	-0.1510	0.0735	-0.0675	-0.240**	0.0699
	[0.1200]	[0.1420]	[0.1220]	[0.0965]	[0.1220]	[0.1170]
Male partner's characteristics						
Male age	-0.0183***	-0.0175***	-0.0178*	-0.0188***	-0.0230***	-0.0106
	[0.0049]	[0.0060]	[0.0108]	[0.0046]	[0.0060]	[0.0078]
Male years of schooling	0.0324*	0.0534**	-0.0338*	0.0084	0.0427**	-0.0747***
	[0.0182]	[0.0208]	[0.0193]	[0.0209]	[0.0201]	[0.0235]
Male takes alcohol	0.4130***	0.4210***	0.2920	0.4010***	0.3970***	0.3380**
	[0.1070]	[0.1230]	[0.2180]	[0.0992]	[0.1360]	[0.1430]
Household characteristics						
Highest education	-0.0920***	-0.0959***	-0.0577*	-0.0702**	-0.0999***	-0.0121
	[0.0278]	[0.0338]	[0.0337]	[0.0297]	[0.0246]	[0.0463]
Prop. of working age	0.0104	-0.0738	0.1530	0.1120	-0.0041	0.2660
	[0.2250]	[0.2490]	[0.3760]	[0.2660]	[0.2970]	[0.4650]
Household size	-0.0023	-0.0055	0.0070	-0.0000	-0.0072	0.0293
	[0.0148]	[0.0135]	[0.0408]	[0.0185]	[0.0147]	[0.0493]
Log expnd. per capita	-0.0399	-0.1000	0.2710**	-0.1260	-0.2350**	0.2070
	[0.0866]	[0.1000]	[0.1150]	[0.0985]	[0.0986]	[0.1300]
Observations	1,703	1,133	571	1,703	1,133	571
Pseudo R2	0.0515	0.0449	0.0737	0.0559	0.0643	0.0754

Clustered robust standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

3.2.2. Analysis of the effect of IPV on food security

In this sub-section, I analyse the effect of IPV on food insecurity. I estimate the effect of IPV on any measure of food insecurity using a standard univariate probit model, given as follows:

$$FI^* = 1[\alpha IPV + X\beta + \varepsilon > 0]$$

FI^* is a latent index driving the outcome of being food insecure, *FI*, where *FI=1* if $FI^* > 0$ and *FI=0* if $FI^* < 0$. The value of the unobserved latent variable FI^* depends on IPV, which is a binary indicator equal to one if a woman experiences IPV and zero otherwise; X is a vector of the woman's characteristics, the male partner's characteristics, and household characteristics; α *and* β are vectors of parameters to be estimated; and ε is the error term, which is normally distributed.

There are two potential endogeneity concerns when estimating the relationship between IPV and household food security. The first potential problem is reverse causality. Household food insecurity may be a source of partner violence. However, the natural setting of the data used is such that IPV enters as a lagged variable. I use the violence module from the first wave of the panel data and food insecurity information from the second wave. This setting offers a modest way to address this endogeneity concern (Hernandez, 2016).

Another potential problem is non-randomness of women's selection into violent relationships. There could be observable and unobservable differences which affect both women's experiences of partner violence and household food insecurity. This creates potential endogeneity problem due to self-selection. The effect of IPV from the estimation will capture not only the true effects of having experienced IPV but also the effect on food insecurity from the unobservable characteristics. While my rich data set allows me to control for a number of observable variables that might be driving those relationships, I cannot control for the unobservable variables. Unobservable factors such as traditional norms and the shares of income and assets between a man and a woman affect both household food security and women's experience of partner violence, making it difficult to infer a causal relationship.

These problems could be addressed by using an instrumental variable strategy, but there was no credible instrumental variable to use in this study. However, it is important to note that even the correlation between women's experience of violence and household food insecurity is interesting for the analysis of the costs of IPV.

The results for probit estimation of the effect of IPV on food security measures are presented in Tables 3-7. The tables report the marginal effects of IPV on food security measures. Tables 3 and 4 report the probit estimation marginal effects of current and lifetime women's experience of violence on binary measures of food insecurity – food uncertainty, shift to undesired diets, reduced food intake, and lack of food – for rural and urban areas, respectively.

Table 3: Marginal effects of current and lifetime IPV on food insecurity in rural areas

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
VARIABLES	Food uncertainty		Undesired diet		Reduced food intake		Lack of food	
Current IPV	0.0434		0.0521*		0.0469		0.0251	
	[0.0493]		[0.0305]		[0.0391]		[0.0183]	
Lifetime IPV		0.0491*		0.0354		0.0248		-0.0018
		[0.0285]		[0.0332]		[0.0271]		[0.0187]
Control variables	YES	YES	YES	YES	YES	YES	YES	YES
Month of interview	YES	YES	YES	YES	YES	YES	YES	YES
Agro Eco Zones	YES	YES	YES	YES	YES	YES	YES	YES
Observations	1,119	1,119	1,119	1,119	1,112	1,112	1,112	1,112

Notes: The controls include: Woman and man's age and years of schooling; dummies for whether a woman owns land, whether a man takes alcohol, whether the household grows its own staple food and whether a man and a woman are in the same occupation; marital status, household size, proportion of household members of working age, value of household's agricultural assets, and household monthly expenditure per capita. Clustered robust standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

For rural areas, Table 3 shows that the marginal effects of current and lifetime women's IPV on food insecurity are positive (except for the relationship between lifetime IPV and lack of food) but they are all insignificant at the 5% level of significance. This implies that women's abuse is not significantly correlated with food insecurity in rural areas.

Table 4 reports these effects for urban areas. Both current and lifetime IPV have positive and significant effects on reduced food intake, whereas only lifetime IPV has a positive and significant correlation with lack of food. In the rest of the relationships, the marginal effects of IPV are positive but not significant at the 5% level of significance. I do not observe significant correlations between IPV and food insecurity. This may be because of lumping together all violent incidents, both severe and less severe. I therefore shift the focus to severe forms of physical violence.

Table 4: Marginal effects of current and lifetime IPV on food insecurity in urban areas

VARIABLES	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	Food uncertainty		Undesired diet		Reduced food intake		Lack of food	
Current IPV	0.0437		0.0237		0.0989***		0.0489	
	[0.0509]		[0.0450]		[0.0334]		[0.0301]	
Lifetime IPV		0.0728		0.0567		0.111***		0.0441**
		[0.0500]		[0.0426]		[0.0309]		[0.0185]
Control variables	YES	YES	YES	YES	YES	YES	YES	YES
Month of interview	YES	YES	YES	YES	YES	YES	YES	YES
Agro Eco Zones	YES	YES	YES	YES	YES	YES	YES	YES
Observations	565	565	571	571	567	567	540	540

Notes: The controls include: Woman and man's age and years of schooling; dummies for whether a woman owns land, whether a man takes alcohol, whether the household grows its own staple food and whether a man and a woman are in the same occupation; marital status, household size, proportion of household members of working age, value of household's agricultural assets, and household monthly expenditure per capita. Clustered robust standard errors in brackets *** p¡0.01, ** p¡0.05, * p¡0.1

Tables 5 and 6 report the probit estimation marginal effects of current and lifetime women's experience of severe violence on binary measures of food insecurity in rural and urban areas, respectively. The marginal effects of severe IPV on food insecurity for most of the measures are not significant in either rural or urban areas.

Table 5: Marginal effects of Severe, Current and Lifetime IPV on food insecurity in rural areas

VARIABLES	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	Food uncertainty		Undesired diet		Reduced food intake		Lack of food	
Severe Current IPV	0.1260		0.0669		0.1170***		0.0427	
	[0.0784]		[0.0503]		[0.0388]		[0.0412]	
Severe Lifetime IPV		0.1030*		0.0639*		0.1010***		0.0271
		[0.0573]		[0.0340]		[0.0392]		[0.0280]
Control variables	YES	YES	YES	YES	YES	YES	YES	YES
Month of interview	YES	YES	YES	YES	YES	YES	YES	YES
Agro Eco Zones	YES	YES	YES	YES	YES	YES	YES	YES
Observations	565	565	571	571	567	567	540	540

Notes: The controls include: Woman and man's age and years of schooling; dummies for whether a woman owns land, whether a man takes alcohol, whether the household grows its own staple food and whether a man and a woman are in the same occupation; marital status, household size, proportion of household members of working age, value of household's agricultural assets, and household monthly expenditure per capita. Clustered robust standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

Table 6: Marginal effects of Severe Current and Lifetime IPV on food insecurity in urban areas

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
VARIABLES	Food uncertainty		Undesired diet		Reduced food intake		Lack of food	
Severe Current IPV	-0.0129		0.0335		0.0328		-0.0241	
	[0.0466]		[0.0397]		[0.0444]		[0.0287]	
Severe Lifetime IPV		-0.0236		-0.0310		-0.0314		-0.0413*
		[0.0268]		[0.0281]		[0.0339]		[0.0234]
Control variables	YES	YES	YES	YES	YES	YES	YES	YES
Month of interview	YES	YES	YES	YES	YES	YES	YES	YES
Agro Eco Zones	YES	YES	YES	YES	YES	YES	YES	YES
Observations	1,119	1,119	1,119	1,119	1,112	1,112	1,112	1,112

Notes: The controls include: Woman and man's age and years of schooling; dummies for whether a woman owns land, whether a man takes alcohol, whether the household grows its own staple food and whether a man and a woman are in the same occupation; marital status, household size, proportion of household members of working age, value of household's agricultural assets, and household monthly expenditure per capita. Clustered robust standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

Lastly, I combine all the aspects of food insecurity into one binary measure. I classify a household as food insecure if it experienced at least one of the four incidents discussed above. Then I estimate the effect of current and lifetime IPV and severe current and lifetime IPV on this combined food insecurity variable. The marginal effects from this estimation are reported in Table 7.

Table 7: Marginal effects of IPV on combined food insecurity aspects in rural and urban areas

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	RURAL				URBAN			
VARIABLES	Food insecurity		Food insecurity		Food insecurity		Food insecurity	
Current IPV	0.0545				0.0767			
	[0.0418]				[0.0601]			
Lifetime IPV		0.0385				0.0909*		
		[0.0357]				[0.0487]		
Severe Current IPV			-0.0288				0.1830***	
			[0.0502]				[0.0582]	
Severe Lifetime IPV				-0.0610**				0.1190**
				[0.0302]				[0.0466]
Control variables	YES	YES	YES	YES	YES	YES	YES	YES
Month of interview	YES	YES	YES	YES	YES	YES	YES	YES
Agro Eco Zones	YES	YES	YES	YES	YES	YES	YES	YES
Observations	1,119	1,119	1,119	1,119	571	571	571	571

Notes: The controls include: Woman and man's age and years of schooling; dummies for whether a woman owns land, whether a man takes alcohol, whether the household grows its own staple food and whether a man and a woman are in the same occupation; marital status, household size, proportion of household members of working age, value of household's agricultural assets, and household monthly expenditure per capita. Clustered robust standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

Table 7 shows that there is weak evidence that IPV is correlated with food insecurity. Only severe current and lifetime abuse is significantly correlated with food insecurity in urban areas. On the other hand, severe lifetime violence is actually correlated with lower food insecurity in rural areas, which is an unexpected result.

4. Conclusion

The rates of IPV in developing countries are high. In Tanzania, about 29 percent of women have experienced violence from their intimate partners. The literature has documented the physical, reproductive and mental effects of violence on women. According to the human capital model of health demand, the stock of health, which is a component of human capital, determines the total amount of time available for market and nonmarket activities and the efficiency in doing those activities. Therefore, the model predicts that, if IPV affects women's health, it will reduce their health capital, which in turn reduces their productivity, resulting in lower earnings in the market sector and low production of commodities, which enter their individual and household utility functions. In this study, I test the hypothesis that IPV affects household food insecurity in Tanzania.

I use data from the first wave of the Tanzania National Panel Survey, collected in 2009/10, which contains a module on violence against women but has no information on food security. This data is matched with the second wave data, which contains food insecurity data but has no violence module. I classify binary violence variables into lifetime and current violence and into variables that depend on the degree of severity. For food insecurity, I construct four binary measures – food uncertainty, reduction in food intake, undesired diets, and lack of food – and one binary measure that combines all four aspects.

I do not find empirical support for the hypothesis that IPV affects household food insecurity in either rural or urban areas. One possible reason that I do not find the effect predicted by human capital theory is that the food security information was a response to what happened in the past seven days. This span might be too short to disentangle the effect of IPV. It could also be that there is heterogeneity in food insecurity among household members which cannot be observed in this study. So, while the household food situation is not affected by IPV, some member's food situation might be affected. Another reason could be that abused women have adopted some adjustment mechanisms to cope with the situation and live a normal life, or do some extra things such as ensuring food is on the table by any means to avoid further violence.

The findings of this study should be considered in the context of its limitations. To estimate the effect of IPV on food insecurity, I face two challenges that potentially give rise to endogeneity problems. First, there is the possibility of reverse causality, where food insecurity in the household leads to violence against women by their partners. The lagged nature of the IPV data used circumvents this challenge. The second challenge is the non-random selection of women into violent relationships, which could be driven by unobservable variables. This problem could be solved by using an instrumental variable technique but I could not find credible instrumental variables for this study. So, I do not claim any causality from my estimations, but rather correlations, which may still be of interest in learning the costs of IPV. Future studies on IPV and food security can explore within-household food heterogeneities and possible coping mechanisms by abused women, as well as expanding the time span and addressing the endogeneity issues.

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