Comprehensive Initiative on Technology Evaluation

FULL REPORT: SCALING ADOPTION OF HERMETIC POST-HARVEST STORAGE TECHNOLOGIES IN UGANDA

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The Comprehensive Initiative on Technology Evaluation (CITE) at MIT is a program dedicated to developing methods for product evaluation in global development. CITE is led by an interdisciplinary team, and draws upon diverse expertise to evaluate products and develop an understanding of what makes products successful in emerging markets.

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Introduction

Post-harvest losses, due to pests (e.g., insects, rodents, birds) or mycotoxins (produced by mold), are an enduring problem throughout the developing world. According to the FAO's Global Food Losses and Food Waste Report, approximately one-third of the food produced for human consumption worldwide is wasted. It is estimated that 54% of losses occur during production, post-harvest handling, and storage. This post-harvest loss (PHL) is responsible for economic costs estimated at US $750 billion.[1] [2]

Various storage technologies have been developed to reduce post-harvest loss. These products include silos, metal canisters/drums, cold chain storage containers, woven bags, plastic bags, insect-proof containers, and adaptations to traditional storage technologies. Many of these products have been piloted in small-scale programs to improve the lives of smallholder farmers in Africa, Southeast Asia, and Central America. However, these technologies have not scaled up to reach broad market penetration.

In 2015, researchers in the MIT Comprehensive Initiative on Technology Evaluation (CITE) conducted a study to better understand the scalability of improved post-harvest storage technologies. The study focused on the World Food Program (WFP) Special Operation 200617 (SO1) in Uganda, which aimed to address post-harvest losses through improved post-harvest handling and the introduction of hermetic crop storage technologies. Operations included training farmers on improved post-harvest processing techniques and establishing supply chains of storage technologies to sell at subsidized prices, which enabled farmers to practice the techniques. The CITE study complements WFP efforts to learn and adapt by gathering and analyzing additional data from supply chain actors and farmers.

Our approach evaluates the scalability of technologies through analysis of embedded supply chains, where one supply chain plays a role in the effectiveness of another. In this case, the supply chains for crop storage technologies play a role in the effectiveness of the agricultural commodity supply chains (see Figure 1). The intersection of the two flows is the point at which a farmer decides whether or not to use a storage technology; the technology adoption point. Technology adoption increases when supply chains can deliver effective and affordable products that are readily available and can be maintained in the after-market (post sale). It also increases when adopters have opportunity to realize the benefits of increased income through participation in a commodity supply chain. This paper considers (1) the scalability of the horizontal storage technology supply chains, which is the flow of money, goods, and information that enables the production, transportation, and sale of each storage technology, and (2) the impact of storage technology adoption among farmers engaged in the vertical crop supply chains and the potential for further adoption.

[1] FAO. (2013). Food wastage footprint - Impacts on natural resources (p. 63).
[2] FAO. (2011). Global Food Losses and Food Waste Report.

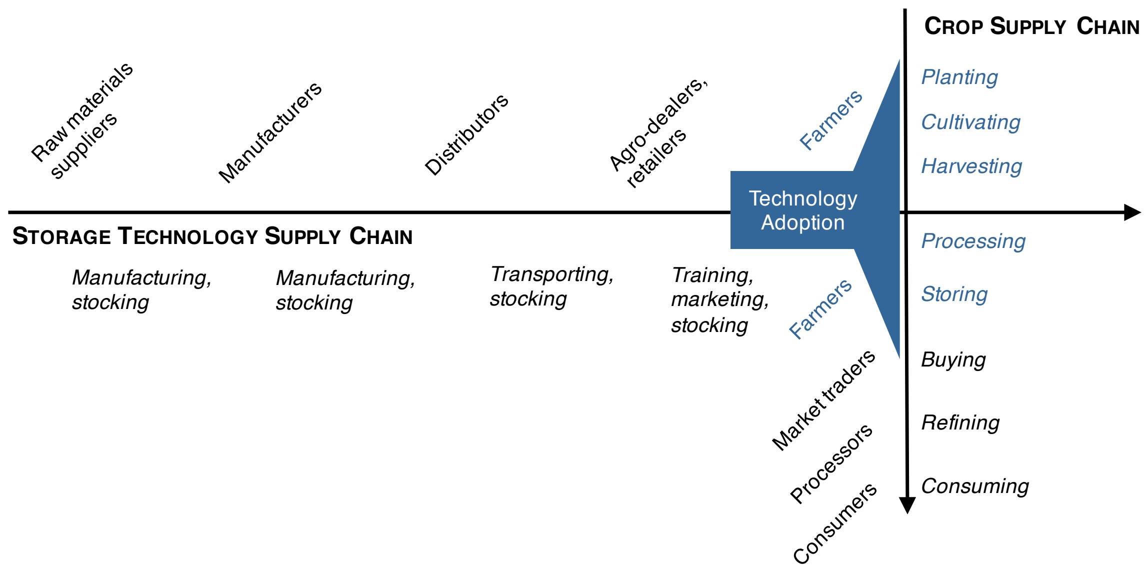

Figure 1: Framework of embedded supply chains in this study

To evaluate the scalability of the storage technology supply chains, we focus on two key aspects that drive technology adoption: affordability and availability. Affordability can be directly improved by reducing the landed cost of the finished good at the point of sale to the farmer; this landed cost combines the cost structure of all upstream actors. Availability can be directly improved by increasing capacity of all upstream actors, but must consider their interest in making investments to do so. These factors lead to the following research questions:

1. What is the **cost structure** of actors in the supply chain for each storage technology? What opportunities exist to reduce costs in order to make the storage technologies more **affordable**?
2. What are the **capacities** of actors in the supply chain for each storage technology? What opportunities exist to increase productivity in order to make the storage technologies more **available**?
3. What are the **risk profiles and behaviors** of actors in the supply chain that affect decisions to carry stock of storage technologies during the short selling season? What opportunities exist to use risk sharing mechanisms in order to make the storage technologies more **available**?

The analysis to answer these questions not only considers the state of the supply chain during the Special Operation but also potential opportunities for improvement. It covers these key supply chain components: production, transportation, and the sales channel that includes training and promotion.

To evaluation the potential adoption of storage technologies we focus on the value proposition among smallholder farmers. The purchase should have a positive impact on an adopter's livelihood and create net value, which, when observed by other farmers in their community, leads to further adoption. We explore the adoption potential by considering the following research questions:

1. What is the impact of storage technology adoption on a farmer's livelihood and what value does it create?

2. What is the potential for storage technology adoption over time?

To answer the first question, we conducted a survey of farmers who purchased a storage technology in the Special Operation. Similar to previous studies, which are reviewed below, we used regression models to assess the impact of adopting the storage technology on the income, food security, and socio-economic well-being of farmer households. The survey also measured the willingness to pay for various storage technologies among these farmers and non-adopters in their community to assess the value proposition. For the second question, we adapted a classic Bass diffusion model to develop a system dynamics simulation that incorporates the availability of products, which depend on the scalability of the horizontal supply chains.

The report is structured as follows. First, we summarize related work on post-harvest storage, followed by descriptions of the study context and data collection. Next, we present analysis for the key supply chain components (production, transportation, and sales channels), evaluate the various technology supply chains, and include with a brief description of adaptation in the subsequent WFP operation. Then we evaluate the farmer impact of storage technologies, including willingness to pay. The analysis concludes with a model that incorporates study evidence to evaluate the potential for technology adoption in various scenarios. We close by summarizing the results and considering opportunities to improve future efforts to scale adoption.

Related Work

This section provides motivation for the growing interest in deploying post-harvest storage technologies among smallholder farmers. It then summarizes results from past work in this area and highlights recent and ongoing implementation activities.

Smallholder farmers' need for better post-harvest storage solutions

Agriculture lies at the heart of Uganda's economic and social existence: 84% of citizens, 31.8 million people, live in rural areas, and agriculture accounts for 66% of national employment.[3] Smallholder farmers account for 80% of agricultural workers, who work on less than two hectares—growing primarily staple grains, such as maize and beans—but who nonetheless account for 70% of national agricultural production. The planting, harvesting, storing and selling of grains are essential for smallholder farmers' well-being, and for the country's socio-economic success.

Most international development efforts focus on addressing challenges in producing and selling crops, e.g., adapting to changing weather patterns and extreme weather events, improving low crop yield, increasing access to knowledge on good agricultural practices, providing access to markets and information on prices. Issues with the storage phase are now receiving more focus, in part due to evidence such as the post-harvest weight loss for maize in Uganda from 2004-2012 ranged from 17-

[3] World Bank, Data Bank, Global Development Indicators.

26%.[4] Several important food security, health, and economic benefits result from improvements in post-harvest handling and storage at the farm level. These include (1) reduction in crop loss that strengthens household food security; (2) increase in farmer income due to the ability to hold crops until market selling price is high; and (3) reduction in the accumulation of mycotoxins.

While losses due to pests (e.g., insects, rodents, birds) are more easily observed, mycotoxins that are produced by some molds are less noticeable and pose severe risks. Mycotoxins have the potential to seriously affect human health by acute and chronic effects such as the induction of hepatocellular carcinoma or sudden death due to acute toxicity in the case of aflatoxins.[5] Increasing awareness of these harmful effects of mycotoxins on the health and productivity of human and animals have persuaded many countries to implement regulations for maximum tolerable levels of these compounds in human food and animal feed.[6]

WFP defines post-harvest losses as "crop losses (in quality and quantity) that occur between harvest and the moment of human consumption." [7] This study considers the challenge of implementing the combination of effective training and proper storage to prevent such losses. This includes the important introduction of improved post-harvest storage technologies that protect stored grains from pests and toxic molds better than traditional storage units such as woven sacks and open-air granaries. More specifically, this study focuses on hermetic storage technologies that can be especially effective. When the hermetic technology is properly sealed, CO2 replaces oxygen through respiration of both the commodity and insects. The lack of oxygen kills the insects and halts the growth of molds that are naturally present in harvested grains.

Past academic work and project reporting

Previous academic work in crop storage has primarily addressed adoption rates of storage, the value that storage brings to the farmers, and the effectiveness of storage. Storage in conjunction with credit might allow for farmers to enjoy higher selling prices.[8,9] Studies have documented the reasons for and impact of storage technology adoption.[10] Superior profitability and effectiveness of hermetic bags has

[4] African Postharvest Losses Information System, http://www.aphlis.net/index.php?form=losses_estimates&co_id=50&c_id=324, accessed September 24, 2016.
[5] Warth, B., et. al., 2012. Quantitation of mycotoxins in food and feed from Burkina Faso and Mozambique using a modern LC-MS/MS multitoxin method. *Journal of agricultural and food chemistry*, 60(36).
[6] Suleiman, R.A. and Rosentrater, K.A., 2015, July. Current maize production, postharvest losses and the risk of mycotoxins contamination in Tanzania. In *Agricultural and Biosystems Engineering Conference Proceedings and Presentations*.
[7] World Food Programme Uganda, 2015. Special Operation 200836.
[8] Burke, Marshall. Selling Low and Buying High: An Arbitrage Puzzle in Kenyan Villages. March 20, 2014. Working Paper. Stanford University.
[9] Stephens, E.C., Barrett, C.B., 2011. Incomplete Credit Markets and Commodity Marketing Behaviour. J. Agric. Econ. 62, 1–24. doi:10.1111/j.1477-9552.2010.00274.x
[10] Bokusheva, Raushan, Robert Finger, Martin Fischler, Robert Berlin, Yuri Marín, Francisco Pérez, and Francisco Paiz. 2012. "Factors Determining the Adoption and Impact of a Postharvest Storage Technology." Food Security 4 (2): 279–93.

been demonstrated over conventional storage treated with insecticides.[11] Storage and thus post-harvest losses might contribute to high food prices, as losses depress the actual supply of crops that reach the market.[12] Metal silos – ranging in cost from $35 to $375 – have been proven effective in protecting stored crops from attack by storage insect pests.[13]

Bokusheva, et al. (2012) studied the adoption of metal silos following the Postcosecha Programme in Central America supported by the Swiss Agency for Development and Cooperation (SDC).[14] They conducted a survey of 1,600 households from El Salvador, Guatemala, Honduras and Nicaragua and used regression models to assess the impact of adopting the silos. Compared to the silo non-adopters, the adopter households experienced a significant improvement in their food security and well-being. However, the impact of their adoption varied across the four countries, demonstrating the relevance of regional policies for their adoption. Our analysis followed their approach to contribute the first evidence from the African continent regarding the farmer impact of improved storage technology adoption.

It is also interesting to consider the supply chain for the Postcosecha Programme. Between 1983 and 2009, Postcosecha produced about 670,000 metal silos with tinsmiths for crop storage.[15] SDC withdrew support in 2003, and an ex-post report found that the production of silos stayed constant or even increased after 2003.[15] In the case of Guatemala there was a strong, direct commercial relationship between tinsmiths and farmers. The ex-post report estimated that 800-900 tinsmiths were active in the four Postcosecha countries by the conclusion of the project, and most reported that silo making was not their primary source of income. [15] Overall, the ex-post report estimates that 21% of staple grain (e.g. maize) producers in the four countries have metal silos. [15] In their ex-post study, Postcosecha used samples of 1,600 farmers and 100 tinsmiths. [15] The Postcosecha supply chain of large, bulky silos relied on very decentralized rural production with tinsmiths.

The other notable post-harvest storage project that has achieved and documented substantial scale is the Purdue Improved Crop Storage (PICS) Program in West Africa. The PICS program relied on local or regional production with sophisticated plastics manufacturing firms. The original PICS program focused on reducing storage losses of cowpeas through a hermetic crop bag. The second iteration (PICS2) demonstrated that the PICS bags could prevent losses with maize, sorghum, wheat, rice, peanut,

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[11] Jones, Michael, Corinne Alexander, and James Lowenberg-deboer. 2011. An Initial Investigation of the Potential for Hermetic Purdue Improved Crop Storage (PICS) Bags to Improve Incomes for Maize Producers in Sub-Saharan Africa. Purdue University Department of Agricultural Economics. Working Paper #11-3

[12] Tefera, Tadele. 2012. "Post-Harvest Losses in African Maize in the Face of Increasing Food Shortage." Food Security 4: 267-27.

[13] Tefera, Tadele, Fred Kanampiu, Hugo De Groote, Jon Hellin, Stephen Mugo, Simon Kimenju, Yoseph Beyene, Prasanna M. Boddupalli, Bekele Shiferaw, and Marianne Banziger. 2011. "The Metal Silo: An Effective Grain Storage Technology for Reducing Post-Harvest Insect and Pathogen Losses in Maize While Improving Smallholder Farmers' Food Security in Developing Countries." Crop Protection 30 (3): 240–45.

[14] Bokusheva, Raushan, Robert Finger, Martin Fischler, Robert Berlin, Yuri Marín, Francisco Pérez, and Francisco Paiz. 2012. "Factors Determining the Adoption and Impact of a Postharvest Storage Technology." Food Security 4 (2): 279–93.

[15] Fishler, Martin. 2011. Postcosecha Programme Central America: 5 Year Ex-Post Impact Study. Swiss Agency for Development and Cooperation.

common bean, hibiscus seed, mung bean, pigeon pea, and Bambara groundnut.[16] The third iteration of the PICS program (PICS3) continues to expand its network. By the end of 2015, PICS had manufacturers in Afghanistan, Burkina Faso, Ghana, Kenya, Mali (2 entities), Nigeria, Rwanda, and Senegal and distributors in Togo, Burkina Faso, Cameroon, Chad (2), Ghana (2), Kenya, Niger, Nigeria, Mali (2), and Senegal.[17] Ex-post evaluation of smaller crop storage projects touched on manufacturing and scale but without a thorough supply chain evaluation.[18,19]

Initiatives to scale on-farm post-harvest storage

In 2013, the United Nations (UN) World Food Program (WFP) launched a Research Action Trial in Uganda and Burkina Faso to explore the feasibility of reducing post-harvest loss in developing countries through training and on-farm storage. In this trial, 200 households in each country received one of five technologies—two brands of hermetic crop bags, a plastic silo, a metal silo, and one silo-sized hermetic crop bag—which were then evaluated in terms of losses prevented and contributions to increases in household income. [20] WFP reported that losses were reduced by 98% and household incomes increased between 60% and 100% across both countries.[20] Based on this success, WFP expanded operations in Uganda and began Special Operation 200617 (SO1) in 2014, which is the focus of this study and is discussed in detail later.

Also in 2013, Kansas State University received an initial five-year $8.5 million award from the US Agency for International Development (USAID) for the Reduction of Post-Harvest Loss.[21] In June 2014, Purdue University received $10 million from the Bill and Melinda Gates Foundation (BMGF) to further commercialize the Purdue Improved Crop Storage (PICS) hermetic bag for various crops across many countries.[22] AgResults, a multi-donor initiative incentivizing and promoting high-impact agricultural innovations, is also piloting a novel incentive program to motivate agricultural dealers in promoting advanced storage technologies in Kenya. In October 2015, the First International Congress on Postharvest Loss Prevention was held in Rome. In 2016, the Rockefeller Foundation announced YieldWise, a $130 million initiative aimed at demonstrating a 50% reduction of post-harvest food loss in sub-Saharan Africa by 2021, and launched efforts with four value chains in three countries: maize in

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[16] PICS. Purdue Improved Cowpea Storage A Brief History. Accessed 4 November 2015. < https://ag.purdue.edu/ipia/pics/Pages/home.aspx >

[17] PICS. Purdue Improved Cowpea Storage Supply. Accessed 4 November 2015. < https://ag.purdue.edu/ipia/pics/Pages/supply.aspx>

[18] George, Maria Luz. 2011. Effective Grain Storage for Better Livelihoods of African Farmers Project. International Maize and Wheat Improvement Center.

[19] ATAI. Experimental Evidence on Grain Storage Among Farmers and Traders in Kenya. Accessed 4 November 2015. http://www.atai-research.org/projects/experimental-evidence-grain-storage-among-farmers-and-traders-kenya

[20] World Food Programme Uganda. (2015) Special Operation 200836

[21] Kansas State University. (2013). University Announces Multimillion-dollar food security program on reducing postharvest loss. Press Release. https://www.k-state.edu/media/newsreleases/dec13/ftfpostharvest121113.html

[22] Purdue University. (2014) Purdue gets funding for commercializing PCIS bags in Africa. Press Release. http://www.purdue.edu/newsroom/releases/2014/Q2/purdue-gets-funding-for-commercializing-pics-bags-in-africa.html

Tanzania, cassava and tomatoes in Nigeria, and mangoes in Kenya. There is significant and growing attention, as well as resources, being focused on post-harvest loss reduction.[23,24,25]

Study Context

The World Food Program (WFP) Special Operation 200617 (SO1) in Uganda was part of a four-year project run with two objectives: (1) to reduce post-harvest crop loss in Uganda by training farmers on improved post-harvest handling techniques, paired with the introduction of subsidized, hermetic crop storage technologies; and (2) to serve as a catalyst for the private sector to develop business models for post-harvest loss reduction that are market driven and self-sustaining.

In SO1, the program sought to train 16,600 farmers in 28 districts and offer storage technologies at a 70% subsidy. Given Uganda's language diversity, WFP prepared training material in 14 different languages. Complementing the long-term goal of improving WFP's ability to source food commodities locally and regionally, 75% of those farmers targeted for SO1 were Purchase for Progress farmers. At trainings, farmers were offered their choice to purchase one of four different storage technologies: hermetic crop bags, plastic silo, medium metal silo, and large metal silo. These products were paired with plastic tarpaulins (tarps) for drying crops. The equipment order sheet is shown in Figure 2. Before SO1, the hermetic crop storage sector in Uganda was limited to imported crop bags. WFP worked with a local plastic water tank manufacturer to design the plastic silo, and with metal artisans throughout Uganda to develop the metal silo design.

[23] Lyons, Kate. *Cutting food waste by a quarter would mean enough for everyone, says UN.* The Guardian. 12 August 2015. Accessed 10 November 2015. < http://www.theguardian.com/environment/2015/aug/12/cutting-food-waste-enough-for-everyone-says-un>

[24] Lyons, Kate, Tom Phillips, Amy Fallon, and Kate Connolly. *Fighting food waste: four stories from around the world. The guardian.* 12 August, 2015. Accessed 10 November 2015. http://www.theguardian.com/lifeandstyle/2015/aug/12/fighting-food-waste-four-stories-from-around-the-world

[25] Arsenault, Chris. *Thirty percent of the world's food wasted.* Al Jazeera. 31 October 2014. Accssed 10 November 2015. http://www.aljazeera.com/indepth/features/2014/10/thirty-percent-world-food-wasted-2014103192739208584.html


POST HARVEST FARMING EQUIPMENT DATE …………………………………

(WORLD FOOD PROGRAMME ORDER DOCUMENT)

NAME OF FARMER ……………………………………… NAME OF FARMER ORGANISER……………………………………………………

DISTRICT…………………………………………… SUB-COUNTY……………………………………………. PARISH……………………………………

SUPER GRAIN BAGS (80KG / per bag)

OPTION 1a.
4 Bags + 1 Plastic Sheet
Total = Sh 65,000
Farmer to pay ⇨ Sh 19,500

OPTION 1b.
4 Bags + 2 Plastic Sheets
Total = Sh 102,000
Farmer to pay ⇨ Sh 31,000

PLASTIC SILO (250KG / per silo)

OPTION 2a.
1 Silo + 1 Plastic Sheet
Total = Sh 147,000
Farmer to pay ⇨ Sh 44,500

OPTION 2b.
1 Silo + 2 Plastic Sheets
Total = Sh 185,000
Farmer to pay ⇨ Sh 56,000

METAL SILO /medium (530KG / per silo)

OPTION 3a.
1 Silo + 1 Plastic Sheet
Total = Sh 393,000
Farmer to pay ⇨ Sh 118,000

OPTION 3b.
1 Silo + 2 Plastic Sheets
Total = Sh 430,000
Farmer to pay ⇨ Sh 129,500

METAL SILO /large (1300KG / per silo)

OPTION 4a.
1 Silo + 1 Plastic Sheet
Total = Sh 550,000
Farmer to pay ⇨ Sh 165,000

OPTION 4b.
1 Silo + 2 Plastic Sheets
Total = Sh 587,000
Farmer to pay ⇨ Sh 176,500

Farmers must only select ONE option

Figure 2: SO1 equipment order sheet. "Farmer to pay" = subsidized prices; "Total" = unsubsidized prices.

Training workshops for farmers, consisting of instruction on improved pre- and post-harvest processing techniques, were a key component of SO1. Figure 3 shows a page from the presentation given to farmers during the trainings, which consisted of an introduction and five sessions centered around a specific topic:

1. Grain quality
2. Pre-harvest, harvest practices
3. Drying techniques
4. Threshing and cleaning techniques
5. Grain storage, post-harvest management

Following the training, farmers could examine storage technologies on display and place a product order. The vast majority of farmers who attended the training workshops during SO1, in excess of 90%, chose to purchase one of the four technologies at the subsidized price.

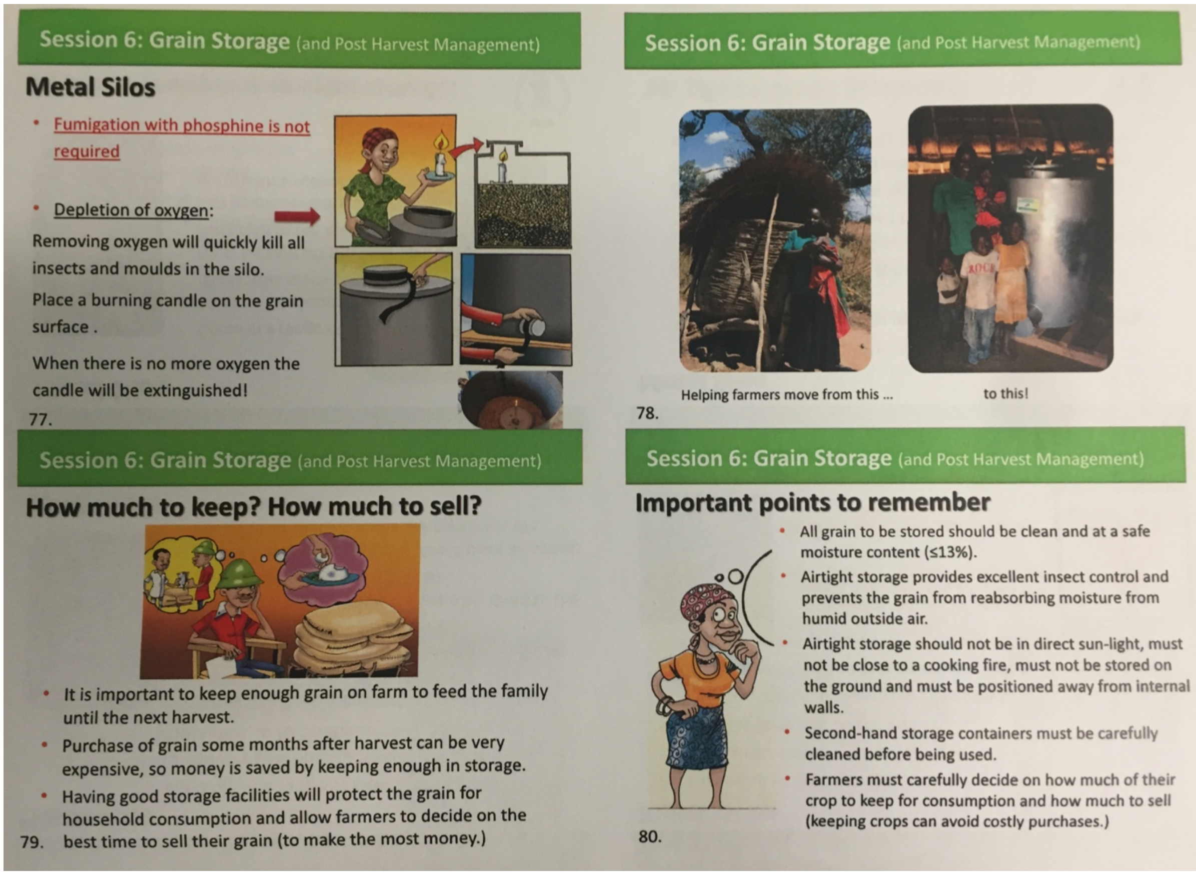

Figure 3: Page from WFP training workshop session on grain storage

The SO1 supply chain is shown in Figure 4. WFP jumpstarted the supply chain by placing orders for equipment (dotted line), then managed the flow of goods throughout the remainder by setting shipment schedules, managing problems and bottlenecks, and conducting quality inspections. WFP paid the manufacturer or importer directly for the equipment, paid the transportation firm for its shipments, and paid partner organizations for farmer trainings and distribution. Farmer payment was collected by partner organizations, and then was passed on to WFP.

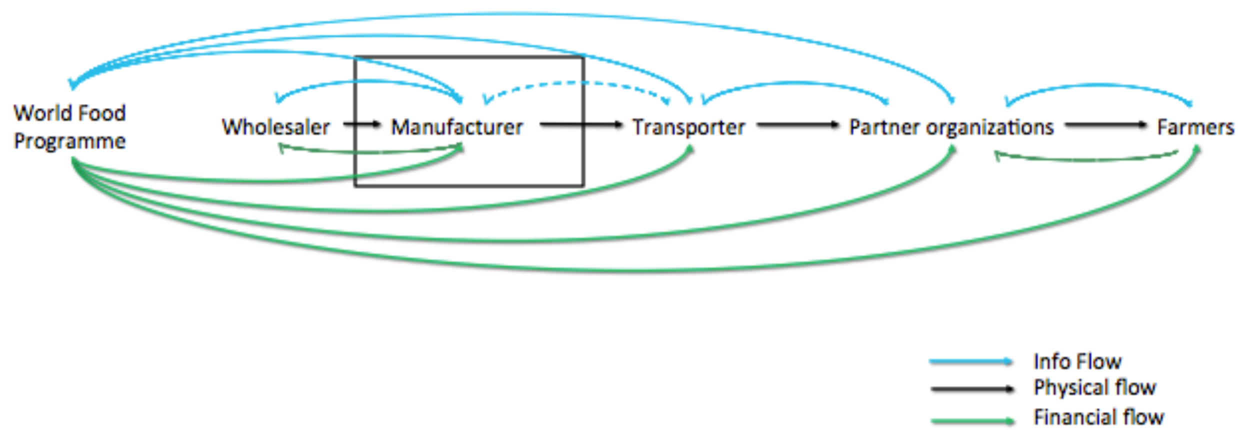

Figure 4 : Pictorial diagram representation of the SO1 supply chain.

The SO1 supply chain was geographically dispersed. The crop bag importer and plastic silo manufacturer were based near Kampala. The six regional metal artisans who participated in SO1 were based in four different regional hub cities. The products produced in and around Kampala (crop bags, plastic silos, and tarps) were aggregated at the WFP warehouse in Kampala before shipment to the regions. One transportation firm, based in Kampala, was hired to handle the entire equipment distribution plan. This firm picked up shipments from the WFP warehouse in Kampala as well as from the six regional metal artisans, and delivered them to Farmer Collection Points (FCPs). Partner organizations conducted the initial farmer trainings and handled the mobilization of farmers to FCPs for equipment pick-up. A geographical representation of the supply chain is seen in Figure 5.

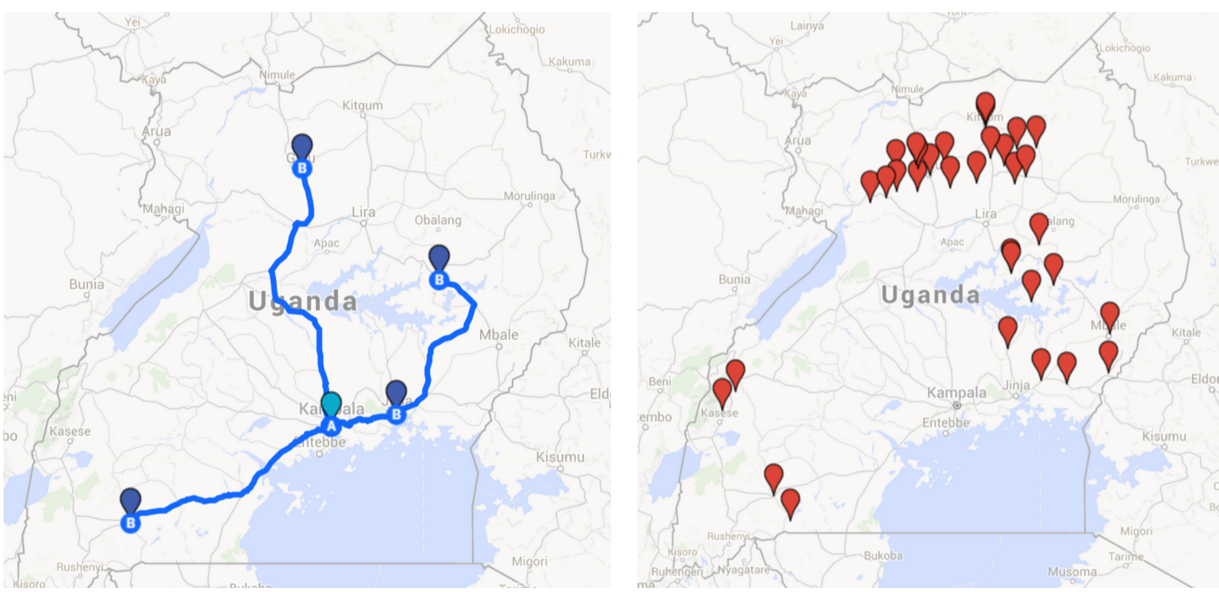

Figure 5: Supply map of equipment pick-up points for SO1 where "A" is the WFP warehouse in Kampala and "B" are regional metal artisan pick-up points (left); Demand map of Farmer Collection Points (FCPs) for SO1 (right).

This supply chain was established for two distinct training and sales seasons, aligned with the two harvest seasons in Uganda each year. Farmers are only interested in purchasing storage technologies when required, around the harvest of their crops. The operation was also designed to train farmers close to the harvest, so there would be maximum retention of key post-harvest handling principles. Manufacturers and distributors have limited working capital and preferred to not build and carry stock. Hence, WFP placed orders and acted as a catalyst to ramp up production and distribution of storage technologies in time for the bi-annual sales seasons.

Following SO1, WFP launched the second iteration of its Special Operation (SO2) in the fall of 2015, which aimed to reach 40,000 farmers in Uganda. While this study does not consider SO2 in detail, a brief discussion near the end highlights adaptations in approach. With growing global interest in post-harvest loss reduction, WFP created a Global Post-harvest Knowledge & Operations Centre (KNOC) in Kampala. Government leaders and WFP staff from 18 countries across several continents attended the KNOC launch in May 2016 to explore implementation of similar post-harvest loss projects. As of publication date, the WFP Post-harvest KNOC has led the rollout of similar projects in Tanzania, Rwanda, Burundi, Sudan, Zambia and Mali.

Data Collection

The analysis is based on multiple data sources. Data from the CITE survey served as the basis to understand the impact of technology adoption, as well as to generate parameters for the system dynamics model.

Supply chain fieldwork

The SO1 storage technology supply chain was well-defined with few actors compared to many commercial supply chains. As a result, this study includes interviews with the majority of the SO1 supply chain actors. The approach used to interview each supply chain actor was a semi-structured interview. Six metal artisan firms, two sheet metal importers, one plastic silo manufacturer, one crop bag importer, and one transportation firm were interviewed as SO1 supply chain actors. To protect confidential information, firm names throughout this document are disguised with names such as HermTech1, HermTech2, PolyPro and Distribution Company.

A two-stage interview was used for respondents, except in cases where time constraints required a consolidated interview. The first stage of the two-stage interview comprised a detailed process mapping of that actor's activities for the SO1. With each respondent, we walked through the process from the WFP's initial contact all the way through the end of SO1. Items such as material requirements, estimated process durations, labor requirements, and costs were all collected. This first stage aimed to gather higher-level information about the supply chain actor's business and operational processes.

The second stage of the two-stage interview was tailored to each respondent's answers in the first stage. After completion of that first stage, a long list of predetermined questions was narrowed down to just the questions that were relevant to that specific actor. Because the operations of each firm involved in the SO1 supply chain varied, this customization approach was critical to the success of the second interview. It also ensured that the respondent would not get tired and frustrated answering questions that did not apply to their operations. Though the two-stage interview process was useful for data collection, some challenges arose: (1) it took business owner's time away from the daily operations; (2) some respondents had difficulty understanding supply chain terminology in the questions; and (3) there may be respondent bias as interviews were set up by WFP, a major buyer of their products.

We also conducted a series of interviews with supply chain actors who were anticipated to be involved in future WFP post-harvest operations. These interviews included six rural private sector distributors based in the WFP's regions of focus, who were given the same interview as the transportation firm involved in SO1. All of these interviews were voice-recorded, and summaries were transcribed after the interview. Specific, quantitative data was collected in writing at the time of response and validated with the voice-recording after the interview.

A second series of interviews was done with retailers of similar agricultural or household products in rural areas. These interviews were used to validate some cost estimates and to gain insights from supply chains with products similar to, and that may in the future include, post-harvest storage technologies. A total of 30 rural retailers and village agricultural agents were given a 5-10 minute structured interview about their business operations. They were asked questions specifically about products similar to crop storage technologies in size, cost, or demand. Additionally, one manufacturer of non-hermetic crop bags was given a full, semi-structured manufacturer interview similar to the one given to SO1 manufacturers. These interviews were not voice-recorded, but all data was recorded in writing at the time of response.

Qualitative interviews were conducted with leaders of similar NGO projects in Uganda ("parallel projects"). These projects included a non-WFP hermetic crop bag project, a project introducing water bladders (flexible tanks) into rural Uganda, an agricultural market information services project, a project for training and registering agro-dealers, and a post-harvest handling training project. These interviews were used to identify lessons of operating in rural Uganda, specifically in the agriculture sector, that might be useful for the WFP's efforts to scale up their project and transition it to the private sector. These interviews were also voice-recorded and summaries transcribed.

Farmer survey

The CITE survey (presented in the appendix) was administered to 202 farmers. Table 1 shows the distribution of these farmers by location and technology. The paper-based survey was designed to: (1) measure how adopters use and value their storage technology; (2) capture grain sales behavior; and (3) document the impact that purchasing the technology has had on farmers' lives and livelihoods thus far. Questions on the survey were based on a literature review and discussions with subject experts.

Table 1: Survey interviews completed, by technology and region

	Bags	Plastic silo	Medium metal silo	Large metal silo	Adopter total	Non-adopters	Total
Eastern	12	32	9	19	72	24	96
Northern	19	47	11	4	81	25	106

Total	31	79	20	23	153	49	202

Sample size was determined based on time and resources available. WFP had recently completed surveys, aiming to include 10% of all adopters. Given the CITE resources — two weeks in the field, two researchers, four translators and four enumerators — we aimed for a sample size of 10% of those surveyed by WFP (though not necessarily the same people, as survey fatigue was a concern). Current and former students from Makerere University served as translators, enumerators and research partners. Training of all research members consisted of reviewing the survey in detail, including proper ways to translate and phrase questions to ensure consistency, and piloting the survey in communities not included in the study.

The Eastern region, centered around the city of Jinja, and the Northern region, centered around the city of Kalongo, were chosen in consultation with WFP staff. These areas had strong project partners who were able to provide access to adopter farmers and their associated communities. A random list of adopter names was generated for each region from a list of all adopters provided by each regional WFP partner. Partners mobilized those selected, informing them of the researchers' presence in-country and desire to interview them. Non-adopter farmers served as a "control" group for comparison. Non-adopters were members of the same communities as adopters, and were selected using a random walk method.

Comparing adopters and non-adopters could result in a selection bias as the non-adopters were selected using different sampling procedures. Each group may have different reporting biases as well. Where possible, alternative data sources were also used to provide validation, particularly for price data. Because of the limited sample size, data for all four storage technologies were combined for some analysis. Regions were also combined, or in some cases treated as an explanatory variable in a regression.

The gender demographics of this study were very similar to the overall WFP Special Operation, where women represented 62% of the 16,600 farmers who participated. Women comprised 95 respondents (62%) in the random sample of adopters and 31 respondents (63%) from the random walk of non-adopters. Gender did not seem to play a role in the technology adoption decision. Among adopters in the study sample, the final decision to buy the storage technology was evenly distributed among the husband (31%), wife (31%), and both husband and wife (35%), with 3% decided by the whole family.

Note that all conversions between Ugandan Shillings (UGX) and US Dollars (USD) for this study use a 2535 UGX/USD exchange rate. This assumption is based on two points of reference. First, we compared the sales price to WFP reported by the Ugandan metal artisans (given in UGX by most respondents) with the purchase price as reported by the WFP (given in USD). Using an exchange rate of 2535 UGX/USD cancelled out the discrepancies and had a maximum absolute difference of less than 3% (see Table 17 in the Appendix). Second, the average exchange rate reported by central banks for the period immediately preceding SO1, from January-July 2014, was 2538 UGX/USD.

Production analysis

This section considers the production processes for each technology offered in the SO1 supply chain. Analysis of production cost and capacity are fundamental to evaluate these newly offered products in Uganda. The analysis also provides a basis for identifying strategies to improve the scale and efficiency of these nascent operations.

Crop bags

The Special Operation included bags that were imported by a distributor as they initially were the only hermetic product option available. We briefly contrast this supply chain with an example from the more prevalent non-hermetic crop bag sector and a new hermetic crop bag manufacturer in Uganda.

Special Operation: HermTech1 Bag

The crop bags used in SO1 were the HermTech1 Bag produced by the HermTech1 Company. They were sold in a set of four and hermetically store roughly 320kg combined. Polypropylene crop bags were used as an outer layer to protect the hermetic bags. The HermTech1 bag is manufactured in Asia, as there is no extruder in Africa that can manufacture at scale the high quality polyethylene required for the bag. However, HermTech1 Company is considering manufacturing in Africa. The machinery for this sort of operation would cost $750,000.

The bags are transported to the Ugandan distributor via one of two routes: (1) from the Asia manufacturing site to the port of Mombasa in Kenya, then transported by truck to the sole Distribution Company in Kampala or (2) from the Asia manufacturing site to the HermTech1 Company's warehouse in Kenya (a wholly owned subsidiary), then transported by truck to the Distribution Company in Kampala. The wholly owned subsidiary mentioned in pathway (2) is able to purchase HermTech1 Company products at a lower price than the distributor.

Crop bags shipped directly from the manufacturer require 2 weeks of manufacturing lead time and 6 weeks of sea transport time. It is generally rare for any of their distributors to place orders more than once every three months. The crop bags are purchased by the Ugandan distributor for $2.00 per bag (including delivery), though this landed cost varies by volume of the order. The bags were priced in the following way for customers: an order of less than 10 bags is 8,873 UGX ($3.50) per bag, and order of more than 10 bags but less than 200 bags is 7,605 UGX ($3.00) per bag, and an order of more than 200 bags is 6,844 UGX ($2.70) per bag. Details regarding production capacity of the manufacturing site in Asia were not provided and there was no evidence provided by the distributor regarding constraints in the supply chain or delays in delivery.

Large scale: polypropylene bag

The Ugandan market for non-hermetic, polypropylene crop bags includes 10-15 companies, typically based in Jinja or Kampala due to infrastructure access. To gain a sense of scale, we held an interview with PolyPro Company, which is a very large firm by Uganda standards selling around 5 million polypropylene sacks a year and 3 million inner liners (e.g. for bagged sugar). The firm also exports sacks to neighboring countries that may not have the industrial infrastructure to produce polypropylene sacks.

They use an ERP system, employ about 600 people, and run 24 hour shifts in the factory. Among those 600 people employed, the vast majority are in production, with a smaller number of warehouse workers, delivery drivers that use a fleet of seven trucks, and management staff. They had ISO certification, which is now outdated, but they are still certified in Uganda and ensure their raw material is food grade.

PolyPro Company sources polypropylene pellets from Saudi Arabia and South Africa, which has a lead-time of about three months between placing an order and arrival. They hold about three months of stock and order every month. They buy 1.3 metric ton (MT) pallet units and the price ranges from 1,000 to 1,500 USD/MT. Moving the raw material from Mombasa to Kampala costs about $50/MT. Their manufacturing line is a conventional polypropylene bag line with an extruder, loom, roller, cutter, etc. that cost in total around $1 million USD; they have three lines. One kilogram of raw material yields about 95 bags of finished goods. They stock about 300 MT of finished goods, 400 MT of raw material, and usually have 300-400 MT of raw material in transit. A manager observes in an interview, "The problem here is raw material. It is the main cost."

Local hermetic: HermTech2 Bag

The first hermetic crop bag to be manufactured within Uganda was the HermTech2 bag in 2015. The HermTech2 bag contains several liners that are not as difficult to manufacture as HermTech1. The HermTech2 Franchise, which supports the HermTech2 bag, contracted with a Ugandan manufacturer based in Kampala to produce the three components of the bag. As HermTech2 Franchise expands in a country, they typically license and work closely with one manufacturer, which produces to order. The lead-time between submitting an order and delivery could be up to three weeks. While more detailed production cost or capacity data were not available, there is further discussion of the HermTech2 sales channel below.

Plastic silos

The plastic silos for the Special Operation were produced in a roto-molding process by a manufacturer whose core business is the production of plastic water tanks. First, polymer pellets and additives (pigment, UV stabilizer, etc.) are compounded, extruded, and pulverized into a powder. The material is then weighed, placed into a mold created specifically for this product, and heated and rotated (a process called "roto-molding") for 20 minutes. After being cooled with fans, the mold is un-clamped, excess material on the finished good is cut off with small knives, and the silo's thickness is inspected for uniformity. Holes are drilled for the lids and fixing screws, the lid is fixed onto the silo, and the label sticker is placed on the exterior. Finished silos are transported from the manufacturer's facility, located in the outskirts of Kampala, to the WFP warehouse in Kampala.

We can estimate the time to manufacture one plastic silo as the sum of time estimates for all production operations, from weighing the polymer pellets to labeling the finished silo. A conservative production time, using the upper ends of all time estimates, was 1.3 hours. The plastic silo manufacturer estimated that with the current roto-molds they have, they could produce 288 SO1 plastic silos per day. WFP reported that actual production from this manufacturer rarely exceeded 100 per day.

The primary raw materials used in plastic silo production in SO1 were polymer pellets, additives, lids, and labels. At the time of the interview, the plastic silo manufacturer had estimated costs for each of these components per silo they had produced. The polymer pellets were 50,000 UGX ($19.72) per silo, the total cost for all additives was 2,000 UGX ($0.79) per silo, the lids cost 29,700 UGX ($11.72) per silo, and the labels were 3,500 UGX ($1.38) per silo. In total, the cost of raw materials per plastic silo was $33.61.

The labor cost per plastic silo had also already been estimated by the manufacturer at $13.00. This estimated labor cost was what the manufacturer called the "production cost," and included both labor and utilities.

The cost of hiring a truck to transport finished plastic silos to the WFP warehouse in Kampala was 160,000 UGX ($63.12). This cost included payment to the driver, money for fuel, and loading/unloading. Approximately 60 silos fit on each truck. The total cost of transport per silo paid by the manufacturer, therefore, is $0.99. The WFP reported the purchase price for plastic silos in SO1 as $38.00 each. According to the costs estimated in the previous sections, the total cost per silo of production and delivery was $47.60.

Metal silos

Metal artisans produced two sizes of metal silos over the course of three months as part of the SO1 project. Silo production was a new line of business for these metal artisans, who reported making a variety of other products (e.g., maize shellers, windows, gates, water tanks). Their production methods varied slightly but included the same major cost categories: raw materials, labor, and transport or delivery. Artisan Manufacturer 3 and Artisan Manufacturer 6 only produced medium metal silos; all other artisans produced both medium and large silos.

Cost

Raw materials were the largest component of finished goods cost for metal artisans in SO1, with sheet metal being the dominant cost. Sheet metal costs for each size and each artisan can be found in Table 14 in the Appendix. For sheet metal costs in which a range of prices was given, the average was used. The total raw material cost also includes inbound transportation. One metal artisan, Artisan Manufacturer 5, did not report a sheet metal cost. Artisan Manufacturer 5 has a parent company that handles most of its procurement and sourcing of raw materials, so we assume that they would procure sheet metal at the market rate, reported by several agricultural actors and metal artisans to be 82,000 UGX ($32.35) per sheet. The transport cost for Artisan Manufacturer 5 is estimated based on its location in Soroti. Soroti is a major transit corridor for imported sheet metal, so it is reasonable to assume the transport cost would be low for this artisan. The transport cost is therefore taken to be equal to the lowest transport cost per sheet for another artisan, 250 UGX ($0.10).

Other raw materials for silo production comprised a much smaller portion of the raw material cost. These costs, combined in Table 14 as "Cost of other raw materials," include items such as bolts, rivets, rubber seals, filler paste, silicon, paint, and locks and chains, if included in the manufacturing process. Costs were included as reported by the artisans, with one exception. Because the WFP requires manufacturers to purchase labels directly for their silos, a label cost was included all artisans even if not reported (using the average of other reported label costs: 2,500 UGX, or $0.99, per label).

Labor costs are the other large cost component for metal silo production. Cost estimates are based on effort captured in the production process description and the cost structure for each metal artisan. Artisans typically reported a direct labor wage per silo, a time spent per silo, or both. In some cases, an additional wage was paid for specialty work (e.g. silicon sealing). Where relevant, this is included. The total labor cost per silo is shown in Table 15 in the Appendix.

The interview process captured business practices that varied. For example, Artisan Manufacturer 1 hired a cohort of artisans and transported them to their site for three months to complete the production. Project-level costs were reported for artisan transport (700,000 UGX; $276.13), accommodation (2,000,000 UGX; $788.95), meals (900,000 UGX; 355.03), and salary (33 million UGX; $13,017). The WFP reported purchasing 699 silos (medium and large inclusive) from them throughout SO1. Thus, the labor cost per silo for Artisan Manufacturer 1 was $20.66. Artisan Manufacturer 5 did not report a labor cost in their interview. To estimate their labor cost per silo, the average of other artisans with similar production strategies (Artisan Manufacturer 2, Artisan Manufacturer 3, Artisan Manufacturer 6, and Artisan Manufacturer 7) was taken.

Transportation costs for finished goods were covered directly by WFP, which hired a transportation firm to pick up silos from artisans and deliver them to farmer collection points. Several artisans did have to pay for loading of the hired truck upon arrival at their facilities. Some interview respondents reported a separate loading cost per truck paid to less-skilled laborers. This cost is divided by the number of silos loaded on the truck as given directly or inferred from the other artisans. Artisan Manufacturer 3 provided the cost of loading per silo directly. The remaining interview respondents included this loading cost in their labor cost estimate; for these respondents the separate loading cost category is reported as $0. The final cost of loading per silo for each artisan is given in Table 16 in the Appendix.

A summary of the raw material, labor, loading, and total costs for each metal artisan can be found in Table 2. The average total cost for a medium silo was $124.65 and for a large silo was $158.73. The largest variation is in raw material cost for sheet metal, which is surprising since it is sold in open markets. One reason for variation is the agricultural input product exemption from 18% Value Added Tax (VAT) in Uganda. Artisan Manufacturer 2 imported the raw sheet metal directly and was unable to avoid VAT, resulting in the highest raw material cost per silo. The remaining artisans either did not report an added VAT cost for their sheet metal or reported one that brought their sheet metal price up to equivalent with the others (Artisan Manufacturer 4). If the VAT exemption was removed, the raw material prices for these metal artisans would increase, further increasing the cost. There is moderate variation in the labor cost. This is in part due to different manufacturing processes and productivity levels that are explored in more detail below. There is also variation in loading cost, though it is a very small component of the overall cost.

Based on these cost estimates, the gross profit per silo for each artisan was determined and reported in Table 18 in the Appendix. Profitability varies across the artisans but could be due in part to two key factors. First, the estimates provided by each artisan could be based on different exchange rate assumptions, which could change profit levels by over $40 per silo considering the range of 2300-2900 UGX/USD seen over three years prior to SO1 (see Table 18). Second, the artisan estimates could reflect respondent bias and/or inaccurate cost approximations, as formal bookkeeping is uncommon.

Table 2: Total costs (including raw materials, labor, and loading) per silo for each artisan.

Metal artisan	*Silo size*	*Raw material cost per silo ($)*	*Labor cost per silo ($)*	*Loading cost per silo ($)*	*Total cost per silo ($)*
AM1	Medium	$ 94.10	$ 20.66	$ 0.00	$ 114.76
AM2	Medium	$ 106.24	$ 37.48	$ 0.70	$ 144.42
AM3	Medium	$ 71.73	$ 6.31	$ 1.18	$ 79.22
AM4	Medium	$ 77.40	$ 55.23	$ 0.88	$ 133.51
AM5	Medium	$ 65.68	$ 50.62	$ 0.00	$ 116.30
AM6	Medium	$ 100.53	$ 59.17	$ 0.00	$ 159.70
AM1	Large	$ 129.51	$ 20.66	$ 0.00	$ 150.17
AM2	Large	$ 152.60	$ 39.45	$ 0.70	$ 192.75
AM4	Large	$ 94.58	$ 55.23	$ 0.88	$ 150.69
AM5	Large	$ 90.01	$ 51.28	$ 0.00	$ 141.29

Capacity

The production capacity in silos per day for each artisan is included in Table 19 in the Appendix. Some artisans reported their capacity in silos per week (Artisan Manufacturer 1, Artisan Manufacturer 4) or silos per employee (Artisan Manufacturer 2). To calculate daily production capacity from these values, we assumed six working days per week and used the number of employees reported to be employed by Artisan Manufacturer 2 for SO1.

In addition to the artisan-reported production data, we estimated each artisan's production capacity using shipment data provided by the transportation firm. We can calculate the production rate for the period between shipments by dividing the shipment quantity by the days since the last shipment. For artisans that were combined into one shipment, the shipment quantity was allocated proportionally to the final number of silos sourced from each artisan. Because Artisan Manufacturer 2 produced silos for two districts (Jinja and Mbarara), we assumed that they produced equal amounts of silos for each. The plots of each artisan's reported and derived capacity over the duration of the project is seen in Figure 6.

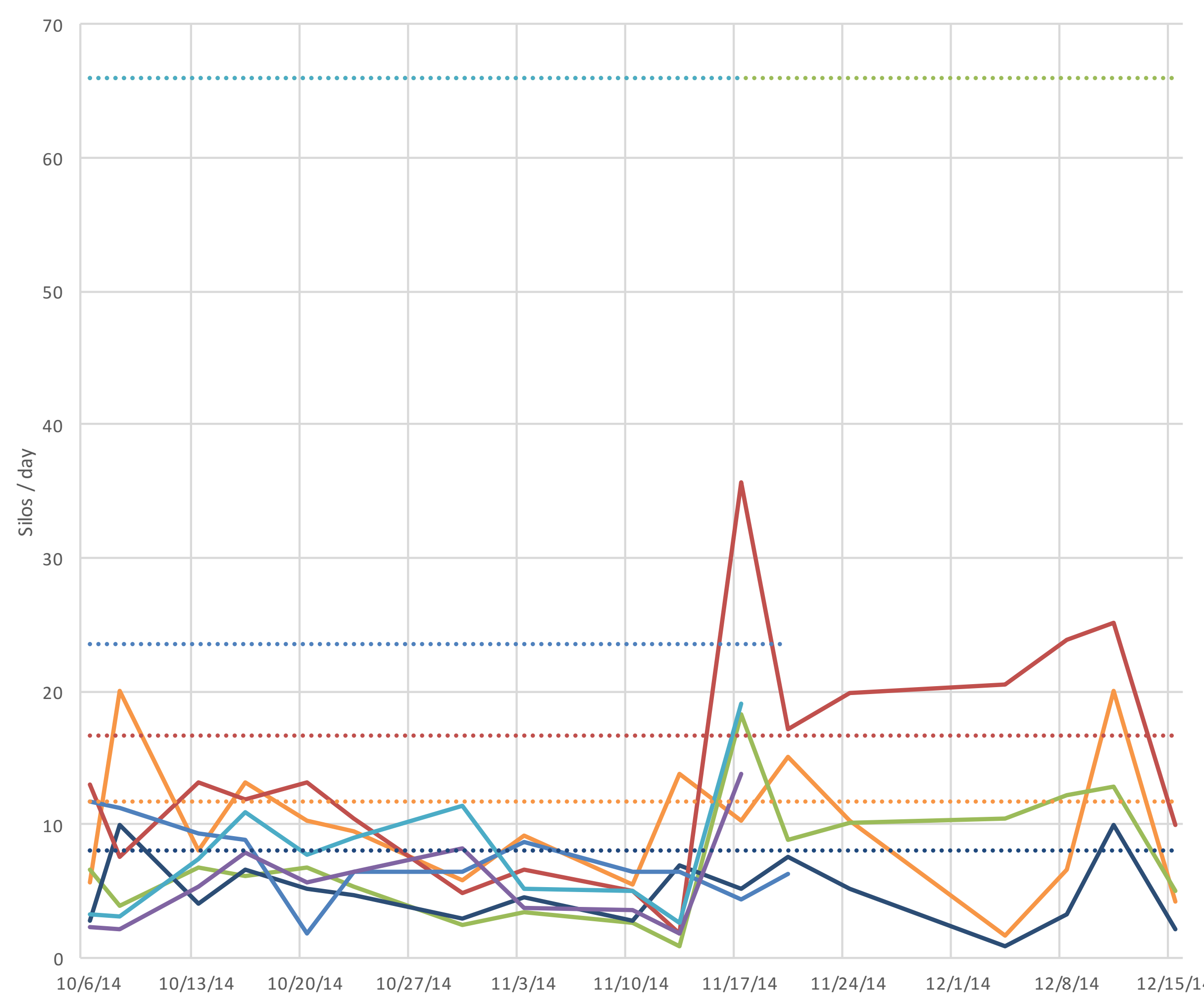

Figure 6: Metal artisan production capacities as reported in interviews (dotted line) and estimated production over time based on transportation firm data (colors correspond to the same artisan).

Several observations can be made by comparing these values. The capacity reported by some artisans was much higher than their derived output. At the same time, other artisans were able to exceed their reported capacity, especially as the sales season approached. There also is a notable increase in capacity among all artisans in the middle of November, which could indicate that WFP played an important role as a catalyst for production to make products available in time for the short selling season.

In addition, these data indicate notable variability in production rates for metal artisans. Data from the transportation firm responsible for distribution in SO1 indicates that in many cases, they were unable to pick up the scheduled amount of equipment from metal artisans because of delays in production.

We also evaluated capacity by calculating the time to produce one silo. This involved detailed process analysis to understand the time for each production step reported by artisans. During the first stage of each interview, the detailed manufacturing process was described by the artisan; time estimates for each step in the process were captured during the second interview. Some artisans also estimated the overall production time per silo directly. For interviews when the production time was not directly reported, it was calculated to be the sum of the time spent on each production step. These values are included in Table 19.

These data regarding artisan capacity do not converge to tell a clear story. When considering silos per day, the reported and derived capacities differ. In addition, the artisan's estimated production time per silo did not align with values calculated by adding times for each step in the manufacturing process. Moreover, the capacity in silos per day does not correspond with the inverse of the production time per silo using a common assumption of working hours per day. These discrepancies may indicate that artisans lack the data and/or the knowledge to effectively predict production capacity or break down production processes. Training efforts to develop skills for data collection and industrial engineering techniques may enable artisans to not only assess but also to increase production capacity.

Potential improvements in production capacity

We close this section by analyzing potential improvements in operations for the metal silo manufacturers. We focus on metal silos because there were multiple firms to compare, while plastic silos and crop bags were sourced from a single vendor. We consider two approaches to improve their production capacity: increasing productivity of the manufacturing process and mitigating the tendency to under-produce due to risk aversion.

Increase productivity

A common focus for increasing capacity is to improve productivity of key inputs. We were able to collect useful input data for four artisan firms, with labor being the most directly reported. The value of labor is derived from self-reported costs from manufacturers, and the value of capital is derived from the purchase cost of short term assets used in production plus the depreciation of long-term assets during the SO1 period. Since self-reported production rates and capacity were not reliable, external data are used to measure output; specifically, we calculate the average number of silos produced per day based on shipment data from the long-haul transporter.

Starting with simple analysis, we see that as the number of workers employed for metal silo production increased, the daily output per employee decreased (see Table 3). While this analysis does not reflect direct data on employee skill levels, interview notes indicated that the firms who employed larger workforces hired inexperienced students in response to the large order. Though they had large teams dedicated to the project, these teams were less skilled and had lower employee productivity than firms with more skilled labor.

Data also show that smaller firms, with fewer workers and fewer total silos produced, invested more in capital equipment. The two smaller manufacturers had each bought large pieces of equipment from abroad that cost significantly more than capital equipment used by the two larger firms. As expected, firms with a higher ratio of capital to labor costs had higher labor productivity. However, semi-structured interviews indicated that the production process need not be capital-intensive. Though one respondent noted that equipment such as large metal sheet cutters and bending tools might have expedited the process, less capital-intensive methods for cutting and bending of metal sheets were not significantly slower. A Cobb-Douglas production function used to determine the relative importance of labor and capital equipment was not statistically significant due to the small sample size (n=4).

Table 3: Key production input and output measures

Artisan firm	Number of employees for SO1	Production rate (silos/day)	Silos produced in SO1	Daily output per employee	Cost of labor (UGX/silo)	Cost of capital (UGX/silo)	Ratio of capital to labor costs
AM3	4	4.99	350	1.25	15,000	4,603	0.31
AM1	10	9.96	699	1.00	52,360	3,656	0.08
AM4	20	14.11	756	0.71	70,000	754	0.01
AM2	33	14.92	774	0.45	75,000	1,436	0.02

These limited data cannot be used to draw conclusions regarding artisan productivity. However, firms that employed more skilled labor and more capital equipment had higher productivity. Further study could better determine the most efficient investment strategy. The value of training laborers could also be explored with better data regarding specific skill profiles for these firms. While metal artisans struggled to meet demand requirements in a timely manner for SO1, the local artisan strategy for producing metal silos has potential for productivity improvements.

Mitigate risk aversion to seasonal over-production

A simple way to increase production output for the bi-annual sales seasons is to commence manufacturing earlier. Artisans generally started production only 2-3 months prior to harvest, which indicates that capacity could be doubled by producing year around. In the current scenario, WFP could place orders even earlier or design a contractual mechanism that penalizes delays in order to encourage early production. Considering the future scenario with WFP no longer placing orders, artisans would have to weigh the risk of producing too little against the risk of having unsold silos at the end of the selling period by starting production too early. This situation is known as the newsvendor problem.[26] [27]

Evidence shows that risk-averse artisans, especially when constrained by lack of credit to maintain finished goods until the next selling season, continually under-produce and thus constrain the scalability of a technology in demand. A study in 10 African countries showed that farmer demand for new crop storage technologies was much higher than the stock levels of distributors; the authors proposed further study of risk sharing mechanisms.[28] Risk sharing contracts between the artisans, raw material suppliers, and even an organization like WFP could be put in place to encourage artisans to produce sufficient quantities in advance. These contracts could take the form of a buyback for raw materials not used or a salvage value for any finished goods not sold, for example.

To examine risk profiles and production behaviors in Uganda, we ran a decision-making experiment with six artisans and 40 undergraduate students from Makerere University in Kampala. First, a standard risk lottery experiment was used to assess the general risk profile for each participant. Their second task was

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[26] Eeckhoudt, L., Gollier, C., H. Schlesinger. 1995. The risk-averse (and prudent) newsboy. Management Science 41 (5): 786–794.
[27] Arrow, KJ, T Harris, and J Marschak. 1951. "Optimal Inventory Policy." Econometrica 9 (3): 250–72.
[28] Coulibaly, et. al, 2012. Purdue Improved Cowpea Storage (PICS) Supply Chain Study. Working Paper #12-4, Department of Agricultural Economics, Purdue University, West Lafayette, IN.

to choose order quantities of the critical raw material (sheet metal) given 28 contracts with varying wholesale prices and buyback prices or finished good (metal silo) salvage prices.

It was expected that managers would be averse to risk in this context, but it was surprising that the general risk aversion was not more extreme than previous studies using the same lottery approach. However, the second task revealed consistent under-ordering among manufacturers and students that is greater than previous studies in different contexts. Ordering results indicate much more aversion to the risk of leftover finished goods than is reflected in the general risk profile. One hypothesis is that behavioral difference may be more attributable to business experiences than to the overall cultural context. For example, aversion to leftovers would be expected from managers who have continually faced constrained resources such as working capital, even if cultural tendencies are not very risk averse.

It is also surprising that results differ based on the contract type: buyback condition participants perform notably better than salvage condition participants. The differences in performance might be attributed to the higher risk, perceived or in reality, of contracts to salvage finished goods (metal silos) compared with returning metal sheets to a wholesaler for a refund. Because silos are a new product on the market, not to mention being bulky to store, the participants may not trust the salvage contract.

A detailed description of this behavioral study is available in Castaneda et al. (2016).[29] It indicates that efforts to facilitate risk sharing mechanisms in the supply chain may be a simple and effective way to improve the capacity for storage technologies.

Transportation Analysis

As detailed in the previous section, production was unreliable and often delayed, especially among metal artisans. In this section, we analyze how these production delays affected the transportation firm's ability to distribute equipment and the cost of doing so.

Special Operation shipment sizes and delays

In SO1, one transportation firm was hired to move all finished goods. The two organizations together planned a distribution schedule for the season. The transportation firm picked up goods from five locations and delivered them to 35 different farmer collection points. Metal silos came from six different regional metal artisans based in four cities while the remaining goods – plastic silos, hermetic bags, and tarps – were collected at the WFP warehouse in Kampala.

According to shipment data provided by the transportation firm, 63% of scheduled metal silo pickups and 78% of WFP warehouse pickups were partially loaded when evaluated against their scheduled loads. Trucks leaving metal artisans partially-loaded were on average 22 units short of their planned amount. Trucks leaving the WFP warehouse partially-loaded were on average 174 bags, 652 tarps, and 30 plastic

[29] Castaneda, J, Brennan, M., and Goentzel, J. "Supply Chain Contract Design for a Newsvendor Problem in a Developing Economy." Working Paper, April 2016.

silos short of their planned amount. Thus, around half of all large silos and around one quarter of all medium silos were not available when scheduled (see Table 4). In contrast, less than 6% of the plastic silos and bags were short of the required amounts in the schedule. This indicates that production capacity was much more reliable for plastic silos and bags. Product shortages lead to delays in downstream distribution and to increased transportation costs from underutilized truck capacity.

Table 4: Number of Silos Produced and Number of Silos Short for all Manufacturers

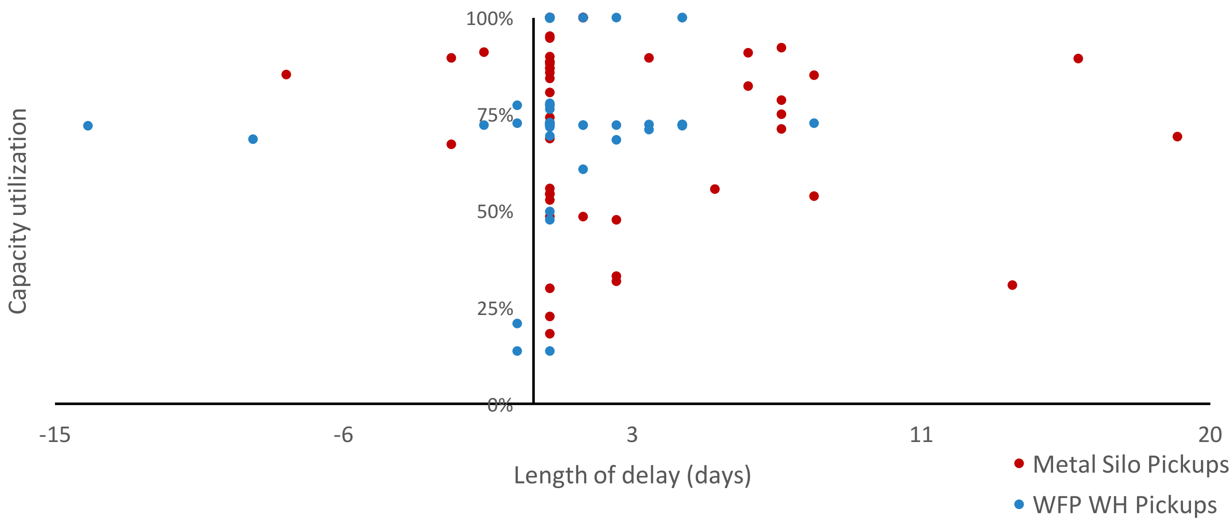
	Large Metal Silos	Medium Metal Silos	Total Metal Silos	Plastic Silos	Hermetic Bags
Total produced	863	2,175	3,038	6,326	27,064
Total number short across scheduled pickups	463	530	993	356	989
Percent short	53%	24%	32%	6%	4%

Not only were trucks not full, many times they were delayed in departure, perhaps waiting for more production to make the trip worthwhile. For all shipments (those delayed and those not delayed), there were on average 2.8 days between a scheduled pickup and the actual departure from a metal artisan production facility and 0.4 days of delay at the WFP warehouse in Kampala.[30] For shipments that were delayed to some degree, trucks waited an average of 8.6 days at regional metal artisans and 3 days at the WFP warehouse.

We further analyzed the relationship between delays and load size to consider the tradeoff between sending a smaller shipment closer to the scheduled shipment date versus waiting to fill the truck further. Graph 1 plots the percentage of the truck capacity filled by each SO1 shipment (by number of units) against the number of days that shipment was delayed. Note that some points represent multiple shipments. Many shipments are sent as scheduled (no delay), though sometimes with less than half of the capacity filled. The graph also shows that many shipments were delayed to increase capacity utilization.

Shipments picked up at the WFP warehouse in Kampala were more likely to be on time, including a few with lower utilization, and all were shipped within eight days of the scheduled shipping date. Delayed WFP warehouse pickups reached 70% capacity utilization; additionally, some shipments reaching 70% left earlier than the scheduled date, including a few from metal artisans. These observations indicate that there was a policy to send trucks as soon as they were 70% full. However, even long delays at some metal artisan locations did not reach this target.

[30] These averages include negative numbers for “negative delays,” or early pickups, from each location.



Graph 1: SO1 transportation data describing the percent of units full each shipment was, as well as how many days it was delayed.

Potential improvements for partial shipments[31]

The previous analysis highlights two managerial options when there is a partial shipment available at the scheduled departure date. The first option is to send the partial shipment as scheduled and later send a second truck for the remaining items. The second option is to delay the departure in order to send a full shipment. The additional costs of each option were evaluated based on data gathered from interviews with the SO1 transportation firm and information collected from agricultural agents.

No delay, second truck

The added cost of sending a second truck later to pick up the remaining equipment was based on all costs associated with commissioning and completing second haul (i.e., driver, truck usage, fuel, loading, unloading). Non-delayed deliveries from the WFP warehouse in Kampala, on average, took 2.83 days to be completed in SO1. Non-delayed deliveries from metal artisans took on average 1.00 days. Assuming no revenue on the backhaul returning from the destination, these numbers were doubled to account for the roundtrip time (Table 5).

A Ugandan commercial truck driver's salary was estimated to be the average of the monthly salary range given by the SO1 transportation firm, $10.83 per day. The firm also reported that drivers were given an additional allowance of $10.00 per day while they are in the field. The cost per day for usage of a second truck was estimated to be 100,000 UGX ($33.33) based on transport costs given by other agricultural product retailers. The cost of fuel for a second haul was estimated using the fuel usage rate given by the SO1 transportation firm: 1.13 L/km. This rate is the sum of the loaded fuel usage rate (0.7 L/km) and the empty backhaul fuel usage rate (0.4 L/km). The price of fuel was estimated to be 3500 UGX/L ($1.17/L), based on fuel prices in Uganda at the time. The resulting cost of fuel per kilometer was $1.32.

[31] All USD estimates in this section on transportation improvements are based on a 3000 UGX/USD exchange rate.

To estimate the length of the SO1 hauls, the average distance between a regional hub and the centroid of that region's delivery points, or Farmer Collection Points (FCPs), was calculated. For trips originating in Kampala, the distance to the regional hub was added to the average distance between that regional hub and its FCP centroid. The resulting distances are found in Table 5.

The costs of additional loading and unloading for the second commissioned truck were based on responses from interviewees in rural areas. The loading costs reported for a truckload of equipment ranged from 50,000 UGX ($16.67) to 100,000 UGX ($33.33), with a mode of 80,000 UGX ($26.67) per truck. The mode, which is the most reliable estimate, was doubled to account for the cost of unloading at the farmer collection point. The extra cost of loading and unloading for the second truck was estimated to be $53.33 per truck.

Using the assumptions and methods mentioned above, the additional cost of sending a second truck to pick up the delayed production is calculated for each origin and destination region. The results are given in Table 6.

Table 5: Estimated round-trip haul times and one-way lengths of each haul for each possible shipment. FCP destinations are the centroid of each region's collection of FCP delivery points.

Origin	*Destination*	*Round-trip duration (days)*	*One-way length of haul (km)*
Kampala	FCP Gulu	5.66	337.91
Kampala	FCP Jinja	5.66	66.80
Kampala	FCP Mbarara	5.66	436.48
Kampala	FCP Soroti	5.66	275.68
Gulu	FCP Gulu	2.00	61.88
Jinja	FCP Jinja	2.00	67.33
Mbarara	FCP Mbarara	2.00	199.13
Soroti	FCP Soroti	2.00	82.30

Delayed shipment, larger load

While delaying a shipment may avoid the direct cost of sending a second truck, the transportation company incurs an opportunity cost from having the idle truck unable to earn revenue from other shippers. The opportunity cost per day of lost revenue is estimated to be 100,000 UGX ($33.33), based on transport costs given by other agricultural product retailers.

For delayed shipments at metal artisan manufacturing sites, the average number of days a truck would wait is 8.6 (the length of the average delay for such shipments). Using this delay estimate and the previously mentioned assumed driver and truck costs, the additional cost of having a truck wait out the delay is $465.83. For delayed shipments at the WFP warehouse, the average wait for a truck is 3.0 days. The added cost of this delay is estimated, based on the previously mentioned assumptions, to be $162.50. Even if these delay costs were not passed on to the shipper in this case, future rates may rise based on transportation providers anticipating such delays.

The combined results in Table 6 indicate that the best approach for pickups at the WFP warehouse is to delay the shipment date. In contrast, it is better to send partial shipments as scheduled from the metal artisan locations and then transport the remaining items with a second truck at a later date. These results reflect the principle that direct transportation costs are lower for decentralized production locations. Thus, in this case it is more attractive to send additional shipments from metal artisan locations that are closer to final destinations than from a central Kampala warehouse. However, the analysis may differ depending on the direct and opportunity cost assumptions.

Table 6: Cost for alternate partial shipment options.

	Metal artisan pickups	*WFP warehouse pickups*
Delayed shipment	$ 465.83	$ 162.50
Second truck		
FCP Gulu	$ 176.58	$ 616.73
FCP Jinja	$ 183.76	$ 259.31
FCP Mbarara	$ 357.52	$ 746.68
FCP Soroti	$ 203.50	$ 534.69

Sales Channel Analysis

Cultivating a market for products is a critical part in scaling the supply chain. We explore the important roles played by local partners in training and promotion for these novel, hermetic technologies and contrast it with approaches for a similar product. We also consider the sales and distribution channel for "parallel supply chains" to identify ideas for the planned transition of the Special Operation into the private sector.

Special Operation training and promotion

Nine WFP Partner Organizations were contracted to provide initial trainings and refresher trainings to farmers in sixteen districts across Uganda. All 16,600 farmers participating in SO1 received a preliminary eight-hour training, in which proper drying and storage placement methods were presented. WFP reported that more than 50% of participating farmers (around 8,400 farmers) received a refresher training that reiterated the points of the initial training.[32] These refresher trainings were conducted as on-farm demonstrations, with groups of 10-15 farmers. Partner Organizations also coordinated farmers to pick up their storage technologies at Farmer Collection Points (FCPs) spread across the country. No two partner organizations operated in the same district; several partner organizations operated in multiple districts.

32 Costa, Simon. Eradicating the World's Greatest Solvable Problem. WFP. 2015

Table 7: Density of Farmer Collection Points (FCPs)

	One FCP	Two FCPs	Three FCPs
Number of Districts	11	3	1

Table 8: Extent of Partner Organizations activity

	1 District	2 Districts	3 Districts	4 Districts
Number of Partner Organizations	6	1	0	2

The Partner Organizations received contractual payment for services provided, with total amounts roughly ranging from 10,000 to 100,000 USD. The average cost per farmer across all Partner Organizations was $22.25, with the rate ranging from $16 to $26 for individual organizations. At a rate of $16 per farmer, the same training budget could have trained over 6,000 additional farmers. This shows the importance of efficiency in all aspects of the supply chain, though quality of training must not be compromised.

Some factors that could yield rate differences among the Partner Organizations in cost per farmer could be the number of farmers trained (i.e., economies of scale), the density of Farmer Collection Points (i.e., economies of scope), and the organization type (e.g. international, local, religious). We performed simple linear regressions on both total cost and cost per farmer with these variables to explore these hypotheses, though the sample size of nine organizations is too small to draw definitive conclusions for this many variables.

First, regressions of total cost were run considering each individual variable (Table 20 in the Appendix, section 1). The number of farmers trained, number of collection points serviced, and density of area serviced were each statistically significant. The number of farmers trained had an R^2 of 0.97, which indicates that it is the most significant variable. We then tested the significance of various combinations of the statistically significant variables (Table 20, sections 2) and of every variable with number of farmers trained (Table 20, section 3). The dummy indicating a religious organization was the only variable that was significant in combination with number of farmers trained and slightly improved the R^2 to 0.98. Finally, we regressed cost per farmer with the four remaining variables (Table 20, section 4), of which none were substantially significant, although again the religious organization is somewhat significant with a p-value of 0.08. However, given small sample, these results do not point to any clear factor that explains variance in training costs other than the direct variable of the number of farmers trained.

Potential improvements in training and promotion

The direct training model was used by similar initiative, but to a lesser extent with lower investment. The HermTech2 Franchise did not provide any financial incentive or meal for farmers to attend trainings. They worked with vendors and partner organizations to conduct trainings in the afternoons, when people left their garden work. Their approach included an awareness meeting after which they asked for volunteers – targeting about 5 people – to donate a crop of their choice that suffers from pest damage.

They asked the volunteers to store that crop for 4 months and were free to keep the bags in their houses. At the end of this period, they created an event around the bag opening, promoting it with local media with the hope that it would become like a village party, with bags for sale.

Radio shows, which were not part of SO1, were commonly considered a cost effective method for reaching rural populations in Uganda for both marketing and training. These findings correspond with findings in literature. "In developing countries, where farmers may not always be literate… radio advertising is often extremely effective."[33] Moreover, demonstrations and field dates were important in raising awareness "as farmers may be reluctant to buy the product until they have observed its performance." [33] The HermTech2 Franchise found success with a model that relied on local radio to support local retailers. To become an approved project vendor, they must consent to having their contact information used in the project's radio campaigns. For example, in an area with a local radio station, the project would include in a radio advertisement the names of 2-3 local vendors. During SO2, WFP saw many of its field distributors already using radio as a means to mobilize farmers, and build awareness.

Empirical analysis of sales channels for parallel supply chains

The WFP goal of cultivating a sustainable private sector hermetic crop storage market to which rural Ugandans will have access is unique in terms of the product, but not in terms of the supply chain. There are several industries in Uganda with products similar in value and size have successfully built markets in and supply chains to rural areas. We detailed the distribution and retail networks of some firms in comparable industries – "parallel supply chains" – and looked at their operations for insights and lessons learned. Distribution or retailer operations selected for survey either distributed or stocked plastic or metal water tanks, or polypropylene bags. We also found, and not by consequence of the SO1, one rural distributor that sold hermetic bags. The rural retail outlets that we studied were small. In Gulu, Lira, Soroti, and Jinja, the retail outlets surveyed were consistently small shops that have about 25-100 square meters of floor space – not including front porches, on which all varieties of products are displayed.

Crop bags

Hermetic crop storage is relatively new to Uganda. The HermTech1 Company has a sole Ugandan distributor, Distribution Company, for their products. The WFP contracted with this distributor in SO1. The distributor sells primarily to large buyers and aggregated individuals (e.g. to farmer groups). From interviews, it appeared that the firm focused more on other hermetic product lines than crop bags. Until recently, Distribution Company was the sole provider of hermetic bags in Uganda.

With the HermTech2 Franchise beginning operations in Uganda, the HermTech2 bag became available in the market in 2015. In its first year, the HermTech2 Franchise sold about 5,000 bags. They had one firm that manufactured, two firms that distributed (one upcountry distributor and one 'Container Village' distributor), and many that sold HermTech2 bags. The HermTech2 Franchise was expanding its rural

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33 Morris, Michael. Maize Seed Industries in Developing Countries. Lynne Rienner Publishers CIMMYT. 1998 Pg. 129.

retail presence in Uganda, which is similar to what it has done in other African countries, with an aim to have one accredited vendor in about 3,200 villages across Uganda in 21 districts this year.

The HermTech2 Franchise's up-country distributor was a large agro-input firm that typically sells a variety of seeds (e.g. maize, rice, soybeans) as well as pesticides and sprayers. It sold about 2-3 MT of maize seed, 0.5 MT of rice seed, and about 10 MT of soybean seed at the time of the interview with one month left in the first 2015 growing season. The distributor partnered with an NGO to have their local office sell the bags. It would take 1-4 weeks to fulfill an order from the NGO. In the spring of 2015 they stocked out of bags after selling 500.

The Distribution Company sold to farmers, farmers groups, and exporters, but not to retail shops. They estimated selling about 1,000 crop bags per month to farmers and institutional or large commercial buyers. They aimed to meet with 10 farmers' groups per month, attend agricultural shows, and partner with organizations like WFP. Based on this evidence, we did not anticipate the Distribution Company developing a large retail network in the coming years. Working with the HermTech2 Franchise retail network, and in particular addressing risks that the HermTech2 Franchise retailers face, might be another effective way to increase availability and capacity of the sales channel.

The PolyPro Company sold only in bulk to wholesalers, retailers, and large farmers or corporate customers (e.g., WFP, sugar companies, and conglomerates) who had the volume to meet the minimum order quantity of 1,000 bags. Some customers came to them to pick up their products; for those that did not, the PolyPro Company did not use an exclusive distributor. They shipped their products using transportation firms (e.g. public transportation) that ran 'upcountry.' Of note, the PolyPro Company branded their bag (as well as bales of the bags) with their logo to reinforce authenticity, since they promoted its superior quality.

In Gulu there was a major street with many retailers selling polypropylene bags, including those of the PolyPro Company. They were typically displayed in the front of the stores. These bags were typically sent via bus by the manufacturer, with the retailer paying the price of transportation. The lead-time for polybags was very low according to proprietors of the shops. In Lira, the polypropylene sack market was less readily transparent than Gulu. However, it was possible to find retailers that sold polybags. In towns like Jinja and Soroti there was a large polybag market as well.

Plastic water tanks

In the Ugandan plastic water tank market, there were around half a dozen large firms with market penetration in both Kampala and rural areas. These included lower-quality brands like VictoriaNile, which was known for tanks that degraded after several months of being exposed to sun and the elements (e.g. are made from injection molding), and higher quality brands like Crestanks, Smile Plast, and PolyTanks. We spoke to firms up and down the water tank supply chain to gain insights into the cost structure.

One Ugandan water tank manufacturer had an exclusive distributor that sold to wholesalers who in turn sold to retailers or walk-in customers. The distributor supplied dealers at 70% of the list price. The distributor bought from the manufacturer for 60% of the list price; of the 10% margin, 2-3% went to transport, leaving a 7% operating margin. The distributor sold about 230,000 USD of products from the manufacturer in one month (without VAT). They hired trucks, tried to always fill the truck, and paid 1,100 UGX ($0.43) per kilometer. They stocked products for the Kampala market at their warehouse; orders from 'upcountry' were sent directly from the manufacturer's inventory. The transporter set minimum charges for certain origin-destination pairs: the minimum charge from Kampala to Masaka was 300,000 UGX ($118.34) per truck, Kampala to Jinja is 200,000 UGX ($78.90), etc. Beyond a major point – such as Masaka, Jinja, or Tororro – the distributor charged 1,100 UGX ($0.43) per kilometer (not inclusive of the return trip). No possible permutation of loading tanks on the trucks could exceed 630kg: the maximum number of tanks was three of the 10,000L size; seven of the 5,000L size; thirteen of the 3,000L size; eighteen of the 2,000 size; thirty of the 1,000L size; and fifty of the 500L size.

In Gulu, the VictoriaNile water tank was the most commonly displayed. These tanks came in 65L, 100L, 120L, and 220L sizes, and – across three shops interviewed – were bought from the manufacturer in Jinja. VictoriaNile provided transportation, and consolidated orders going to Gulu in order to fill truckloads. In Lira, VictoriaNile was again the most prominent water tank, but advertisements for and stock of 'higher quality' water tanks from Crestanks and Smile Plast were apparent in the retail shops in town. The retailer that stocked higher quality tanks made a point of noting the quality difference. In Lira, VictoriaNile provided transportation for water tanks. Smile Plast, in contrast, did not provide transportation. In Soroti and Jinja, brands such as Crestanks, Smile Plast, PolyTanks, and VictoriaNile were available at retail shops. VictoriaNile, recognizing that cost was its competitive advantage, helped reduce cost by coordinating transportation.

Metal tanks

In Uganda, a Ugandan Large Metal Products Manufacturer produced steel water tanks in Kampala and sold them across the country. They did consider the cost of transportation from Kampala to a rural area when calculating the total landed cost of the silo at the destination. The manufacturer used their own trucks for distribution. They ensured full truckloads. They also had 7-8 downstream retail outlets at which they sold silos. They sold 1,000-1,500 water tanks per month in a broad range of sizes for an average price of 120 USD.[34]

Supply Chain Evaluation

To evaluate the scalability of the storage technology supply chains, we consolidated the analysis above using the two key criteria: affordability and availability. We considered the supply chain for all four

[34] The firm also does not consider labor costs when calculating TLC of silos and setting a margin – the cost comes from materials and transport (transport within Uganda will be 15-20% of the selling price). They let their other profitable product lines pay for labor costs as their chairman, a Ugandan, wants to do corporate-social responsibility.

technologies offered in SO1: hermetic crop bags, plastic silo, medium metal silo, and large metal silo. The discussion addresses both aspects of our research questions in exploring both the current supply chain as well as opportunities to improve it.

Affordability

Affordability is driven by the cost structures and profit margins for all actors in the supply chain. Table 9 shows the consolidated cost analysis for each technology and determines profit margins based on the full retail price used in SO1. Analysis was clear for the suppliers, comparing the estimated cost with the sales price to WFP. The remaining channel costs were determined by subtracting the supplier price from the full retail price. It is important to note that some SO1 channel costs, such as transportation and training, were paid directly by WFP and thus are not included in the channel cost.

Profit margins are a critical measure for the scalability of the supply chain – clearly affecting affordability but also availability since actors are less likely to invest in capacity for low margin items. The suppliers for metal silos had positive margins for both large (11.8%) and medium (4.1%) sizes. The bag supplier margin could not be determined since the team did not visit the firm's manufacturing site in Asia to conduct cost analysis. The most concerning observation was that the plastic silo supplier lost $9.60 per silo (-25.3% gross margin), with a manufacturing cost that alone exceeded the SO1 full retail price.

For the channels, it was important to consider the estimated gross profit available given the SO1 full retail price. The gross profits ranged from $5.39 to $21.89 per silo, but were slightly negative for the bags. These profit levels could not support the average training cost of $22.25 per farmer observed in SO1, much less the transportation cost that was also covered separately. Clearly, the training cost per farmer must come down.

In terms of differentiating products by channel cost structure, we did not have cost breakdowns by product from the transportation firm or training partners. We could project that bags have much lower transportation cost, since they are very small and light to ship. However, bag revenue per farmer is low and any transportation cost savings would be needed to support training. Conversely, silos offer more revenue per farmer to support training, but these bulky products are also expensive to ship.

Table 9: Affordability evaluation based on supply chain cost structures. (Notes: the data in this table are for one bag even though they were sold in SO1 as a package of 4 units; negative numbers are in parentheses).

	Supplier Cost	Supplier Price	Supplier Gross Profit	Supplier Gross Margin	Channel Gross Profit	Channel Gross Margin	Full Retail Price	Subsidized Retail Price
Metal Silo Large	$158.73	$180.00	$21.28	11.8%	$21.84	12.1%	$201.84	$60.55
Metal Silo Medium	$124.65	$130.00	$5.35	4.1%	$10.04	7.7%	$140.04	$42.01
Plastic	$47.60	$38.00	$(9.60)	(25.3%)	$5.39	14.2%	$43.39	$13.02

Silo								
Bag	n/a	$2.70	n/a	n/a	$(0.07)	(2.6%)	$2.63	$0.79

To evaluate potential improvements in the supply chain for each product, we determined a projected retail price based on existing supplier costs and margins that would be reasonable for actors in the supply chain. We assumed a supplier margin of 8%, which is the midpoint between medium and large silo margins for the metal artisans. The pre-tax margin for several related sectors (Machinery, Packaging & Container, Diversified) in emerging markets is also around 8%, as documented in a widely referenced database published by Prof. Aswath Damodaran from the Stern School of Business at New York University[35]. Though retailers and distributors typically have lower margins than manufacturers, we assumed a higher margin of 12% for the channel for several reasons: it aligned with the channel margins in the SO1, channel profits may need to support the profitability of more than one actor, and the farmer training was time-intensive but should be supported.

We compared these projected prices with the SO1 full retail prices, as shown in Table 10. The projected price as a percent of the full retail price in the far right column provided a baseline for assessing improvements. Based on average costs for the metal silo supply chain, the projected price was very close to the current retail price. However, using the minimum cost among the six firms, the price of large silos could be reduced by 14% and medium silos by 30%. It is important to note here that the projected price does not represent a supplier bid, which could be distorted by on a firm's desire to win a particular contract, but rather is a "bottom up" calculation based on empirical cost structure and process analysis. Thus, the data showed that the underlying cost structure for current artisans offered a potential improvement of 14-30% in the metal silo retail price.

For plastic silos and bags we only had the cost structure for one supplier, which does not enable us to assess a range of cost structures. However, the projected price determines the gap that improvements would need to address. Significant cost structure improvements would be required for plastic silos, which projected to be 35% above the retail price. A large gap like this may indicate the need for a new business model or product design. The 16% gap for bags may be able to be addressed through incremental improvement of existing models and designs, though the operational changes may still be significant.

Table 10: Affordability evaluation based on projected retail prices. (Note: the first two rows represent the average supplier cost among the six firms and the next two rows represent the minimum cost for the same sample.)

	Supplier Cost	Supplier Gross Margin	Supplier Price	Channel Gross Margin	**Projected Retail Price**	SO1 Full Retail Price	Percent of Full Price

[35] The source is a spreadsheet dated 1/5/2015 for Profit Margins in Emerging Markets, downloaded from this site: http://www.stern.nyu.edu/~adamodar/New_Home_Page/data.html

Metal Silo Large (average)	$158.73	8.0%	$172.53	12.0%	**$196.05**	$201.84	97%
Metal Silo Medium (average)	$124.65	8.0%	$135.49	12.0%	**$153.97**	$140.04	110%
Metal Silo Large (minimum)	$141.29	8.0%	$153.58	12.0%	**$174.52**	$201.84	86%
Metal Silo Medium (minimum)	$79.22	8.0%	$86.11	12.0%	**$97.85**	$140.04	70%
Plastic Silo	$47.60	8.0%	$51.74	12.0%	**$58.79**	$43.39	135%
Bag	$2.48	8.0%	$2.70	12.0%	**$3.06**	$2.63	116%

Availability

Availability depends on capacity across the supply chain and the ability for actors to reliably deploy it for product delivery. Starting with the consumer, capacity for the last mile was provided by the consumer (farmer) them self in transporting the storage technology home from the collection point. Empirical evidence indicated that there was not a shortage of transportation capacity from supplier to the collection point; in fact, there were often idle transportation assets awaiting upstream products. So the best metric for availability from our analysis was the percent short at the supplier site, as reported in Table 4. The inability to meet an agreed production schedule indicated a lack of capacity, low reliability in deploying it, or a combination of both.

Bags were the most available, missing shipments for only 4% of the required products. Plastics silos performed nearly as well with 6% short. In contrast, the metal silo suppliers struggled to meet requirements with 24% of the medium and 53% of the large silos falling short of expectation.

While the current metal silo supply chain performed poorly overall, the suppliers showed some potential for improvement with the ability to ramp up deliveries starting in November 2014, as seen in Figure 6. The plastic silo manufacturer may also be able to improve availability, if their self-estimated capacity of 288 plastic silos per day can be realized. This would be a notable increase from the average of 53 silos per day, assuming a four-month (120 day) production period, to reach the 6,326 total plastic silos shipped in SO1. We did not have sufficient information regarding the bag manufacturing capacity to assess the potential improvements.

Supply chain adaptation

There were several changes made to the supply chain's structure for the second year of the Special Operation (SO2), which began in August 2015. This section briefly outlines changes in production, distribution, financing, and training to address many of the challenges outlined earlier in this analysis.

The supply base and product design for plastic and metal silos changed. To reduce transportation cost, WFP worked with a new manufacturer to design a stackable, nested plastic silo. Figure 7 shows the plastic silo design for both Special Operations. With this design, plastic silos could be stacked 15-high on a truck, significantly increasing the number of silos per truckload and commensurately reducing the transportation cost per silo. The number of plastic silos per truckload increased over ten-fold, drastically reducing transport costs.

Figure 7: Plastic silo for Special Operation 1 (left) and the redesigned plastic silo for Special Operation 2 to enable nested transport (right)

Due to supply reliability issues for metal artisans, WFP also changed sourcing for the metal silos in SO2. WFP procured all metal silos from a large metal water tank manufacturer (and sheet metal importer) in Kampala. This also led to an increase in the level of quality control and, even though silos were made out of stainless steel instead of galvanized sheets, a drop in unit cost.

The transportation and distribution approach also changed in SO2. Regional private sector distributors (PSDs) were responsible for distributing equipment and collecting farmer payments (instead of NGOs). Thirteen companies placed bids to serve the five districts targeted for SO2, many of whom who were already active as agricultural input distributors.

In order to streamline the distribution process and lower its cost, the orders in SO2 were consolidated weekly and delivered from central locations. The equipment manufacturer delivered storage technologies from the manufacturing site to the “first major town,” where the PSD took ownership for transportation to the Farmer Collection Points. There were 7 “first major towns” in total for the country. This approach was possible for SO2 because the equipment manufacturers were now large and centrally located, unlike the dispersed, small-scale production by local artisans in SO1.

The design of information and financial flows also changed in SO2. WFP was responsible for the contractual arrangements with the manufacturer of hermetic bags, plastic silos, and metal silos. WFP estimated the order volumes at the onset, and informed NGOs and PSDs of their allocated distributions of each of the products. Using this information, which is effectively the stock available, the PSDs then took equipment orders and a down payment from farmers at the training sessions. Farmers made a down payment of 10% of the total equipment cost at the training sessions; PSDs then collected the another 40% upon delivery, resulting in a farmer subsidy of 50%, down from 70% in SO1. The PSDs then paid WFP for the equipment, less a 20% gross profit margin (i.e., 10% of the total equipment cost) to cover their distribution operations. Additionally, farmers that required financing had an option to take an equipment voucher, given to them upon the down payment, to a Ugandan bank with a substantial rural client base for the remaining 40% of the total equipment cost.

Initial farmer orders for SO2 were much lower than the previous training season, where farmers were not required to make a down payment. WFP adjusted the initial down payment, setting it at UGX 10,000 ($3.94), and orders resumed at a pace similar to SO1. The market for silos also expanded in two directions. First, WFP extended the post-harvest loss reduction project to farmers within its refugee livelihood and resilience projects in Karamoja. Second, school headmasters, many of whom receive grains in lieu of fees, took the initiative to purchase hermetic storage for their schools.

One other notable adaptation in SO2 was the embedding of a PSD agent with the NGO training partners, and shared facilitation of the farmer training sessions. The intent was for the private sector to become fully responsible for both the training and the distribution in the future without NGO or WFP involvement – an independent, market-driven business to supply hermetic storage options to farmers.

Farmer Impact Evaluation

Analysis of the CITE survey served as the basis to understand two key issues: the impact of storage technology adoption on a farmer's livelihood and the value it created for them. Our impact analysis followed the approach used by Bokusheva, et al. (2012) in Central America to contribute similar insights for an African country context. We then analyzed farmers' willingness to pay for storage technologies in order to better understand the perceived value creation.

Income impact

To assess the impact of adopting a storage technology on farmer income, we compared the sales prices of maize under different practices as reported by farmers over 138 observations (which include multiple sales dates from some individual farmers). Overall, 74% of sales occurred within a farmer's village (the remainder was directly from their farmstead) and 77% of sales were to middlemen or dealers. Maize with no storage fetched a median price of 400 UGX/kg ($0.16/kg), traditional storage 550 UGX/kg ($0.22/kg), and silo/bag storage 700 UGX/kg ($0.28); see the boxplots in Figure 8. The price resulting from hermetic storage was higher than no storage ($p<0.01$) and traditional storage ($p<0.01$) practices.

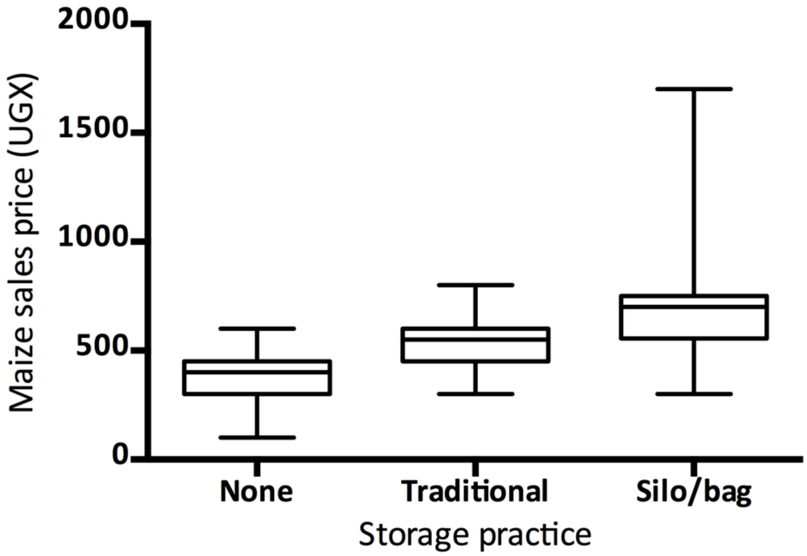

Figure 8: Sales price of maize per kg, by storage practice

Food security impact

In addition to income from the sale of crops, adopting the storage technology can have a direct impact on food security for the farmer's household. To assess food security, the survey included questions about the number of months over the past year that a farmer purchased maize and beans for consumption. Less purchasing indicates higher food security from their stored harvest. Adopters reported the need to purchase a median of 2 months' worth of maize, while non-adopters reported a median of 6 months. Likewise, adopters reported needing to purchase a median of 2 months' worth of beans, while non-adopters reported 4 months. It should be noted that several adopters had purchased their storage technology less than a year prior to the survey period, so that the benefit may not have been fully realized.

To test for significance, we used a Tobit regression because the dependent variable $Months_{purchase}$, the number of months a household needed to purchase maize or beans, was often 0 (i.e., censored at 0):

$$Months_{purchase} = \beta_0 + \beta_1 D_{non\text{-}user} + \beta_2 D_{region} + \beta_3 D_{non\text{-}user} * D_{region},$$

β_0 is the intercept, $D_{non\text{-}user}$ is the dummy variable for storage technology non-adopter, D_{region} is the dummy variable for geographical region, and $D_{non\text{-}user} * D_{region}$ is the interaction of the two dummy variables; Table 11 shows the results. Although the R^2 was low, storage technology adoption reduced external purchasing for maize by 1.51 months ($p < 0.01$) and beans by 0.90 months ($p < 0.05$). The interaction term indicates more impact on maize and beans purchasing in the Eastern region than in the Northern region.

Table 11: Regression analysis for months of maize and bean purchases

	Months of maize purchasing	Months of bean purchasing
Intercept	0.24	0.23
Dummy Non-Adopter (v. Adopter)	1.51***	0.90**
Dummy Northern (v. Eastern)	0.22 (n.s.)	0.70**
Dummy Non-Adopter * Northern	–1.41***	–0.83 (n.s.)
Observations	202	202
Adjusted R2	0.06	0.02

** and *** indicate significance at p < 0.05 and p < 0.01, respectively

Socio-economic impact

To complement specific impacts on income and food security, the survey asked about the well-being of farmers across a wide variety of social and economic indicators. Nearly two-thirds of adopters, 65%, reported an improvement in both household health and family income that they attributed—either very much or somewhat—to the purchase and use of their new silo or hermetic bags. Table 12 displays the results of regression analyses for 12 socio-economic variables. Responses to these survey questions were recorded on the following scale: 1 (much better over the past year), 2 (somewhat better over the past year), 3 (same over the past year), 4 (somewhat worse over the past year), and 5 (much worse over the past year). Adopters had lower values on the scale (indicating improved conditions over the past year) for every variable. The adopters improvement was nearly a full point on the 5-point scale and was significant (p<0.01) for the following variables: food availability, household health, sons' schooling, daughters' schooling, women's workload, family income, women's socio-economic status, men's status in the community, and women's status in the community. These results, including the R^2 values, were similar to results from the study in Central America.

Table 12: Regression analysis for economic and social impacts

	Food availability	Household health	Housing	Sons' schooling	Daughters' schooling	Mens' workload
Intercept	1.36***	1.97***	2.26***	2.19***	2.18***	2.32***
Dummy Non-Adopter (v. Adopter)	0.88***	0.74***	0.36*	0.72***	0.72***	0.14
Dummy Northern (v. Eastern)	0.14	–0.24*	0.05	–0.58***	–0.52***	–0.42**
Dummy Non-Adopter * Northern	–0.60**	0.2	0.03	0.07	–0.001	0.37
Degrees of Freedom	191	191	182	162	161	149
Adjusted R2	0.12	0.15	0.03	0.23	0.21	0.03

	Women's workload	Family income	Farm production	Women's socio-econ. status	Men's status in community	Women's status in community
Intercept	2.15***	2.13***	2.13***	1.89***	1.74***	1.67***
Dummy Non-Adopter (v. Adopter)	0.85***	0.91***	0.66***	0.88***	0.82***	0.83***
Dummy Northern (v. Eastern)	–0.21	–0.23*	–0.17	0.01	0.3	0.25
Dummy Non-Adopter * Northern	–0.11	0.02	–0.14	–0.35	–0.37	–0.28
Degrees of Freedom		189	189	144	130	142
Adjusted R2		0.16	0.06	0.09	0.08	0.11

*, ** and *** indicate significance at 10%, 5% and 1%, respectively.

Willingness to Pay

Researchers also asked survey participants, both adopters and non-adopters, an open-ended question about their willingness to pay (WTP), using the original order sheet with subsidized and unsubsidized prices as a reference. These results enabled a stated preference contingent valuation approach for estimating WTP. Our research design aimed to control various biases in stated preference studies.

We incorporated the order sheet with two reference price points to mitigate the risk of information bias where respondents lack knowledge of the good or service; in this case we wanted farmers to know the full retail price. The risk was introducing starting-point bias, where WTP anchors on a reference price. However, several studies have found anchoring effects to be small or even non-existent in when respondents are familiar with the goods[36 37 38].

A common ex ante approach to mitigate hypothetical bias, where participants fail to take questions seriously, incorporates a "cheap talk" design with explicit discussion of the problem. While we did not formally discuss "hypothetical bias" with farmers, respondents were informed that results would be shared with WFP to improve future storage technology options. Knowledge that their responses have a potential direct impact on future product offerings reduced the risk of hypothetical bias. However, the researchers' relationship with WFP may have introduced different biases, such as a type of "yea saying" bias where participants may have aimed to please the enumerator, and indirectly the product provider.

[36] Sugden, R., Zheng, J. and Zizzo, D.J., 2013. Not all anchors are created equal. *Journal of Economic Psychology*, 39, pp.21-31.
[37] Bateman, I., Munro, A., Rhodes, B., Starmer, C.V. and Sugden, R., 2006. Anchoring and yea-saying with private goods: an experiment. *Using Experimental Methods in Environmental and Resource Economics*, pp.1-19.
[38] Onwujekwe, O. and Nwagbo, D., 2002. Investigating starting-point bias: a survey of willingness to pay for insecticide-treated nets. *Social science & medicine*, 55(12), pp.2121-2130.

While further study could improve protocols for WTP elicitation among rural farmers, this study offers a useful starting point in understanding the value of storage technologies.

Figure 9 shows the results for each technology: at 0 USD, 100% of farmers would be willing to purchase the technology. As the price increases, the percent willing to pay decreases until it reaches a price for which 0% of farmers would purchase the product. There was a sizable portion of the population who were willing to pay above the subsidized price, but below the unsubsidized price.

Though not depicted separately in Figure 9, the WTP was higher among non-adopters at almost every price level for all products. This may be an indicator of positive experiences among adopters and word-of-mouth communication. Further research should explore the dynamic of such relationships in adoption of these technologies.

Though most of the “demand curves” in Figure 9 look similar, the WTP for plastic silos was slightly higher. At both the unsubsidized and subsidized prices the plastic silos had the highest percent willing to pay. In addition, for prices up to 35% higher than the subsidized price, the plastic silo demand tracked much higher than other products. Perhaps this is an indicator that plastic silos provide good value for the farmer’s investment. It could also indicate that prices were set a little too low relative to other technologies at the SO1 launch.

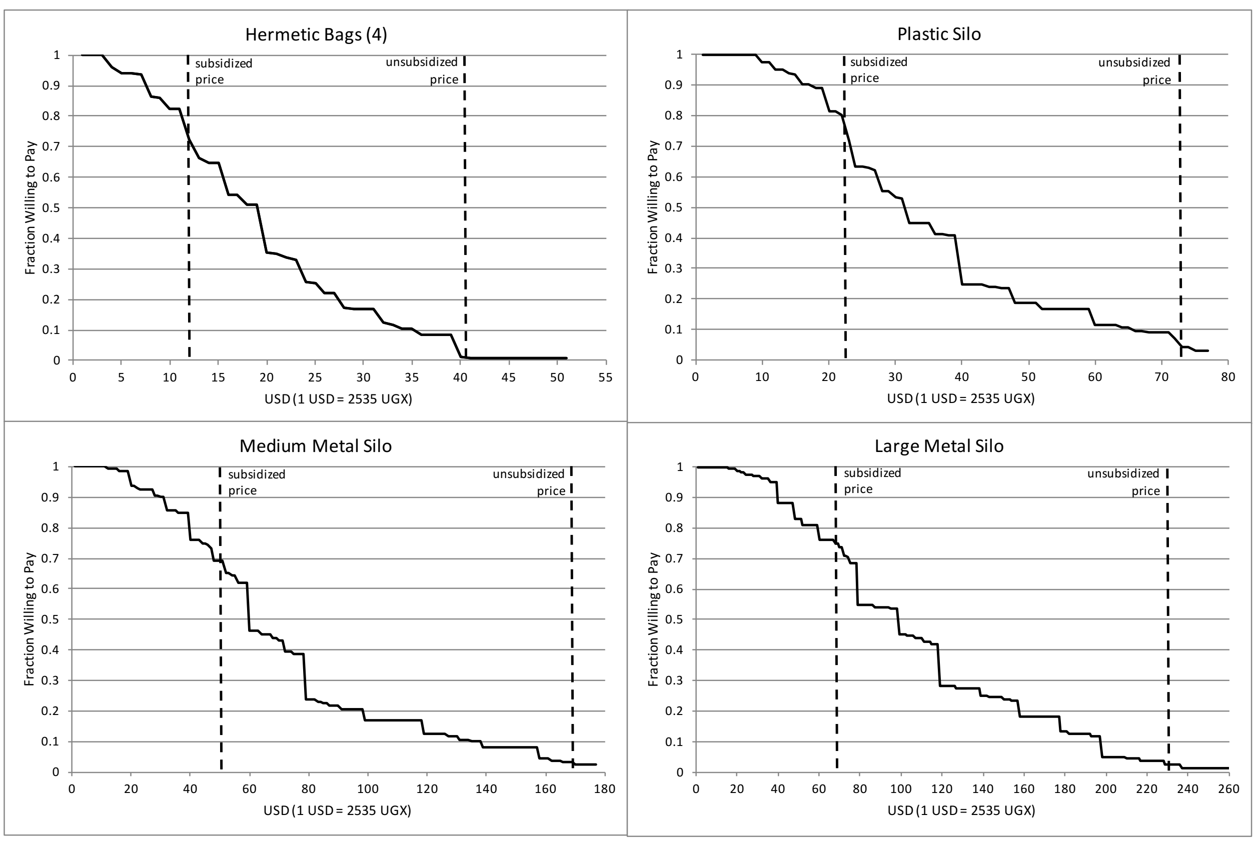

Figure 9: Willingness to pay, by storage technology (price includes 2 plastic sheets)

Adoption Evaluation

The storage technologies in SO1 were new to the market. Forecasting the demand for new products is very difficult, though models can help assess the impact of various factors on future adoption. By modeling how product and market attributes affect adoption, we can evaluate the scalability of demand for the SO1 storage technologies.

Bass diffusion models are commonly used to project the uptake of new products in a market. These mathematical models are rooted in system dynamics methodology that connects system structure with behavior dynamics. In this case, adoption of new storage technologies in Uganda is related to the market system structure and policies as well as behaviors of customers, suppliers, and other stakeholders in the market.

System dynamics models consist of stocks (accumulations of items) and flows (rates of change). Stocks and flows interact through a system of causal loops, which form the basis for the system's structure. Drawing from our field research, we modeled the Uganda SO1 market as a Bass diffusion model. One important adaptation was directly incorporating the availability (or stock) of products based on our empirical research of the SO1 supply chains. To evaluate the scalability of demand, we simulated how future stocks that represented adoption of storage technologies changed dynamically under various scenarios. Scenarios enabled sensitivity analysis of key inputs and assumptions for all four technologies offered in SO1: hermetic crop bags, plastic silo, medium metal silo, and large metal silo.

Structure

The system dynamics model combined a Bass diffusion sub-model, where potential technology adopters become actual adopters via social and/or marketing dynamics, and a supply chain sub-model, which incorporates technology availability as a constraint on the adoption rate. Figure 10 shows a simplified version of the model structure; Appendix B contains detailed figures of the model, and Appendix C contains the entire model documentation.

The technology diffusion sub-model determined the pool of potential adopters as a fraction of all rural households in Uganda, incorporating population growth and subtracting those who had already adopted. The fraction of households willing to adopt a storage technology was based on the relationship between the price and the fraction willing to pay that price, based on our survey data. The fraction willing to adopt at a given price was increased in scenarios with access to credit, again based on survey data.

In keeping with what occurred in SO1, we assumed that products were sold at a subsidized price until the subsidy budget was exhausted; any remaining products were sold at the SO1 retail price. We also assumed that subsidies were given without regard for willingness to pay a higher price. Thus, subsidized and unsubsidized adopters drew from the same potential adopter pool.

Adoptions due to word of mouth were a "reinforcing" loop, whereby the spread of awareness about the technology increased adoption. The number of such adoptions in a month was the number of previous adopters multiplied by an assumed number of contacts per month, a potential adoption probability given a word of mouth contact, and the fraction willing to pay the given price. The adoptions were also multiplied by a training and advertising effect, expressed as a sensitivity to the training or advertising budget.

The supply chain sub-model served to constrain the adoption rate, i.e. the transition from potential to actual adopter, by inventory available. They affected the parallel adoption rates, subsidized and unsubsidized. The subsidized inventory available, which constrained adoption at that price, depended on the combination of total inventory in the system and the subsidy budget. Unsubsidized adoption could occur beyond that enabled by the subsidy budget, depending on the willingness to pay that price and the remaining inventory. The option of risk mitigation contracts increased total inventory.

The factors in blue can be altered to explore their effect on the market system. Note that budget size and allocation facilitates many of these factors. System dynamics models such as this could be useful for donors in designing programs.

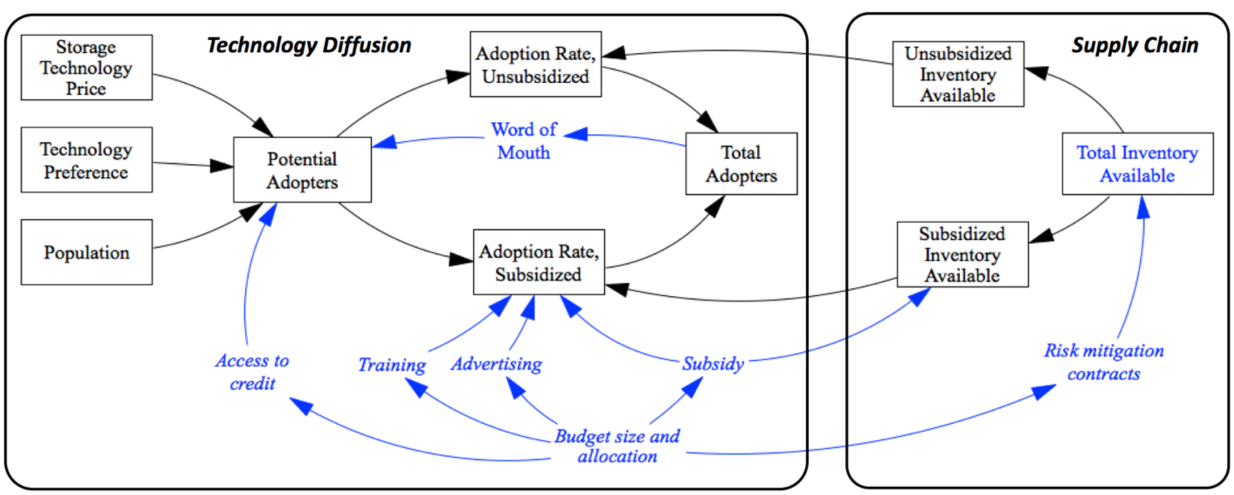

Figure 10: Model structure (given model components, black; scenario model components, blue)

Parameters and scenarios

Though promoted through the same channels, SO1 incorporated four distinct technologies. Each technology was modeled distinctly by segmenting the population: the initial proportion of adopters selecting each of the four technologies was based on sales from SO1. The simulation was run over a 10-year period, starting in 2014 when SO1 began. The model simulated national diffusion among rural households to understand adoption trajectory; it could be extended to incorporate regional differences as empirical evidence allows. Disadoption was not included in the model, since the silos' expected lifetime of 15-20 years exceeds the model horizon of 10 years. Some disadoption of the bags, which have an expected lifetime of 2 years, may occur but was not considered. Following common practice for such models, inventory and sales were simulated over monthly increments rather than on an annual cycle.

Table 13 lists the key parameters with data sources. Parameters that could not be inferred from empirical data were drawn from literature or assumed. SO1 was used as a baseline. For instance, donor or producer budgets for subsidies and training in 2014 were taken as the SO1 budgets. The 70% subsidy is reduced to 50% in 2015 and assumed to continue but at decreasing levels: 100% of products subsidized in 2014 and 2015, 90% in 2016, … , 0% in 2025. Several scenarios were created to conduct sensitivity analysis; rows highlighted in gray in Table 13 indicate parameters that changed for these scenarios.

Table 13: Model parameters for baseline scenario (HB = hermetic bags, PS = plastic silos, MMS = medium metal silo, LMS = large metal silo)

Parameter	**Value**	**Source**
Initial rural households	6 million	Uganda Census 2014
Growth rate of rural households	2.5%	Uganda Census 2014
Proportion of population with preference for each technology	HB: 0.25 PS: 0.35 MMS: 0.34 LMS: 0.06	SO1 proportions
Price of technology, unsubsidized (UGX)	HB: 102,000 PS: 185,000 MMS: 430,000 LMS: 587,000	SO1. Price includes 2 plastic sheets.
Fraction willing to adopt at 70% subsidized, 50% subsidized, and unsubsidized	HB: 0.72; 0.35; 0.01 PS: 0.80; 0.41; 0.05 MMS: 0.67; 0.23; 0.03 LMS: 0.74; 0.39; 0.02	CITE survey data
Subsidy rate	2014: 0.70 2015 beyond: 0.50	Based on subsidies for SO1 and SO2. Plastic sheets are not subsidized.
Subsidy rate phaseout	2014: 0.70 2015: 0.50 2016: 0.30 2017: 0.20 2018: 0.10 2019-2025: 0	Assumption. Plastic sheets are not subsidized.
Initial inventory (units)	HB: 15,000 PS: 90,140 MMS: 2,175 LMS: 863	SO1, interviews with manufacturers

Percent of inventory quantity subsidized	2014: 100% 2015: 100% 2016: 90% … 2025: 0%	Assumption
Increase in total inventory	HB: 5000 units/year PS: 10%/year MMs: 10%/year LMS: 10%/year	Assumption, 10%/year from initial (SO1) values
Increase in inventory due to risk mitigation contracts	HB: 0% PS: 0% MMs: 20% LMS: 20%	Increases available inventory by 20%. Only applicable to metal silo producers. Based on CITE behavioral operations experiment.
Percent increase in fraction willing to adopt with access to credit	HB: 7% PS: 15% MMS: 18% LMS: 12%	CITE survey data
Unsubsidized price reductions due to supply chain efficiency	2% per year; 3% per year	Different levels of assumption
Budget sensitivity of advertising	0.1	Tellis G. 2009. "Generalizations about Advertising Effectiveness in Markets." Journal of Advertising Research 49(2): 240-245.
Initial advertising budget	1 (multiplier)	SO1 did not have advertising, so the multiplier of 1 has no effect on initial (SO1) adoption
Advertising budget growth rate (annual)	3%	Assumption
Budget sensitivity of training	0.9	Assumes no fixed costs and that the adoptions per additional training are 90% of the adoptions per baseline training budget.
Initial training budget	1 (multiplier)	SO1
Training budget growth rate (annual)	3%	Assumption
Contact rate	50/year	Assumption
Potential adoption proportion per contact	0.015	Rahmandad H and Sterman J. 2012. “Reporting Guidelines for Simulation-based Research in Social Sciences.” System Dynamics Conference.

Results

Model results for the baseline and interesting scenarios are depicted in graphs that show cumulative adoption of technologies over the 10-year time horizon. Total adopters for the baseline, and for most scenarios, grew initially before tailing off in the latter half of the horizon. The total over all four technologies reached 1.05 million households (17.5% of the market total) by 2024. Figure 11 breaks down the adoption by technology.

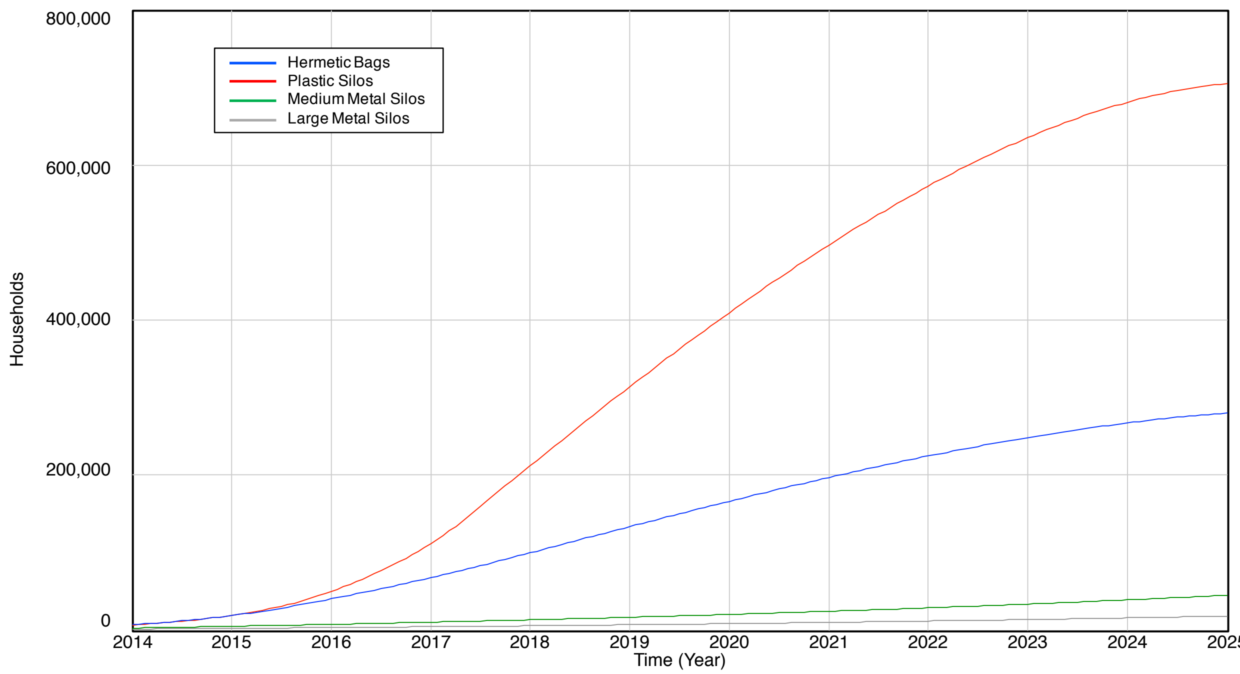

Figure 11: Baseline scenario, adopters by storage technology

Plastic silo adoption far outpaced other technologies, driven by two key factors. First, as noted earlier, the willingness to pay for plastic silos based on SO1 prices was higher than the other technologies. Second, and more important, the plastic silo manufacturer had higher inventory levels to accommodate the attractive value proposition for farmers under the subsidy. Figure 12, which shows the adoption rate for subsidized sales, illustrates this impact. Only in the fourth year does subsidized plastic silo adoption become constrained by the inventory level, due to the declining percent of inventory that is subsidized. Note that the subsidized adoption rate for all technologies declines to zero by the end of 10 years, when the subsidy is phased out. Unsubsidized sales rates are much lower and are easily handled by the production capacity.

In contrast, the other products struggle with capacity. Grain bag sales are constrained by inventory in the second year, and capacity cannot support the potential of unsubsidized sales until the fifth year. Metal silo capacity is so low that is never fulfills the full unsubsidized sales demand during the ten-year horizon. In fact, adoption for metal silos continues to grow through the end of the horizon, in spite of the subsidy phase out, since it cannot even keep pace with market demand at the full retail price.

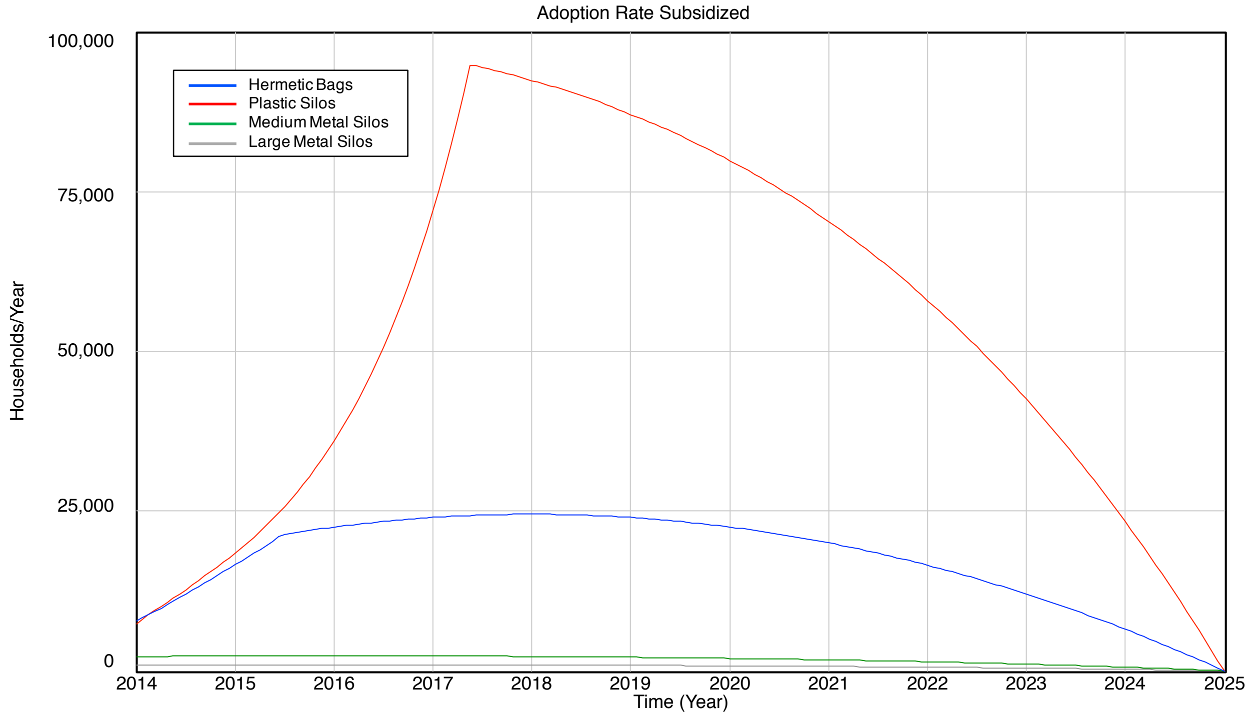

Figure 12: Baseline scenario, subsidized adoption rate by storage technology

In analyzing results for various scenarios, inventory, access to credit, and word-of-mouth contact each have a stronger positive impact on adoption. For instance, doubling available inventory stock alone increased the final total adoption to 1.55 million (26% of the market), as shown in Figure 13. Note that this growth is compounded by the assumption that the subsidy supports a (declining over time) percentage of capacity rather than a fixed amount. Increased access to credit results in 1.82 million adopters (30% of the market). On the other hand, increasing budgets for advertising and trainings did little, in and of itself, to yield greater adoption. This does not diminish the importance of training in order for farmers to realize the value of storage technologies. However, it does highlight a broader set of factors in driving adoption than may normally be considered.

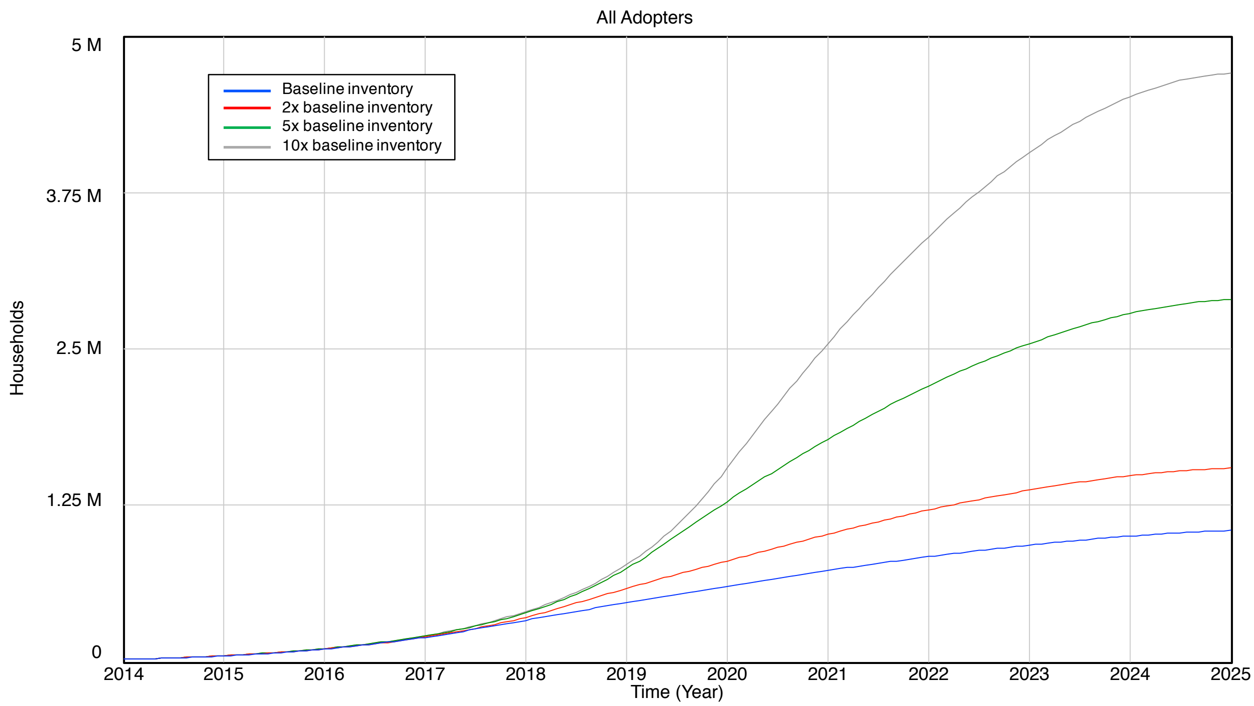

Figure 13: Inventory effect on total adopters

Often the primary focus for new product introductions in low-income countries is price. Figure 14 shows that a 2% annual price reduction over ten years increased the final total adoption to 1.12 million (19% of the market). Similarly, a 5% annual price reduction over the same period increased the final total adoption to 1.19 million (20% of the market). While lower price alone has a positive impact on adoption, higher inventory is required to capitalize on the opportunity. For example, a reduction in unsubsidized price by one-third – to $22 for hermetic bags, $41 for plastic silos, $95 for medium metal silos, and $129 for large metal silos — while increasing inventory four-fold resulted in 50% market saturation over ten years.

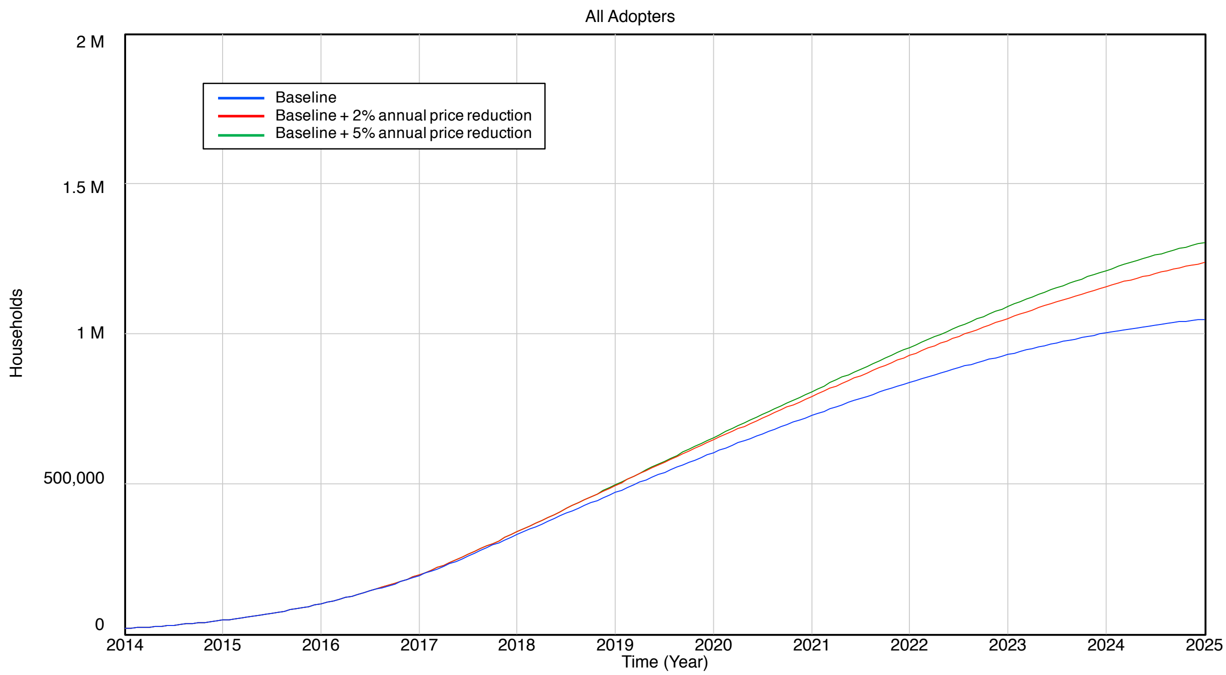

Figure 14: Price reduction effect on total adopters

Noting the importance of combining price reductions with higher inventory (affordability and availability), we created a "strong supply chain" scenario that combined the two. The objective was to explore how strengthening private sector supply chains fared as an alternative to long-term subsidies. Based on CITE analysis of supply chain cost reduction and capacity improvement opportunities, we created a plausible scenario for subsidy phase-out, prices, and available inventory with the following inputs:

1. The subsidy is phased out over five years: 70% in 2014, 50% in S015, 30% in 2016, 20% in 2017, 10% in 2018, 0% in 2019 and following.
2. The quantity of subsidized inventory is held constant at SO1 (2014) levels through 2018, when it becomes 0 as the subsidy ends.
3. The unsubsidized price of each technology is reduced 3% annually from 2015 to 2025.
4. Quantity of total inventory increases by an additional 10% annually from the baseline scenario.

While the baseline performs slightly better through year 6, the trajectory of the "strong supply chain" did not show the decline in future years, resulting in 321,000 more adopters than the baseline, and a total adoption of 1.37 million (23% of the market). Supply chain improvements leading to higher inventory and lower prices is a much better foundation for sustainable growth in storage technology adoption.

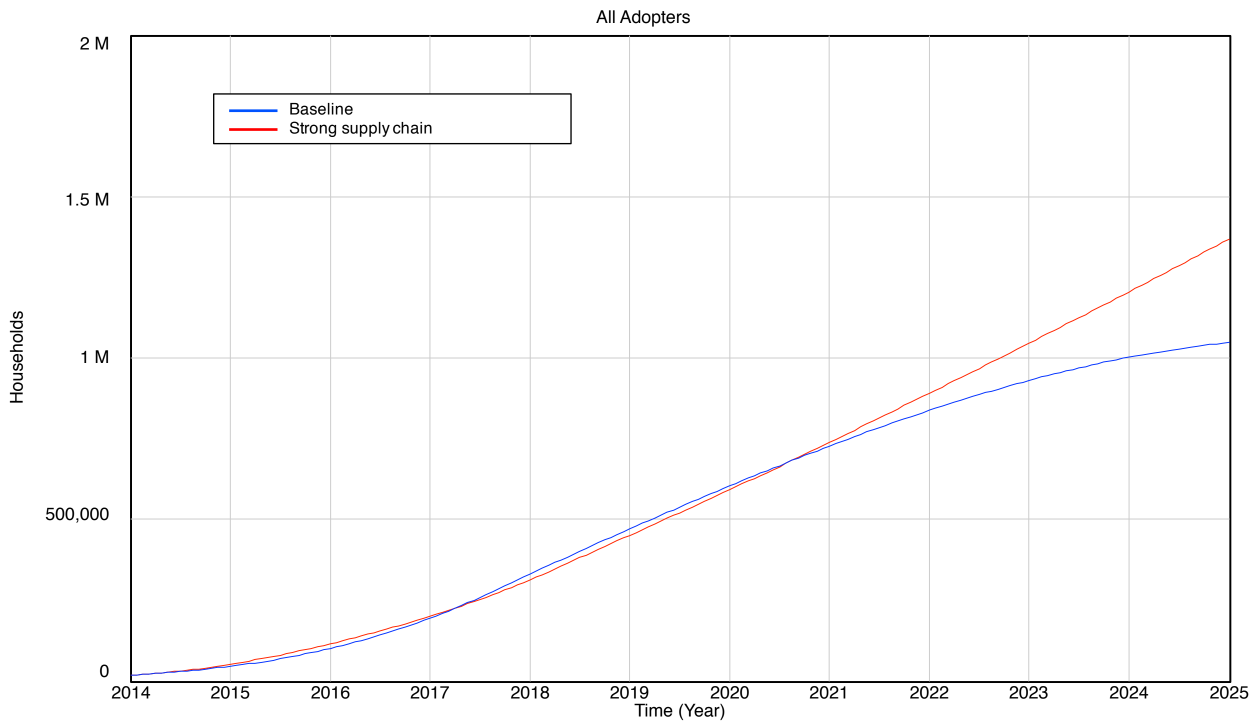

Figure 15: "Strong supply chain" and baseline scenarios, total adopters

Conclusions

We close this report with a summary of the results addressing the research questions regarding the supply chain scalability for storage technologies in Uganda and their impact among farmers. We also consider opportunities to improve future efforts to scale adoption.

Supply chain scalability

Studying the cost structures and capacities of supply chains established by the World Food Program (WFP) Special Operation (SO1) in Uganda provided insights regarding the affordability and availability of improved post-harvest storage technologies – two key enablers of widespread adoption among farmers. Evaluation of these nascent supply chains was not intended to predict which of the new hermetic crop storage technologies would be most scalable over the long term. Rather, the analysis was aimed to provide evidence that can focus and guide efforts to improve the supply chain for each technology. We close by summarizing the cost and capacity challenges and highlighting opportunities for improvement.

To assess the cost structure, we applied sustainable profit margin assumptions to each technology and compared the projection to the SO1 retail price. The cost structure for metal silos was reasonable with projections 3% below the SO1 retail price for large silos and 10% higher for medium silos. Data from six artisans also revealed an opportunity to maintain good margins while reducing the metal silo retail price by 14-30%. Cost structures for plastic silos and hermetic bags, which relied on data from the single supplier for each technology, were not as promising. Significant cost structure improvements would be required for plastic silo production, which projects to be 35% above the SO1 retail price. A large gap like this may indicate the need for a new business model or product design. The 16% price premium for bags may be able to be addressed through improvement of existing models and designs, albeit with notable efficiency gains.

While cost structure challenges varied in magnitude by technology, widespread adoption will require lower retail prices than offered in SO1 for all technologies. There are several opportunities to improve costs for these nascent supply chains, which should be pursued in combination. First, incremental changes in production and distribution processes offer many cost reduction options at this early stage in a product launch. For example, transportation analysis showed that when faced with product shortages, it is better to delay shipments from a central shipping location (e.g. single urban manufacturer) and better to send partial shipments as scheduled from decentralized locations (e.g. multiple rural artisans). Second, larger sales volumes could offer cost reductions through economies of scale. For example, centralizing all metal silo production with one supplier in SO2 reduced the price per unit even though they were made out of stainless steel instead of galvanized sheets; consolidated procurement of raw materials, which comprised 69%-74% of the metal silo cost, might have alone produced similar cost reductions for decentralized metal artisans. Third, new business models, new vendors, and/or new product designs could offer "step change" opportunities to dramatically lower prices to farmers. For example, the redesigned plastic silo in SO2 could be stacked 15-high on a truck, significantly increasing the truckload capacity and commensurately reducing the transportation cost. Finally, it is important to remember that public policy can have a dramatic impact on cost structures. For example, given the significant raw materials cost for metal silos, changes in the Value Added Tax (VAT) policy for sheet metal alone would have a dramatic impact on costs.

Another cost structure challenge was promotion and training, where the average cost of $22.25 per farmer exceeded the channel profit from the sale of any technology to a farmer. Given the combined channel, costs could not be further differentiated by storage technology. Regression analysis of the direct training operations for various organizations showed that cost was highly dependent on the number of farmers trained. New approaches are needed to reduce the variable cost to reach and train farmers. Opportunities identified through study of supply chains for similar products include a different model for direct training, the potential to leverage existing retail networks that serve farmers, and increasing the use of radio promotion.

Capacity was assessed by on-time delivery for the production schedules set by manufacturers for the transportation provider. Bag availability was very good, with only 4% of the required products missing shipment schedules. Plastics silos performed nearly as well with only 6% shortfall. In contrast, the metal silo suppliers struggled to meet requirements with 24% of the medium and 53% of the large silos falling short of scheduled delivery.

Despite low availability in SO1, operational analysis indicates potential for local artisan productivity improvements. Though based on a small sample, data showed that firms employing higher skilled labor and firms investing more in capital equipment had higher productivity. Higher production levels toward the end of the SO1 period also point to a learning effect. Further study is merited to better understand the value of training laborers with specific skill profiles and to identify the most effective investments in manufacturing equipment technology.

The artisans' low availability may also reflect innate reluctance to invest in inventory, a risk-avoidance behavior that was documented in a previous study of storage technologies in 10 African countries. One opportunity to mitigate this behavior is risk sharing mechanisms. However, our behavioral experiment where artisans and students ordered the key raw material for metal silos with a risk mitigation option indicated more aversion to leftover finished goods than was reflected in their general risk profile, as measured by a standard risk lottery experiment. Further, the results differed based on the contract type. Given the same risk exposure, participants with the supplier buyback option for raw materials performed better than participants with the third party salvage option for finished goods. These results may indicate lack of trust in contracts to mitigate inventory risks generally, and especially after further investment to complete the finished good.

Overall, this MIT CITE study highlighted how strategic support from a development organization in establishing a supply chain enables key opportunities to increase affordability and availability of a new technology. This type of facilitative approach can have a similar effect as directly subsidizing products or production capacity but is more sustainable as the organization can more naturally phase out its involvement. However, this approach relies on deeper engagement than is typical in development work in analyzing operational processes (e.g. production, transportation, sales channel) and monitoring improvement to effectively ramp down facilitation support. Evidence from this study indicates that, with operational facilitation to realize key improvement opportunities, supply chains for hermetic crop storage technologies have the potential to scale beyond previous pilots.

Farmer impact

Despite increasing efforts to address post-harvest losses among smallholder farmers through use of hermetic crop storage technologies, there is little research regarding the factors that facilitate large-scale adoption of these technologies. Results from our survey in communities that gained access to such technologies through the World Food Program (WFP) Special Operation (SO1) contribute evidence regarding the impact on and value to farmers. We combined this evidence with our analysis of the supply chains for these technologies in a model that simulates future adoption. We aimed to provide a broader systems approach in understanding the key factors that drive adoption among farmers. We close by summarizing this evidence and considering the implications on future efforts to scale adoption.

The survey results showed positive impact of storage technology adoption in all three areas of focus – farmers' income, food security, and socio-economic well-being. Regarding income, the maize sales price was higher ($p<0.01$) for the improved technologies relative to both no storage and traditional storage approaches. Food security improved as storage technology adoption reduced external purchasing for maize by 1.51 months ($p<0.01$) and beans by 0.90 months ($p<0.05$). Finally, various socio-economic conditions improved for technology adopters as their responses were nearly a full point lower on a five-point scale where *1=much better over the past year* and *5=much worse over the past year*. The adopters' improvement was statistically significant ($p<0.01$) for the following variables: food availability (0.88 improvement on the five-point scale), household health (0.74), sons' schooling (0.72), daughters' schooling (0.72), women's workload (0.85), family income (0.91), women's socio-economic status (0.88), men's status in the community (0.82), and women's status in the community (0.83). These results, which were consistent with results from the study in Central America,[39] are the first of their kind on the African continent to characterize the impact of post-harvest storage on smallholder farmers.

These results indicate that support for storage technology adoption has implications in achieving various international development objectives. As households begin to consume more of the food they harvest and store, the reduced food expense enables financial flexibility to consider other expenses or investments. Storage technologies also contribute to financial stability since grains can be sold incrementally throughout the post-harvest season, if needed. Hence, it was not surprising to observe positive externalities in areas such as children's education, as grains are often a suitable form of tuition payment, and greater gender equality, as women in households with storage technology are no longer required to shell harvested grains on a daily basis.

The next key question was how much value farmers attribute to these benefits, which clearly influences their buying decision. Survey results revealed a sizable portion of the population who were willing to pay above the subsidized SO1 price, but below the unsubsidized price. Willingness to pay (WTP) was higher among non-adopters at almost every price level for all products. Distinguishing among technologies, WTP for plastic silos was slightly higher; this could indicate that they provide good value for money to farmer or that prices were set a little too low relative to other technologies at the SO1 launch.

WTP results are critical in designing the "go-to-market" strategy for actors in the storage technology sector. For example, higher WTP among non-adopters in the adopter communities may indicate strong communication of the value proposition by word-of-mouth. Future research should explore the dynamics of community relationships in adoption of these technologies. In addition, the higher value of plastic silos based on SO1 prices highlights the importance of pricing, especially given the evidence from our supply chain research that the price did not cover the manufacturer's costs. Market-based prices leading to effective cost targets for manufacturers are critical for product and supply chain design. Future research should improve elicitation methods for stated preference data collection, and future farmer surveys should incorporate questions that enable a contingent valuation approach for estimating willingness to pay.

The system dynamics model that combined technology diffusion with supply chain capability addressed our third, and most essential, question regarding the potential for storage technology adoption. Total adopters for the baseline case grew initially before tailing off, with the total over all four technologies reaching 1.05 million households (17.5% of the market) by 2024. Scenario analysis pointed to inventory, access to credit, and word-of-mouth contact as having a stronger positive impact on adoption, while higher budgets for advertising and training did less to facilitate greater adoption.

[39] Bokusheva, Raushan, Robert Finger, Martin Fischler, Robert Berlin, Yuri Marín, Francisco Pérez, and Francisco Paiz. 2012. "Factors Determining the Adoption and Impact of a Postharvest Storage Technology." Food Security 4 (2): 279–93.

Focusing on affordability, a price reduction of 5% reduction annually from 2015 to 2024 resulted in 1.19 million adopters (20% of the market). Availability had a bigger impact, as doubling inventory alone resulted in 1.55 million adopters (26% of the market). While lower prices drive adoption, higher inventory is required to capitalize on the opportunity. Leveraging this insight, we compared the baseline ten-year subsidy with a “strong supply chain” scenario that phased out the subsidy over five years but added 3% annual price reductions and 10% higher inventory. While the strong supply chain scenario tracked slightly behind the baseline in the early years, as its subsidy was phased out faster, it maintained steady growth trajectory over the ten-year horizon, resulting in a total adoption of 1.37 million (23% of the market).

The model results demonstrated that supply chain improvements are critical in technology adoption. The combination of price reductions and inventory increases offered a much better foundation for sustainable storage technology adoption than long-term subsidies. Effective supply chains enable early adoption that expands through word-of-mouth, which is the most effective driver of further adoption, and provide markets with sustainably better priced and stocked products. The model itself could further assist in calibrating efforts to facilitate storage technology adoption, e.g. quantifying cost targets for manufacturers and financing levels for banks or savings groups.

Storage technology adoption relies on positive experiences among farmers and supply chains that effectively deliver the products. This research offered evidence about the current capabilities and potential improvements among the various supply chains in Uganda. The scale of the first Special Operation provided ample opportunity to identify paths to further scale future efforts. This research also offered evidence about the impact of storage technology on an adopter’s livelihood. It further offered evidence about the storage technologies’ perceived value in their community and demonstrated how communicating this value via word-of-mouth is key to further adoption. And finally, it showed how a portfolio of factors, especially supply chain improvements, contribute toward scaling adoption of post-harvest storage technologies.

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Appendix A: Supplemental Supply Chain Analysis

Table 14: Raw material costs for metal artisans. Numbers noted with an asterisk (*) are estimated based on assumptions detailed above.

Metal artisan	Silo size	Cost per sheet (UGX)	Sheets used per silo	VAT cost per sheet (UGX)	Transport cost per silo (UGX)	Total sheet metal cost ($)	Cost of other raw materials per silo (UGX)	Label cost (UGX)	Total raw material cost ($)
AM1	Medium	82,000	2.5	0	19,375	$ 89	11,680	2,500*	$ 94.10
AM1	Large	82,000	3.5	0	27,125	$ 124	11,680	2,500*	$ 129.51
AM2	Medium	97,500	2	17,550	4,950	$ 93	31,759	2,500*	$ 106.24
AM2	Large	97,500	3	17,550	7,425	$ 139	31,759	2,500*	$ 152.60
AM3	Medium	82,000	2	0	500	$ 65	14,333	3,000	$ 71.73
AM4	Medium	70,000	2	12,600	9,000	$ 69	19,500	2,500*	$ 77.40
AM4	Large	70,000	2.5	12,600	11,250	$ 86	19,500	2,500*	$ 94.58
AM5	Medium	82,000*	2	0	500*	$ 65	0	2,000	$ 65.68
AM5	Large	82,000*	2.75	0	688*	$ 89	0	2,000	$ 90.01
AM6	Medium	97,000	2	0	2,333	$ 77	56,000	2,500*	$ 100.53

Table 15: Labor costs for metal artisans. Numbers noted with an asterisk (*) are estimated based on assumptions detailed above.

Metal artisan	Silo size	Direct labor salary per silo (UGX)	Extra labor cost per silo (UGX)	Description of extra cost	Total labor cost per silo ($)
AM1	Medium	N/A	0	N/A	$ 20.66
AM1	Large	N/A	0	N/A	$ 20.66
AM2	Medium	75,000	20,000	Supervision	$ 37.48
AM2	Large	80,000	20,000	Supervision	$ 39.45
AM3	Medium	15,000	1,000	Silicone	$ 6.31
AM4	Medium	140,000	0	N/A	$ 55.23
AM4	Large	140,000	0	N/A	$ 55.23
AM5	Medium	128,333*	0	N/A	$ 50.62
AM5	Large	130,000*	0	N/A	$ 51.28
AM6	Medium	150,000	0	N/A	$ 59.17

Table 16: Loading cost for artisans. Numbers noted with an asterisk (*) are estimated based on assumptions detailed in the text.

Metal artisan	Silo size	Loading cost per truck (UGX)	Number of silos per truck	Total loading cost per silo ($)
AM1	Medium	0	N/A	$ 0.00
AM1	Large	0	N/A	$ 0.00
AM2	Medium	80,000	45	$ 0.70
AM2	Large	80,000	45	$ 0.70
AM3	Medium	N/A	N/A	$ 1.18

AM4	Medium	100,000	45*	$ 0.88
AM4	Large	100,000	45*	$ 0.88
AM5	Medium	0	N/A	$ 0.00
AM5	Large	0	N/A	$ 0.00
AM6	Medium	0	N/A	$ 0.00

Table 17: Selling prices as reported by artisans and the WFP.

Metal artisan	Silo size	Artisan-reported price (UGX)	Artisan-reported price ($)	WFP-reported price ($)	Difference (at 2535 UGX/USD)
AM1	Medium	N/A	$ 132	$ 130	N/A
AM1	Large	N/A	$ 180	$ 180	N/A
AM2	Medium	N/A	N/A	$ 120	N/A
AM2	Large	N/A	N/A	$ 172	N/A
AM3	Medium	320,000	N/A	$ 130	$ (3.77)
AM4	Medium	338,000	N/A	$ 130	$ 3.33
AM4	Large	450,000	N/A	$ 180	$ (2.49)
AM5	Medium	335,000	N/A	$ 130	$ 2.15
AM5	Large	458,000	N/A	$ 180	$ 0.67
AM6	Medium	330,000	N/A	$ 130	$ 0.18

Table 18: Estimated gross profit per silo for each metal artisan and silo size. Costs include raw materials, labor, and transport/delivery. Revenue is based on the WFP-reported sales price.

Metal artisan	Silo size	Estimated gross profit ($/silo) [2300 UGX/USD]	Estimated gross profit ($/silo) [2535 UGX/USD]	Estimated gross profit ($/silo) [2700 UGX/USD]	Estimated gross profit ($/silo) [2900 UGX/USD]
AM1	Medium	$ 4.30	$ 15.24	$ 21.79	$ 28.72
AM1	Large	$ 38.35	$ 50.49	$ 57.75	$ 65.44
AM2	Medium	$ (38.97)	$ (24.41)	$ (15.71)	$ (6.48)
AM2	Large	$ (40.14)	$ (20.75)	$ (9.15)	$ 3.14
AM3	Medium	$ 42.68	$ 50.78	$ 55.62	$ 60.75
AM4	Medium	$ (16.78)	$ (3.50)	$ 4.44	$ 12.86
AM4	Large	$ 14.38	$ 29.32	$ 38.26	$ 47.73
AM5	Medium	$ 1.81	$ 13.69	$ 20.80	$ 28.33
AM5	Large	$ 24.27	$ 38.70	$ 47.34	$ 56.49
AM6	Medium	$ (45.92)	$ (29.70)	$ (19.99)	$ (9.71)

Table 19: Production capacities of various metal artisans as self-reported and as determined from data provided by the transportation firm used for SO1. Numbers noted with an asterisk (*) are estimated based on assumptions detailed in the text.

Metal artisan	Silo size	Number of workers for SO1	Production time per silo (hours)	Artisan-reported production capacity (silos/day)	Average production (silos/day) based on transport data*

AM1	Medium	10	2.3	11.7	9.96
AM1	Large		2.3		
AM2	Medium	33	5.3	132	7.22 (Jinja) 7.70 (Mbarara)
AM2	Large		5.3		
AM3	Medium	4	2.0	8	4.99
AM4	Medium	20	4.6	17	14.11
AM4	Large		4.6		
AM5	Medium	N/A	2.8	16	7.35
AM5	Large	N/A	2.8	8	
AM6	Medium	N/A	5.1	8	5.57

Table 20: Regression results for sales channel costs

	Total Cost	Est.	P	Est.	P	Est.	P	Est.	P	Est.	P
	Intercept	-6624	0.13	34703	0.03	93182	0.0001	-2877	0.84	11309	0.57
	No. Trained	26	0.0001								
	Religious			20498	0.40						
1	International					-66402	0.00				
	No. FCPs							19986	0.01		
	Density									156	0.11
	R2	0.97		0.10		0.84		0.66		0.32	
	AR2	0.97		-0.02		0.81		0.61		0.23	

	Total Cost	Est.	P	Est.	P	Est.	P	Est.	P	Est.	P
	Intercept	3758	0.85	11264	0.50	55722	0.20	67522	0.04	6538	0.71
	No. Trained	20	0.01	21	0.00					20	0.01
	Religious									6562	0.18
2	International	-9146	0.50	-12979	0.28	-45568	0.10	-51739	0.02	-11165	0.35
	No. FCPs	1152	0.73	490	0.87	7299	0.32	6415	0.31	348	0.90
	Density	18	0.52			26	0.68			12	0.60
	R2	0.98		0.98		0.86		0.86		0.99	
	AR2	0.96		0.97		0.79		0.82		0.97	

	Total Cost	Est.	P	Est.	P	Est.	P	Est.	P
	Intercept	-7337	0.06	12108	0.40	-6984	0.16	-8595	0.08
	No. Trained	25	0.0001	21	0.00	25	0.00	25	0.0001
	Religious	6762	0.11						
3	International			-13368	0.21				
	No. FCPs					1203	0.69		
	Density							23	0.30
	R2	0.98		0.98		0.97		0.98	
	AR2	0.98		0.97		0.96		0.97	

	Cost/Farmer	Est.	P	Est.	P	Est.	P	Est.	P	Est.	P
	Intercept	18.6	0.13	19.31	<.0001	24.68	<.001	17.12	0.00	18.71	0.00
	Religious	4.0	0.22	5.01	0.08						
	International	-1.6	0.80			-4.74	0.16				
4	No. FCPs	0.9	0.64					1.74	0.12		
	Density	0.0	0.92							0.01	0.37
	R2	0.56		0.38		0.26		0.30			
	AR2	0.13		0.29		0.16		0.21			

Appendix B: Farmer Survey

Hi, my name is __________. I am part of a project with the Massachusetts Institute of Technology, the World Food Program and [*local project partner*] conducting research on the introduction of storage technologies in Uganda.

Our main goal is to understand how farmers make their decision to store their crops.

You were selected randomly to answer some questions about your storage practices. These questions should take about 30 minutes to answer. Any information you give us will be confidential. You can choose not to answer any questions you wish, and you can end this interview at any time.

Your answers are important as we hope to understand how farmers, traders and the overall agricultural supply chains in Uganda change with the introduction of storage technologies.

Do you consent to participate in this study? If yes, please sign here:

____

Signature (or other mark)

Do you give permission to use photographs of you in our publications and other content resulting from this study? ☐ Yes ☐ No

Full name of interviewee: ____________________________________ Age: __________

District: ____________________________ Sub-County: _________________________________

Parish: _____________________________ Village: ______________________________________

Name of interviewer: ____

Name of translator (if used): ____

Date of interview: _________ (dd) __________ (mm) ___________ (yyyy) ________ (time)

I. GENERAL INFORMATION ON FAMILY, HOUSEHOLD AND FARM

1. How many people are in the household (eat meals together)? ______________
2. How many children between 6 to 18 years old live in the household?
   A. Boys: ________ B. Girls: ________
3. Do all children between 6 to 18 years old attend school?
   ☐ A. Not all attend
   ☐ B. All attend government schools
   ☐ C. None attend
   ☐ D. All attend, and one or more go to a private, NGO/religious, or boarding school
4. What is the highest grade that the male and female heads have completed?
   A. Male: __________ B. Female: __________
5. What is the major roofing material of your house?
   ☐ A. Thatch, straw, other ☐ B. Iron sheets, or tiles
6. What is the major construction material of the external wall?
   ☐ A. Un-burnt bricks, mud and poles, thatch/straw. timber, stone, burnt bricks w/ mud
   ☐ B. Burnt bricks with cement, or cement blocks
   ☐ C. Other (*specify*): ______________________________________
7. What is the main source of lighting in your house?
   ☐ A. Firewood
   ☐ B. Tadooba, or other
   ☐ C. Kerosene/paraffin lantern, or electricity (grid, generator, solar)
   ☐ D. Other (*specify*): ______________________________________
8. What type of toilet is used mainly in your house?
   ☐ A. Bush (none)
   ☐ B. Covered pit latrine (private or shared), VIP latrine (private or shared), uncovered pit latrine, flush toilet (private or shared), or other
9. Do you or anyone in your household currently own any electronic equipment (*TV, radio, cassette, etc.; does not include mobile phones*)? ☐ A. Yes ☐ B. No
10. Does every household member own at least 2 sets of clothes? ☐ A. Yes ☐ B. No
11. Does every household member own at least 2 sets of shoes? ☐ A. Yes ☐ B. No

12. What is the entire household's typical annual income? ___________________________ UGX
13. Do you or any household member belong to the following organizations? (*tick all that apply*)
☐ A. Farmers' association ☐ C. NGO ☐ E. Other (*specify*):
☐ B. Cooperative ☐ D. Savings group
14. How many acres of land do you own, rent, lend and farm?
A. Own: ____________ B. Rent: ____________ C. Lend: ____________ D. Farm: ___________
15. When was your most recent harvest? _________ (dd) _________ (mm) __________ (yyyy)
16. In the past two years, has anyone in your household received any agricultural trainings? ☐ A. Yes ☐ B. No
    1. If yes, from whom did you receive training(s)? ☐ A. WFP ☐ B. Other (*specify*): _____
    2. If yes, what did you learn about in these trainings? (*tick all mentioned*)
    ☐ A. Grain quality ☐ D. Threshing and cleaning
    ☐ B. Pre-harvest, harvest practices ☐ E. Grain storage, post-harvest management
    ☐ C. Drying grain ☐ F. Other (*specify*): ___________________________

II. ADOPTION AND MANAGEMENT OF SILO/BAG

1. Which silo/bag did you purchase? How many?

A. Super Grain (80 kg/bag)	B. Plastic silo (250 kg)	C. Medium metal silo (530 kg)	D. Large metal silo (1300 kg)	E. No. of plastic sheets? *1 or 2*

2. When did you purchase the silo/bag? A. Month: ______________ B. Year: _____________
3. For how many harvests have you used the bag? ☐ A. 1 ☐ B. 2 ☐ C. 3 ☐ D. 4
4. What reasons influenced your decision to purchase a new silo/bag? (*tick all that apply*)
☐ A. Excessive crop loss ☐ D. Want more crops for home consumption
☐ B. Want to sell crop at better price ☐ E. Other (*specify*): ___________________________
☐ C. No place to store grain
    1. Of the reasons you just mentioned, which was the most important reason in your decision to buy the new silo/bag? ____
5. Why did you choose this silo/bag over the other silo/bag options available? (*tick all mentioned*)
☐ A. Price ☐ C. Strength ☐ E. Ease of use (time, steps, maintenance)
☐ B. Size ☐ D. Effectiveness ☐ F. Other (*specify*): ______________________
6. Who made the final decision to buy the silo/bag?
☐ A. Husband ☐ C. Both A. and B. ☐ E. Daughter
☐ B. Wife ☐ D. Son ☐ F. Other (*specify*): ___________________
7. Did you talk to anyone who influenced your decision to purchase a new silo/bag?
☐ A. Yes ☐ B. No

1. If yes, who did you talk to?
   ☐ A. Family member ☐ C. Colleague ☐ E. Farmers' group/association
   ☐ B. Neighbor ☐ D. Community member ☐ F. Other (*specify*): ____________
2. If yes, what did you discuss? ____

8. Do you know anyone in your community who bought the same silo/bag?
   ☐ A. Yes ☐ B. No (*skip to next question*)
   1. If yes, how many people? __________
   2. If yes, how are they related to you? (*tick all mentioned*)
      ☐ A. Family member ☐ C. Colleague ☐ E. Farmers' group/association
      ☐ B. Neighbor ☐ D. Community member ☐ F. Other (*specify*): ____________
9. Have you spoken to anyone about your silo/bag who did not attend the WFP trainings? ☐ A. Yes ☐ B. No
   1. If yes, how many people? __________
   2. If yes, how are they related to you? (*tick all mentioned*)
      ☐ A. Family member ☐ C. Colleague ☐ E. Farmers' group/association
      ☐ B. Neighbor ☐ D. Community member ☐ F. Other (*specify*): ____________
   3. If yes, how many showed interest in learning more or buying the silo/bag? _______
10. What, if any, are the advantages you have found in using your new silo/bag? (*tick all mentioned*)
    ☐ A. Better protection from pests ☐ F. Less exposure to agrochemicals
    ☐ B. Better protection from water, mold ☐ G. Better hygiene, cleaner house
    ☐ C. More/better food available for HH ☐ H. More secure
    ☐ D. Higher crop sale prices/sell later ☐ I. Takes up less space
    ☐ E. Easier to use and maintain ☐ J. Other (*specify*): ________________________
    1. Additional notes: ____
11. What, if any, are the disadvantages you have found in using your new silo/bag?
    ____
    ____
12. What other storage units do you use?

Storage unit*	A. How many? *Number*	B. What is the (unit) cost? *UGX*	C. Lifespan *Years of use*	D. What crop(s) do you store? *1. Maize* *2. Beans* *3. Sorghum* *4. Other (specify)*	E. Do you use protectant (chemicals)? *1. Yes (specify, if known)* *2. No*	F. Why do you still use this storage unit?

1.						
2.						
**Key: 1. Traditional granary 2. Open weave basket or sack 3. Metal barrel 4. Plastic barrel 5.Other (specify) 6. None*						

13. Have you stopped using any other storage units since you bought your new silo/bag?

    ☐ A. Yes ☐ B. No (*skip to next question*)

    1. If yes, what type(s)? (*tick all that apply*)

       ☐ A. Traditional granary ☐ C. Metal barrel ☐ E. Other (*specify*): ___________

       ☐ B. Open weave basket/sack ☐ D. Plastic barrel

    2. If yes, did you use protectant (chemical)? ☐ A. Yes (specify: _____________) ☐ B. No
    3. If yes, why did you stop using it/them? ____

14. How would you rate your old/alternative storage unit(s) and the new silo/bag for:

	1. Old/alternative storage	2. New silo/bag storage
A. Affordability		
B. Performance		
C. Ease of use		
D. Overall value		
Key: 1. Very good (100-76) 2. Somewhat good (75-51) 3. Somewhat bad (50-26) 4. Very bad (≤ 25)		

15. How much did you pay for the new silo/bag? (in UGX, unit cost)

I. Super Grain (80 kg/bag)	II. Plastic silo (250 kg)	III. Medium metal silo (530 kg)	IV. Large metal silo (1300 kg)

16. How did you pay for the silo/bag?

    ☐ A. In full ☐ C. With credit

    ☐ B. In installments ☐ D. With borrowed money

17. If the silo/bag were [*unsubsidized price from below*], how likely are you to buy it?

	1. Super grain *65,000 UGX* *100,000 UGX*	2. Plastic silo *150,000 UGX* *185,000 UGX*	3. Med. silo *390,000 UGX* *430,000 UGX*	4. Large silo *550,000 UGX* *590,000 UGX*
A. Pay with your money:				
B. Pay with credit:				
Key: 1. Very likely (100-76) 2. Somewhat likely (75-51) 3. Somewhat unlikely (50-26) 4. Very unlikely (≤25)				

18. What is the highest price you would pay for each storage technology (UGX)?

I. Super Grain (80 kg/bag)	II. Plastic silo (250 kg)	III. Medium metal silo (530 kg)	IV. Large metal silo (1300 kg)

III. STORAGE SALES, USE AND PRACTICE

1. Storage

Note: Base the following tables on most recent harvest.

Silo/bag:

Grain	A. Which silo/bag? *1. Super grain* *2. Plastic silo* *3. Med. metal silo* *4. Large metal silo*	B. Quantity of grain harvested *Kg*	C. Quantity of grain not stored (sale, consumption at harvest) *Kg*	D. Quantity of grain stored in silo/bag *Kg*	E. How full was the silo/bag filled? *1. Completely full* *2. Mostly full* *3. Half full* *4. Less than half full*	F. Percent estimate of grain loss in silo/bag %	G. Use of grain stored (*tick all mentioned*) *1. Home consumption* *2. Seed* *3. Sale* *4. Livestock feed* *5. Other (specify)*	H. Indicate % use *For example: 75% home consumption, 25% sale*	I. Where is the silo/bag stored? *1. Inside home* *2. Warehouse* *3. Outside* *4. Other (specify)*	J. Until when do you plan to store the grain? *mm/yyyy: specify beginning, middle, end of month*
1.										
2.										
3.										

Other storage unit(s):

Grain	A. Which silo/bag? *1. Traditional granary* *2. Open weave basket or sack 3. Metal barrel* *4. Plastic barrel*	B. Quantity of grain harvested *Kg*	C. Quantity of grain not stored (sale, consumption at harvest) *Kg*	D. Quantity of grain stored in silo/bag *Kg*	E. How full was the silo/bag filled? *5. Completely full* *6. Mostly full* *7. Half full* *8. Less than half full*	F. Percent estimate of grain loss in silo/bag %	G. Use of grain stored (*tick all mentioned*) *1. Home consumption* *2. Seed* *3. Sale* *4. Livestock feed* *5. Other (specify)*	H. Indicate % use *For example: 75% home consumption, 25% sale*	I. Where is the silo/bag stored? *1. Inside home* *2. Warehouse* *3. Outside* *4. Other (specify)*	J. Until when do you plan to store the grain? *mm/yyyy: specify beginning, middle, end of month*
1.										
2.										
3.										

2. Sales of grain # 1 (most sold, specify): ___________________________

	Type of sale	A. Harvest date *mm/yyyy: specify beginning, middle, end of month*	B. Quantity sold *Kg*	*C. Date of sale* *mm/yyyy: specify beginning, middle, end of month*	D. Price sold for *UGX (unit price)*	E. Where did you sell? *1. On farm* *2. In village* *3.Other village* *4. Other district* *5. Other (specify)*	F. To whom did you sell? *1. Direct to consumer* *2. Local shops* *3. Farmers organization* *4. Agro-dealer* *5. Middleman* *6. Other (specify)*
Grain not stored	*Immediately after harvest (*< 1 month)						
Grain stored in silo/bag	*Early (1-6 months post-harvest)*						
	Late (6+ months post-harvest)						
Grain stored in other storage units (or none)	*Early (1-6 months post-harvest)*						
	Late (6+ months post-harvest)						

3. Sales of grain # 2 (second-most sold, specify): ___________________________

	Type of sale	A. Harvest date *mm/yyyy: specify beginning, middle, end of month*	B. Quantity sold *Kg*	*C. Date of sale* *mm/yyyy: specify beginning, middle, end of month*	D. Price sold for *UGX (unit price)*	E. Where did you sell? *1. On farm* *2. In village* *3.Other village* *4. Other district* *5. Other (specify)*	F. To whom did you sell? *1. Direct to consumer* *2. Local shops* *3. Farmers organization* *4. Agro-dealer* *5. Middleman* *6. Other (specify)*
Grain not stored	*Immediately after harvest (*< 1 month)						
Grain stored in silo/bag	*Early (1-6 months post-harvest)*						
	Late (6+ months post-harvest)						
Grain stored in other storage	*Early (1-6 months post-harvest)*						

units (or none)	*Late (6+ months post-harvest)*						

4. Storage use and practice

1. Who is responsible for post-harvest activities?

A. Activity	B. Who is responsible?*	A. Activity (continued)	B. Who is responsible?* (continued)
1. Harvesting grain		6. Emptying silo	
2. Drying grain		7. Cleaning silo	
3. Threshing grain		8. Selling grain	
4. Cleaning grain		9. Other (*specify*):	
5. Filling silo			
Key: 1. Husband 2. Wife 3. Both 1. And 2. 4. Son(s) 5. Daughter(s) 6. Hired workers 7. Other (specify):			

2. How is using your new silo/bag different from your previous/other storage unit(s) (how do the steps and overall process differ)?

Difference	Is this difference good or bad? *1. Good 2. bad*
1.	
2.	
3.	

3. Describe the actions you should do before you put the grains in storage to ensure that they will be of good quality once stored. (*tick all mentioned*)

☐ A. Harvest during hot, dry weather
☐ B. Transport grain from farm to home as quickly as possible
☐ C. Transport grain in clean, dry containers
☐ D. Do not let grain come in contact with soil
☐ E. Dry grain properly (plastic sheet, single layer, turn crop often, away from animals)
☐ F. Determine that grain is dry enough to store (≤13% moisture content)
☐ G. Thresh grain properly to avoid damage to grains
☐ H. Sort, clean grain (remove stones, husks, pods, bad grain; winnow, sieve, hand-pick)
☐ I. Other (*specify*):

____

4. Describe the steps required to use the silo/bag properly.

Step:	*Tick all mentioned:*	*Tick all observed:*
A. Do not store in direct sunlight	☐	☐
B. Do not store on the ground	☐	☐
C. Position away from internal walls	☐	☐
D. Keep away from fires	☐	☐
E. Close carefully (tied twice) (plastic bags only)	☐	☐
F. Seal openings (grease or rubber tire) (silos only)	☐	☐
G. Kept closed for 30 days without opening (silos only)	☐	☐
H. Place burning candle on grain surface (metal silo only)	☐	☐
I. Other (*specify*)	☐	☐

IV. IMPACTS

1. Employment

Time	1. How many paid, full-time workers worked on your farm?		2. How many paid, part-time workers work on your farm?	
	Men	Women	Men	Women
Harvest before silo/bag				
Most recent harvest				

2. Income and expenditure (*Note: Row totals must add up to 100%; totals for annual)*

1. Where does your income come from?

Time	Percent of annual income: agricultural activities	Percent of annual income: livestock activities	Percent of annual income: off-farm activities	Percent of annual income: outside the country (remittances)	Percent of annual gross income: other (*specify*)
Year prior to silo/bag					
Present year					

2. How do you mainly spend your income? (*percent of annual spending*)

A. Food	B. Housing (maintenance, services)	C. Clothing and household goods	D. Education	E. Health	F. Agriculture	G. Other (*specify*):

3. Food security

	1. What is your annual household consumption need for grain? *Kg*	2. How many months out of the past year has the family lived mainly on own (farm) production? *No. 1 – 12*	3. In the last year, did you have to buy grains for consumption? *1. Yes (indicate # of months)* *2. No*	4. Why did you need to buy the grains? *1. Didn't grow* *2. Bad harvest* *3. Little storage capacity* *4. Not enough production because of small land size* *5. Sale of harvest due to urgency/problem* *6. Other (specify)*	5. Do you buy these grains every year to satisfy your family consumption needs? *1. Yes* *2. No, only if harvest is bad* *3. Only in exceptional cases*
Crop 1:					
Crop 2:					

4. Livelihood

1. How do you see the changes (evolution) in your livelihood since you bought the new silo/bag, with respect to the following issues?

Issue:	Scale: *1. Much better* *2. Somewhat better* *3. Same* *4. Somewhat worse* *5. Much worse* *6. Don't know*	Does the change have to do with the use of the silo/bag? *1. Very much* *2. Somewhat* *3. A little* *4. No* *5. Don't know*	Notes *(if needed)*
1. Food availability			
2. Health			
3. Housing			
4. Schooling of sons			
5. Schooling of daughters			
6. Workload of men			

7. Workload of women			
8. Family income			
9. Farm production			
10. Socio-economic status of women			
11. Status/reputation of men in the community			
12. Status/reputation of women in the community			

V. CONCLUSION

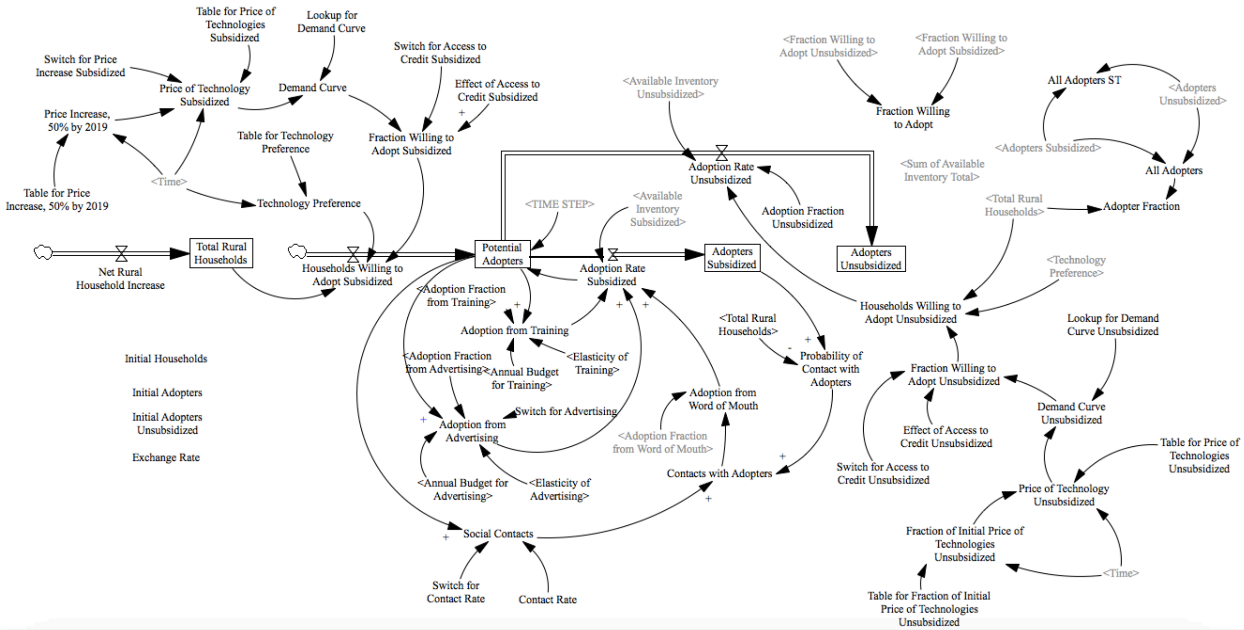
1. Finally, in your opinion, what has been the most important change in your life since you acquired your new silo/bag?

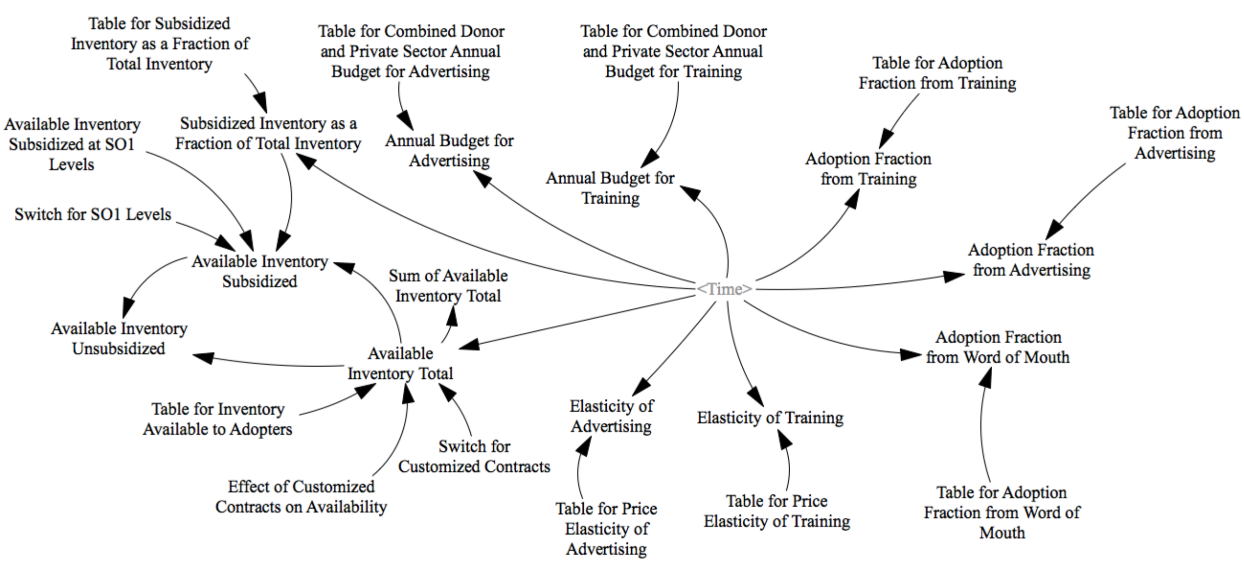
2. Is there anything else you would like to tell us that you think is important for us to know?

3. Notes and observations:

Webale! Thank you!

Appendix C: System Dynamics Model Structure





Appendix D: System Dynamics Model Documentation

Adopter Fraction=
All Adopters / Total Rural Households
Units: Fraction

Adopters Subsidized[Technology]= INTEG (
Adoption Rate Subsidized[Technology],
Initial Adopters[Technology])
Units: Households
The population that have adopted the product.

Adopters Unsubsidized[Technology]= INTEG (
Adoption Rate Unsubsidized[Technology],
Initial Adopters Unsubsidized[Technology])
Units: Households

Adoption Fraction from Advertising[Technology]=
Table for Adoption Fraction from Advertising[Technology](Time)
Units: Fraction
The fraction of the population adopting each year as the result of hearing an advertisement.

Adoption Fraction from Training[Technology]=
Table for Adoption Fraction from Training[Technology](Time)
Units: Fraction
The fraction of the population adopting each year as the result of attending a training. Assumed to be held constant at SO1 levels: that is, adoption fraction = adopters in SO1[technology] (SG:6766, PS:6363, MMS:2400, LMS:1075) / potential adopters in SO1 (1,200,000).

Adoption Fraction from Word of Mouth[Technology]=
Table for Adoption Fraction from Word of Mouth[Technology](Time)
Units: Fraction
The probability of adoption given a word of mouth contact with an adopter. Assumed to be 0.005 for all technologies.

Adoption Fraction Unsubsidized[Technology]=

0.03,0.03,0.03,0.03
Units: Fraction
Fraction of the population buying unsubsidized products. Assumed
to be 0.03 for all technologies.

Adoption from Advertising[Technology]=
Switch for Advertising[Technology] * ((Potential Adopters[Technology] * Adoption Fraction from Advertising
[Technology]) + ((Potential Adopters[Technology] * Adoption Fraction from Advertising
[Technology]) * ((Annual Budget for Advertising[Technology] - 1) * Elasticity of Advertising
[Technology] * 100)))
Units: Households/Year
Adoption resulting from exposure to advertising. Proportional to
the potential adopter population.

Adoption from Training[Technology]=
(Potential Adopters[Technology] * Adoption Fraction from Training[Technology
]) + ((Potential Adopters[Technology] * Adoption Fraction from Training[Technology
]) * ((Annual Budget for Training[Technology] - 1) * Elasticity of Training
[Technology] * 100))
Units: Households/Year
Proportional to the number of potential adopters and the
adoption fraction from training (in the future, this should be
proportionally linked to the relative allocation of budget to
training versus other activities, e.g., advertising).

Adoption from Word of Mouth[Technology]=
Adoption Fraction from Word of Mouth[Technology] * Contacts with Adopters[
Technology]
Units: Households/Year
The rate at which households decide to adopt the product as the
result of word of mouth and social contagion.

Adoption Rate Subsidized[Technology]=
MAX(0, MIN(Available Inventory Subsidized[Technology], Adoption from Advertising
[Technology] + Adoption from Training[Technology] + Adoption from Word of Mouth
[Technology]))
Units: Households/Year
The annual rate at which households purchase the storage
technologies. Constrained by manufacturers' production capacity.

Adoption Rate Unsubsidized[Technology]=
MAX(MIN(Available Inventory Unsubsidized[Technology], Households Willing to Adopt Unsubsidized
[Technology] * Adoption Fraction Unsubsidized[Technology]), 0)
Units: Households/Year

All Adopters=
SUM(Adopters Subsidized[Technology!]) + SUM(Adopters Unsubsidized[Technology !])
Units: Households

All Adopters ST[Technology]=
Adopters Subsidized[Technology] + Adopters Unsubsidized[Technology]
Units: Households

Annual Budget for Advertising[Technology]=
Table for Combined Donor and Private Sector Annual Budget for Advertising[Technology](Time)
Units: Fraction
Assumed to increase annually by 3%. Budget is normalized, to 1 = budget in SO1.

Annual Budget for Training[Technology]=
Table for Combined Donor and Private Sector Annual Budget for Training[Technology](Time)
Units: Fraction
Assumed to grow at an annual increase of 3%. Budget is normalized, to 1 = budget in SO1.

Available Inventory Subsidized[Technology]=
(Available Inventory Total[Technology] * Subsidized Inventory as a Fraction of Total Inventory [Technology] * (1 - Switch for SO1 Levels [Technology])) + (Available Inventory Subsidized at SO1 Levels[Technology] * Switch for SO1 Levels[Technology])
Units: Units/Year
Driven by the donor budget allocated to a subsidy. Currently assumed to decrease by 10% annually.

Available Inventory Unsubsidized[Technology]=
Available Inventory Total[Technology] - Available Inventory Subsidized[Technology]
Units: Units/Year

Contact Rate[Technology]=
50,50,50,50
Units: 1/Year
Value is an assumption

Contacts with Adopters[Technology]=
Probability of Contact with Adopters[Technology] * Social Contacts[Technology]
Units: Households/Year

The total number of contacts the potential adopters have with
adopters each year. Determined by the total contact volume,
given by Social Contacts SC, and the probability that any such
contact occurs with an adopter.

Demand Curve[Technology]=
Lookup for Demand Curve[Technology](Price of Technology Subsidized[Technology
])
Units: Fraction

Demand Curve Unsubsidized[Technology]=
Lookup for Demand Curve Unsubsidized[Technology](Price of Technology Unsubsidized
[Technology])
Units: Fraction

Effect of Access to Credit Subsidized[Technology]=
1.07, 1.15, 1.18, 1.12
Units: Dimensionless
Increase in likelihood to buy technology. Derived from CITE
survey data.

Effect of Access to Credit Unsubsidized[Technology]=
1.07, 1.15, 1.18, 1.12
Units: Fraction
Increase in likelihood to buy technology. Derived from CITE
survey data.

Elasticity of Advertising[Technology]=
Table for Price Elasticity of Advertising[Technology](Time)
Units: Dimensionless
For a 0.01 (1%) increase in the total advertising budget, an x%
increase in adoption from advertising is observed, assumed to be
0.001 (0.1%). Source, from literature: Tellis, G. 2009.
"Generalizations about Advertising Effectiveness in Markets."
Journal of Advertising Research 49(2): 240-245.

Elasticity of Training[Technology]=
Table for Price Elasticity of Training[Technology](Time)
Units: Dimensionless
In SO1, WFP paid project partners $373,826 to administer farmer
trainings. The partners trained 16,800 farmers, which equates to
an average cost of approximately $22 per farmer. Thus, an
additional $3,738 (1% increase) yields an additional 168 (1%
increase) farmers trained. Since in excess of 90% of those
trained bought a storage technology, a conservative estimate is
that a 0.01 (1%) increase in training budget yields a 0.009

(.09%) increase in adoption from training.

Exchange Rate=
3000
Units: UGX/USD
Ugandan Shillings per Dollar

Fraction of Initial Price of Technologies Unsubsidized[Technology]=
Table for Fraction of Initial Price of Technologies Unsubsidized[Technology
](Time)
Units: Fraction
The Baseline scenario assumes no price reduction over time (no
change in the unsubsidized price). Thus, the fraction is 1.

Fraction Willing to Adopt[Technology]=
Fraction Willing to Adopt Subsidized[Technology] + Fraction Willing to Adopt Unsubsidized
[Technology]
Units: Fraction

Fraction Willing to Adopt Subsidized[Technology]=
MAX(0,MIN(1,Demand Curve[Technology]) + (Switch for Access to Credit Subsidized
[Technology] * Effect of Access to Credit Subsidized[Technology]))
Units: Fraction

Fraction Willing to Adopt Unsubsidized[Technology]=
MAX(0,MIN(1,Demand Curve Unsubsidized[Technology]) + (Switch for Access to Credit Unsubsidized
[Technology] * Effect of Access to Credit Unsubsidized[Technology]))
Units: Fraction

Households Willing to Adopt Subsidized[Technology]=
Fraction Willing to Adopt Subsidized[Technology] * Technology Preference[Technology
] * Total Rural Households
Units: Households/Year

Households Willing to Adopt Unsubsidized[Technology]=
Fraction Willing to Adopt Unsubsidized[Technology] * Technology Preference
[Technology] * Total Rural Households
Units: Households

Initial Adopters[Technology]=
6766, 6362, 2400, 1075
Units: Households [0,1e+06,1000]
The initial number of adopters in the population during SO1.
Taken from WFP data for SO1.

Initial Adopters Unsubsidized[Technology]=

0,0,0,0
Units: Households

Initial Households=
6e+06
Units: Households
The initial number of total rural households, which was
approximately 6,000,000 in 2014. Source: National Population and
Housing Census 2014, Provisional Results.

Lookup for Demand Curve[SG](
[(0,0)-(151000,1)],(0,1),(11000,0.96129),(12000,0.95484),(13000,0.94194),(
17000,0.93548),(19000,0.92903),(20000,0.91613),(21000,0.86452),(23000,0.85806
),(26000,0.82581),(29000,0.81935),(31000,0.72258),(32000,0.67742),(33000,0.66452
),(35000,0.65806),(36000,0.64516),(39000,0.63871),(41000,0.54194),(46000,0.50968
),(51000,0.35484),(52000,0.34839),(55000,0.34194),(56000,0.33548),(57000,0.32903
),(61000,0.25806),(64000,0.25161),(65000,0.24516),(66000,0.21935),(71000,0.17419
),(73000,0.16774),(81000,0.12258),(82000,0.11613),(86000,0.10323),(91000,0.08387
),(101000,0.0129),(103000,0.00645),(151000,0))
Lookup for Demand Curve[PS](
[(0,0)-(231000,1)],(0,1),(26000,0.97605),(31000,0.9521),(36000,0.94012),(
39000,0.93413),(41000,0.90419),(45000,0.8982),(46000,0.89222),(51000,0.81437
),(56000,0.8024),(57000,0.71856),(61000,0.63473),(66000,0.62874),(67000,0.62275
),(71000,0.5509),(76000,0.53293),(79000,0.52695),(81000,0.4491),(91000,0.41317
),(96000,0.40719),(101000,0.24551),(111000,0.23952),(116000,0.23353),(121000
,0.18563),(131000,0.16766),(151000,0.11377),(161000,0.10778),(166000,0.09581
),(171000,0.08982),(181000,0.07186),(186000,0.04192),(191000,0.02994),(201000
,0.00599),(231000,0))
Lookup for Demand Curve[MMS](
[(0,0)-(531000,1)],(0,1),(31000,0.99375),(41000,0.9875),(51000,0.9375),(56000
,0.93125),(57000,0.925),(71000,0.90625),(76000,0.9),(81000,0.85625),(91000
,0.85),(101000,0.7625),(111000,0.75),(116000,0.74375),(119000,0.73125),(121000
,0.69375),(130000,0.66875),(131000,0.65),(136000,0.64375),(141000,0.61875)
,(151000,0.4625),(161000,0.45625),(162000,0.45),(171000,0.4375),(176000,0.43125
),(181000,0.39375),(191000,0.3875),(201000,0.2375),(211000,0.23125),(216000
,0.225),(221000,0.21875),(231000,0.20625),(251000,0.16875),(301000,0.125),
(321000,0.11875),(331000,0.10625),(341000,0.1),(351000,0.08125),(401000,0.04375
),(411000,0.0375),(421000,0.03125),(431000,0.025),(451000,0.0125),(501000,
0.00625),(531000,0))
Lookup for Demand Curve[LMS](
[(0,0)-(781000,1)],(0,1),(41000,0.99371),(51000,0.98742),(56000,0.98113),
(61000,0.97484),(71000,0.96855),(81000,0.96226),(91000,0.94969),(101000,0.8805
),(121000,0.83019),(131000,0.81132),(151000,0.76101),(171000,0.74843),(176000
,0.74214),(177000,0.73585),(181000,0.71069),(187000,0.7044),(191000,0.68553
),(201000,0.54717),(221000,0.54088),(241000,0.53459),(251000,0.45283),(261000
,0.44654),(271000,0.44025),(281000,0.42767),(291000,0.42138),(301000,0.28302

),(321000,0.27673),(351000,0.25157),(361000,0.24528),(381000,0.23899),(391000
,0.2327),(401000,0.18239),(451000,0.13208),(461000,0.12579),(488000,0.1195
),(501000,0.05031),(531000,0.04403),(551000,0.03774),(581000,0.02516),(601000
,0.01258),(751000,0.00629),(781000,0))
Units: Fraction

Lookup for Demand Curve Unsubsidized[SG](
[(0,0)-(151000,1)],(0,1),(11000,0.96129),(12000,0.95484),(13000,0.94194),(
17000,0.93548),(19000,0.92903),(20000,0.91613),(21000,0.86452),(23000,0.85806
),(26000,0.82581),(29000,0.81935),(31000,0.72258),(32000,0.67742),(33000,0.66452
),(35000,0.65806),(36000,0.64516),(39000,0.63871),(41000,0.54194),(46000,0.50968
),(51000,0.35484),(52000,0.34839),(55000,0.34194),(56000,0.33548),(57000,0.32903
),(61000,0.25806),(64000,0.25161),(65000,0.24516),(66000,0.21935),(71000,0.17419
),(73000,0.16774),(81000,0.12258),(82000,0.11613),(86000,0.10323),(91000,0.08387
),(101000,0.0129),(103000,0.00645),(151000,0))
Lookup for Demand Curve Unsubsidized[PS](
[(0,0)-(231000,1)],(0,1),(26000,0.97605),(31000,0.9521),(36000,0.94012),(
39000,0.93413),(41000,0.90419),(45000,0.8982),(46000,0.89222),(51000,0.81437
),(56000,0.8024),(57000,0.71856),(61000,0.63473),(66000,0.62874),(67000,0.62275
),(71000,0.5509),(76000,0.53293),(79000,0.52695),(81000,0.4491),(91000,0.41317
),(96000,0.40719),(101000,0.24551),(111000,0.23952),(116000,0.23353),(121000
,0.18563),(131000,0.16766),(151000,0.11377),(161000,0.10778),(166000,0.09581
),(171000,0.08982),(181000,0.07186),(186000,0.04192),(191000,0.02994),(201000
,0.00599),(231000,0))
Lookup for Demand Curve Unsubsidized[MMS](
[(0,0)-(531000,1)],(0,1),(31000,0.99375),(41000,0.9875),(51000,0.9375),(56000
,0.93125),(57000,0.925),(71000,0.90625),(76000,0.9),(81000,0.85625),(91000
,0.85),(101000,0.7625),(111000,0.75),(116000,0.74375),(119000,0.73125),(121000
,0.69375),(130000,0.66875),(131000,0.65),(136000,0.64375),(141000,0.61875)
,(151000,0.4625),(161000,0.45625),(162000,0.45),(171000,0.4375),(176000,0.43125
),(181000,0.39375),(191000,0.3875),(201000,0.2375),(211000,0.23125),(216000
,0.225),(221000,0.21875),(231000,0.20625),(251000,0.16875),(301000,0.125),
(321000,0.11875),(331000,0.10625),(341000,0.1),(351000,0.08125),(401000,0.04375
),(411000,0.0375),(421000,0.03125),(431000,0.025),(451000,0.0125),(501000,
0.00625),(531000,0))
Lookup for Demand Curve Unsubsidized[LMS](
[(0,0)-(781000,1)],(0,1),(41000,0.99371),(51000,0.98742),(56000,0.98113),
(61000,0.97484),(71000,0.96855),(81000,0.96226),(91000,0.94969),(101000,0.8805
),(121000,0.83019),(131000,0.81132),(151000,0.76101),(171000,0.74843),(176000
,0.74214),(177000,0.73585),(181000,0.71069),(187000,0.7044),(191000,0.68553
),(201000,0.54717),(221000,0.54088),(241000,0.53459),(251000,0.45283),(261000
,0.44654),(271000,0.44025),(281000,0.42767),(291000,0.42138),(301000,0.28302
),(321000,0.27673),(351000,0.25157),(361000,0.24528),(381000,0.23899),(391000
,0.2327),(401000,0.18239),(451000,0.13208),(461000,0.12579),(488000,0.1195
),(501000,0.05031),(531000,0.04403),(551000,0.03774),(581000,0.02516),(601000
,0.01258),(751000,0.00629),(781000,0))

Units: Fraction

Net Rural Household Increase=
1.025
Units: Households/Year
The net increase in the number of rural households per year. For rural Uganda, the net household increase for 2014 is 2.5%. For the BAU case, this is assumed constant. Source: National Population and Housing Census 2014, Provisional Results.

Potential Adopters[Technology]= INTEG (
MAX(0, Households Willing to Adopt Subsidized[Technology] - (Adoption Rate Subsidized [Technology]*TIME STEP) - (Adoption Rate Unsubsidized[Technology]*TIME STEP
)),
1.2e+06)
Units: Households
The potential adopter population is the total population willing to buy the product, less those who already have, and constrained to be nonnegative. At the moment, the initial value is an assumption: there were approximately 6 million rural households in 2014, and only about 20% lived in areas where WFP SO1 operated (21 / 112 districts = 18.75 % of districts), so this comes out to approximately 1.2 million potential adopter households. If WFP can provide a list of the 21 districts in which they operated for SO1, we can input a more accurate initial value.

"Price Increase, 50% by 2019"[Technology]=
"Table for Price Increase, 50% by 2019"[Technology](Time)
Units: $/unit

Price of Technology Subsidized[Technology]=
Switch for Price Increase Subsidized[Technology] * "Price Increase, 50% by 2019" [Technology] + (1-Switch for Price Increase Subsidized[Technology
]) * Table for Price of Technologies Subsidized[Technology](Time)
Units: UGX/unit

Price of Technology Unsubsidized[Technology]=
0.66 * Table for Price of Technologies Unsubsidized[Technology](Time) * Fraction of Initial Price of Technologies Unsubsidized
[Technology]
Units: UGX/unit

Probability of Contact with Adopters[Technology]=
Adopters Subsidized[Technology]/Total Rural Households
Units: Dimensionless

In the Bass model, we assume that the population is well mixed,
so that the probability of contacting an adopter is simply the
proportion of adopters to the total household population.

Social Contacts[Technology]=
Contact Rate[Technology] * Potential Adopters[Technology] * Switch for Contact Rate
[Technology]
Units: Household/Year
The total number of contacts generated by the potential adopters
each year is determined by the size of the potential adopter
population and the average number of contacts each person has
per year (the Contact Rate, c).

Sum of Available Inventory Total=
SUM(Available Inventory Total[Technology!])
Units: Units/Year

Switch for Access to Credit Subsidized[Technology]=
0,0,0,0
Units: Dimensionless
0 when switched off, 1 when switched on. Should be off, 0, in
Baseline scenario.

Switch for Access to Credit Unsubsidized[Technology]=
0,0,0,0
Units: Dimensionless
0 when switched off, 1 when switched on. Should be off, 0, in
Baseline scenario.

Switch for Advertising[Technology]=
0,0,0,0
Units: Dimensionless
0 when switched off, 1 when switched on. Should be off, 0, in
Baseline scenario.

Switch for Contact Rate[Technology]=
1,1,1,1
Units: Dimensionless
0 when switched off, 1 when switched on. Should be on, 1, in
Baseline scenario.

Switch for Price Increase Subsidized[Technology]=
0,0,0,0
Units: Dimensionless
0 when switched off, 1 when switched on. Should be off, 0, in
Baseline scenario.

Table for Fraction of Initial Price of Technologies Unsubsidized[SG](
[(2014,0.6)-(2025,1)],(2014,1),(2015,0.97),(2016,0.94),(2017,0.91),(2018,0.88
),(2019,0.85),(2020,0.82),(2021,0.79),(2022,0.76),(2023,0.73),(2024,0.7),(2025
,0.67))
Table for Fraction of Initial Price of Technologies Unsubsidized[PS](
[(2014,0.6)-(2025,1)],(2014,1),(2015,0.97),(2016,0.94),(2017,0.91),(2018,
0.88),(2019,0.85),(2020,0.82),(2021,0.79),(2022,0.76),(2023,0.73),(2024,0.7
),(2025,0.67))
Table for Fraction of Initial Price of Technologies Unsubsidized[MMS](
[(2014,0.6)-(2025,1)],(2014,1),(2015,0.97),(2016,0.94),(2017,0.91),(2018,
0.88),(2019,0.85),(2020,0.82),(2021,0.79),(2022,0.76),(2023,0.73),(2024,0.7
),(2025,0.67))
Table for Fraction of Initial Price of Technologies Unsubsidized[LMS](
[(2014,0.6)-(2025,1)],(2014,1),(2015,0.97),(2016,0.94),(2017,0.91),(2018,
0.88),(2019,0.85),(2020,0.82),(2021,0.79),(2022,0.76),(2023,0.73),(2024,0.7
),(2025,0.67))
Units: Fraction

"Table for Price Increase, 50% by 2019"[SG](
[(2014,30000)-(2025,50000)],(2014,31000),(2015,34100),(2016,37200),(2017,40300
),(2018,43400),(2019,46500),(2020,46500),(2021,46500),(2022,46500),(2023,46500
),(2024,46500),(2025,46500))
"Table for Price Increase, 50% by 2019"[PS](
[(2014,50000)-(2025,90000)],(2014,56000),(2015,61600),(2016,67200),(2017,
72800),(2018,78400),(2019,84000),(2020,84000),(2021,84000),(2022,84000),(2023
,84000),(2024,84000),(2025,84000))
"Table for Price Increase, 50% by 2019"[MMS](
[(2014,100000)-(2025,200000)],(2014,129500),(2015,142450),(2016,155400),(
2017,168350),(2018,181300),(2019,194200),(2020,194200),(2021,194200),(2022
,194200),(2023,194200),(2024,194200),(2025,194200))
"Table for Price Increase, 50% by 2019"[LMS](
[(2014,100000)-(2025,300000)],(2014,176500),(2015,194150),(2016,211800),(
2017,229450),(2018,247100),(2019,264800),(2020,264800),(2021,264800),(2022
,264800),(2023,264800),(2024,264800),(2025,264800))
Units: UGX/unit

Table for Price of Technologies Subsidized[SG](
[(2014,0)-(2025,200000)],(2014,31000),(2015,51000),(2016,71400),(2017,81600
),(2018,91800),(2019,102000),(2020,102000),(2021,102000),(2022,102000),(2023
,102000),(2024,102000),(2025,102000))
Table for Price of Technologies Subsidized[PS](
[(2014,0)-(2025,200000)],(2014,56000),(2015,92500),(2016,129500),(2017,148000
),(2018,166500),(2019,185000),(2020,185000),(2021,185000),(2022,185000),(2023
,185000),(2024,185000),(2025,185000))
Table for Price of Technologies Subsidized[MMS](

[(2014,0)-(2025,500000)],(2014,129500),(2015,215000),(2016,301000),(2017,344000),(2018,387000),(2019,430000),(2020,430000),(2021,430000),(2022,430000),(2023,430000),(2024,430000),(2025,430000))

Table for Price of Technologies Subsidized[LMS](
[(2014,0)-(2025,600000)],(2014,176500),(2015,293500),(2016,410900),(2017,469600),(2018,528300),(2019,587000),(2020,587000),(2021,587000),(2022,587000),(2023,587000),(2024,587000),(2025,587000))

Units: UGX/unit

Prices includes 2 plastic sheets. 70% subsidized price in SO1,
50% subsidized price in S02 and following.

Table for Price of Technologies Unsubsidized[SG](
[(2014,100000)-(2025,200000)],(2014,102000),(2015,102000),(2016,102000),(2017,102000),(2018,102000),(2019,102000),(2020,102000),(2021,102000),(2022,102000),(2023,102000),(2024,102000),(2025,102000))

Table for Price of Technologies Unsubsidized[PS](
[(2014,100000)-(2025,200000)],(2014,185000),(2015,185000),(2016,185000),(2017,185000),(2018,185000),(2019,185000),(2020,185000),(2021,185000),(2022,185000),(2023,185000),(2024,185000),(2025,185000))

Table for Price of Technologies Unsubsidized[MMS](
[(2014,400000)-(2025,500000)],(2014,430000),(2015,430000),(2016,430000),(2017,430000),(2018,430000),(2019,430000),(2020,430000),(2021,430000),(2022,430000),(2023,430000),(2024,430000),(2025,430000))

Table for Price of Technologies Unsubsidized[LMS](
[(2014,500000)-(2025,600000)],(2014,587000),(2015,587000),(2016,587000),(2017,587000),(2018,587000),(2019,587000),(2020,587000),(2021,587000),(2022,587000),(2023,587000),(2024,587000),(2025,587000))

Units: UGX

Prices includes 2 plastic sheets

Table for Technology Preference[SG](
[(2014,0.2)-(2025,0.3)],(2014,0.25),(2015,0.25),(2016,0.25),(2017,0.25),(2018,0.25),(2019,0.25),(2020,0.25),(2021,0.25),(2022,0.25),(2023,0.25),(2024,0.25),(2025,0.25))

Table for Technology Preference[PS](
[(2014,0.3)-(2025,0.4)],(2014,0.35),(2015,0.35),(2016,0.35),(2017,0.35),(2018,0.35),(2019,0.35),(2020,0.35),(2021,0.35),(2022,0.35),(2023,0.35),(2024,0.35),(2025,0.35))

Table for Technology Preference[MMS](
[(2014,0.3)-(2025,0.4)],(2014,0.34),(2015,0.34),(2016,0.34),(2017,0.34),(2018,0.34),(2019,0.34),(2020,0.34),(2021,0.34),(2022,0.34),(2023,0.34),(2024,0.34),(2025,0.34))

Table for Technology Preference[LMS](
[(2014,0.05)-(2025,0.06)],(2014,0.06),(2015,0.06),(2016,0.06),(2017,0.06),(2018,0.06),(2019,0.06),(2020,0.06),(2021,0.06),(2022,0.06),(2023,0.06),(2024,0.06),(2025,0.06))

Units: Fraction

Technology Preference[Technology]=
Table for Technology Preference[Technology](Time)
Units: Fraction
Source: WFP, "Qual write-up - WFP"

TIME STEP = 0.0625
Units: Year [0,?]
The time step for the simulation.

Total Rural Households= INTEG (
Net Rural Household Increase,
Initial Households)
Units: Households
The total number of households.

Adoption Fraction from Advertising[Technology]=
Table for Adoption Fraction from Advertising[Technology](Time)
Units: Fraction
The fraction of the population adopting each year as the result
of hearing an advertisement.

Adoption Fraction from Training[Technology]=
Table for Adoption Fraction from Training[Technology](Time)
Units: Fraction
The fraction of the population adopting each year as the result
of attending a training. Assumed to be held constant at SO1
levels: that is, adoption fraction = adopters in SO1[technology]
(SG:6766, PS:6363, MMS:2400, LMS:1075) / potential adopters in
SO1 (1,200,000).

Adoption Fraction from Word of Mouth[Technology]=
Table for Adoption Fraction from Word of Mouth[Technology](Time)
Units: Fraction
The probability of adoption given a word of mouth contact with
an adopter. Assumed to be 0.005 for all technologies.

Annual Budget for Advertising[Technology]=
Table for Combined Donor and Private Sector Annual Budget for Advertising[
Technology](Time)
Units: Fraction
Assumed to increase annually by 3%. Budget is normalized, to 1 =
budget in SO1.

Annual Budget for Training[Technology]=

Table for Combined Donor and Private Sector Annual Budget for Training[Technology
](Time)
Units: Fraction
Assumed to grow at an annual increase of 3%. Budget is
normalized, to 1 = budget in SO1.

Available Inventory Subsidized[Technology]=
(Available Inventory Total[Technology] * Subsidized Inventory as a Fraction of Total Inventory
[Technology] * (1 - Switch for SO1 Levels
[Technology])) + (Available Inventory Subsidized at SO1 Levels[Technology]
* Switch for SO1 Levels[Technology])
Units: Units/Year
Driven by the donor budget allocated to a subsidy. Currently
assumed to decrease by 10% annually.

Available Inventory Subsidized at SO1 Levels[Technology]=
15000,90144,2175,863
Units: Units/Year
Holds subsidized inventory constant at SO1 levels.

Available Inventory Total[Technology]=
(Table for Inventory Available to Adopters[Technology](Time) * (1 - (Switch for Customized Contracts
[Technology]))) + (
Effect of Customized Contracts on Availability[Technology] * Table for Inventory Available to Adopters
[Technology](Time)
* Switch for Customized Contracts[Technology])
Units: Units/Year
SG units are assumed to be sold in units of 4, as in SO1.
Therefore, 15,000 in SO1 reflects 15,000 purchases ("units") but
60,000 bags, which is the reported buffer stock from ASKAR in
Kampala in SO1 ("PHFS input data sheet.xlsx). For SG, production
capacity (functionally, local inventory) is assumed to increase
by an additional 20,000 bags (5,000 units) annually. For PS, MMS
and LMS, production capacity is assumed to increase by 10%
annually.

Available Inventory Unsubsidized[Technology]=
Available Inventory Total[Technology] - Available Inventory Subsidized[Technology
]
Units: Units/Year

Effect of Customized Contracts on Availability[Technology]=
1,1,1.2,1.2
Units: Dimensionless
Increases manufacturing capacity (functionally, available
inventory) by 20%. Only applicable to metal silo producers.

Based on behavioral operations experiment run by Scalability team.

Elasticity of Advertising[Technology]=
Table for Price Elasticity of Advertising[Technology](Time)
Units: Dimensionless
For a 0.01 (1%) increase in the total advertising budget, an x% increase in adoption from advertising is observed, assumed to be 0.001 (0.1%). Source, from literature: Tellis, G. 2009. "Generalizations about Advertising Effectiveness in Markets." Journal of Advertising Research 49(2): 240-245.

Elasticity of Training[Technology]=
Table for Price Elasticity of Training[Technology](Time)
Units: Dimensionless
In SO1, WFP paid project partners $373,826 to administer farmer trainings. The partners trained 16,800 farmers, which equates to an average cost of approximately $22 per farmer. Thus, an additional $3,738 (1% increase) yields an additional 168 (1% increase) farmers trained. Since in excess of 90% of those trained bought a storage technology, a conservative estimate is that a 0.01 (1%) increase in training budget yields a 0.009 (.09%) increase in adoption from training.

Subsidized Inventory as a Fraction of Total Inventory[Technology]=
Table for Subsidized Inventory as a Fraction of Total Inventory[Technology
](Time)
Units: Units/Year

Sum of Available Inventory Total=
SUM(Available Inventory Total[Technology!])
Units: Units/Year

Switch for Customized Contracts[Technology]=
0,0,0,0
Units: Dimensionless
0 when switched off, 1 when switched on. Should be off, 0, in Baseline scenario.

Switch for SO1 Levels[Technology]=
0,0,0,0
Units: Dimensionless
0 when switched off, 1 when switch on. Should be off, 0, in Baseline scenario.

Table for Adoption Fraction from Advertising[SG](

[(2014,0.007)-(2025,0.008)],(2014,0),(2015,0.0075),(2016,0.0075),(2017,0.0075
),(2018,0.0075),(2019,0.0075),(2020,0.0075),(2021,0.0075),(2022,0.0075),(2023
,0.0075),(2024,0.0075),(2025,0.0075))

Table for Adoption Fraction from Advertising[PS](
[(2014,0.007)-(2025,0.008)],(2014,0),(2015,0.0075),(2016,0.0075),(2017,0.0075
),(2018,0.0075),(2019,0.0075),(2020,0.0075),(2021,0.0075),(2022,0.0075),(2023
,0.0075),(2024,0.0075),(2025,0.0075))

Table for Adoption Fraction from Advertising[MMS](
[(2014,0.007)-(2025,0.008)],(2014,0),(2015,0.0075),(2016,0.0075),(2017,0.0075
),(2018,0.0075),(2019,0.0075),(2020,0.0075),(2021,0.0075),(2022,0.0075),(2023
,0.0075),(2024,0.0075),(2025,0.0075))

Table for Adoption Fraction from Advertising[LMS](
[(2014,0.007)-(2025,0.008)],(2014,0),(2015,0.0075),(2016,0.0075),(2017,0.0075
),(2018,0.0075),(2019,0.0075),(2020,0.0075),(2021,0.0075),(2022,0.0075),(2023
,0.0075),(2024,0.0075),(2025,0.0075))

Units: Fraction

No advertising was done in 2014/SO1; hence, an adoption fraction of 0. In the future, an adoption fraction that is half the adoption fraction from word of mouth is assumed (0.0075), reflecting the assumption that a household is more likely to purchase a bag or silo based on the recommendation of someone in their social network than from a marketing advertisement.

Table for Adoption Fraction from Training[SG](
[(2014,0.005)-(2025,0.006)],(2014,0.0056),(2015,0.0056),(2016,0.0056),(2017
,0.0056),(2018,0.0056),(2019,0.0056),(2020,0.0056),(2021,0.0056),(2022,0.0056
),(2023,0.0056),(2024,0.0056),(2025,0.0056))

Table for Adoption Fraction from Training[PS](
[(2014,0.005)-(2025,0.006)],(2014,0.0053),(2015,0.0053),(2016,0.0053),(2017
,0.0053),(2018,0.0053),(2019,0.0053),(2020,0.0053),(2021,0.0053),(2022,0.0053
),(2023,0.0053),(2024,0.0053),(2025,0.0053))

Table for Adoption Fraction from Training[MMS](
[(2014,0.001)-(2025,0.003)],(2014,0.002),(2015,0.002),(2016,0.002),(2017,
0.002),(2018,0.002),(2019,0.002),(2020,0.002),(2021,0.002),(2022,0.002),(2023
,0.002),(2024,0.002),(2025,0.002))

Table for Adoption Fraction from Training[LMS](
[(2014,0.0008)-(2025,0.0009)],(2014,0.00089),(2015,0.00089),(2016,0.00089
),(2017,0.00089),(2018,0.00089),(2019,0.00089),(2020,0.00089),(2021,0.00089
),(2022,0.00089),(2023,0.00089),(2024,0.00089),(2025,0.00089))

Units: Fraction

Table for Adoption Fraction from Word of Mouth[SG](
[(2014,0)-(2025,0.02)],(2014,0.015),(2015,0.015),(2016,0.015),(2017,0.015)
,(2018,0.015),(2019,0.015),(2020,0.015),(2021,0.015),(2022,0.015),(2023,0.015
),(2024,0.015),(2025,0.015))

Table for Adoption Fraction from Word of Mouth[PS](

[(2014,0)-(2025,0.02)],(2014,0.015),(2015,0.015),(2016,0.015),(2017,0.015
),(2018,0.015),(2019,0.015),(2020,0.015),(2021,0.015),(2022,0.015),(2023,0.015
),(2024,0.015),(2025,0.015))
Table for Adoption Fraction from Word of Mouth[MMS](
[(2014,0)-(2025,0.02)],(2014,0.015),(2015,0.015),(2016,0.015),(2017,0.015
),(2018,0.015),(2019,0.015),(2020,0.015),(2021,0.015),(2022,0.015),(2023,0.015
),(2024,0.015),(2025,0.015))
Table for Adoption Fraction from Word of Mouth[LMS](
[(2014,0)-(2025,0.02)],(2014,0.015),(2015,0.015),(2016,0.015),(2017,0.015
),(2018,0.015),(2019,0.015),(2020,0.015),(2021,0.015),(2022,0.015),(2023,0.015
),(2024,0.015),(2025,0.015))
Units: Fraction

Table for Combined Donor and Private Sector Annual Budget for Advertising[SG
](
[(2014,0.9)-(2025,2)],(2014,1),(2015,1.03),(2016,1.06),(2017,1.09),(2018,1.12
),(2019,1.15),(2020,1.18),(2021,1.21),(2022,1.24),(2023,1.27),(2024,1.3),(2025
,1.33))
Table for Combined Donor and Private Sector Annual Budget for Advertising[PS
](
[(2014,0.9)-(2025,2)],(2014,1),(2015,1.03),(2016,1.06),(2017,1.09),(2018,
1.12),(2019,1.15),(2020,1.18),(2021,1.21),(2022,1.24),(2023,1.27),(2024,1.3
),(2025,1.33))
Table for Combined Donor and Private Sector Annual Budget for Advertising[MMS
](
[(2014,0.9)-(2025,2)],(2014,1),(2015,1.03),(2016,1.06),(2017,1.09),(2018,
1.12),(2019,1.15),(2020,1.18),(2021,1.21),(2022,1.24),(2023,1.27),(2024,1.3
),(2025,1.33))
Table for Combined Donor and Private Sector Annual Budget for Advertising[LMS
](
[(2014,0.9)-(2025,2)],(2014,1),(2015,1.03),(2016,1.06),(2017,1.09),(2018,
1.12),(2019,1.15),(2020,1.18),(2021,1.21),(2022,1.24),(2023,1.27),(2024,1.3
),(2025,1.33))
Units: USD/Year
Assumed to increase annually by 3%.

Table for Combined Donor and Private Sector Annual Budget for Training[SG](
[(2014,0.9)-(2025,2)],(2014,1),(2015,1.03),(2016,1.06),(2017,1.09),(2018,1.12
),(2019,1.15),(2020,1.18),(2021,1.21),(2022,1.24),(2023,1.27),(2024,1.3),(2025
,1.33))
Table for Combined Donor and Private Sector Annual Budget for Training[PS](
[(2014,0.9)-(2025,2)],(2014,1),(2015,1.03),(2016,1.06),(2017,1.09),(2018,
1.12),(2019,1.15),(2020,1.18),(2021,1.21),(2022,1.24),(2023,1.27),(2024,1.3
),(2025,1.33))
Table for Combined Donor and Private Sector Annual Budget for Training[MMS]
(

[(2014,0.9)-(2025,2)],(2014,1),(2015,1.03),(2016,1.06),(2017,1.09),(2018,
1.12),(2019,1.15),(2020,1.18),(2021,1.21),(2022,1.24),(2023,1.27),(2024,1.3
),(2025,1.33))
Table for Combined Donor and Private Sector Annual Budget for Training[LMS]
(
[(2014,0.9)-(2025,2)],(2014,1),(2015,1.03),(2016,1.06),(2017,1.09),(2018,
1.12),(2019,1.15),(2020,1.18),(2021,1.21),(2022,1.24),(2023,1.27),(2024,1.3
),(2025,1.33))
Units: USD/Year

Table for Inventory Available to Adopters[SG](
[(2014,0)-(2025,70000)],(2014,15000),(2015,20000),(2016,25000),(2017,30000
),(2018,35000),(2019,40000),(2020,45000),(2021,50000),(2022,55000),(2023,60000
),(2024,65000),(2025,70000))
Table for Inventory Available to Adopters[PS](
[(2014,0)-(2025,300000)],(2014,90144),(2015,99158),(2016,109074),(2017,119982
),(2018,131980),(2019,145178),(2020,159696),(2021,175665),(2022,193232),(2023
,212555),(2024,233810),(2025,257191))
Table for Inventory Available to Adopters[MMS](
[(2014,0)-(2025,7000)],(2014,2175),(2015,2393),(2016,2632),(2017,2895),(2018
,3184),(2019,3503),(2020,3853),(2021,4238),(2022,4662),(2023,5129),(2024,5641
),(2025,6206))
Table for Inventory Available to Adopters[LMS](
[(2014,0)-(2025,3000)],(2014,863),(2015,949),(2016,1044),(2017,1149),(2018
,1264),(2019,1390),(2020,1529),(2021,1682),(2022,1850),(2023,2035),(2024,2238
),(2025,2462))
Units: Units/Year

Table for Price Elasticity of Advertising[SG](
[(2014,0)-(2025,0.002)],(2014,0.001),(2015,0.001),(2016,0.001),(2017,0.001
),(2018,0.001),(2019,0.001),(2020,0.001),(2021,0.001),(2022,0.001),(2023,0.001
),(2024,0.001),(2025,0.001))
Table for Price Elasticity of Advertising[PS](
[(2014,0)-(2025,0.002)],(2014,0.001),(2015,0.001),(2016,0.001),(2017,0.001
),(2018,0.001),(2019,0.001),(2020,0.001),(2021,0.001),(2022,0.001),(2023,0.001
),(2024,0.001),(2025,0.001))
Table for Price Elasticity of Advertising[MMS](
[(2014,0)-(2025,0.002)],(2014,0.001),(2015,0.001),(2016,0.001),(2017,0.001
),(2018,0.001),(2019,0.001),(2020,0.001),(2021,0.001),(2022,0.001),(2023,0.001
),(2024,0.001),(2025,0.001))
Table for Price Elasticity of Advertising[LMS](
[(2014,0)-(2025,0.002)],(2014,0.001),(2015,0.001),(2016,0.001),(2017,0.001
),(2018,0.001),(2019,0.001),(2020,0.001),(2021,0.001),(2022,0.001),(2023,0.001
),(2024,0.001),(2025,0.001))
Units: Dimensionless

Table for Price Elasticity of Training[SG](
[(2014,0.008)-(2025,0.009)],(2014,0.009),(2015,0.009),(2016,0.009),(2017,0.009
),(2018,0.009),(2019,0.009),(2020,0.009),(2021,0.009),(2022,0.009),(2023,0.009
),(2024,0.009),(2025,0.009))
Table for Price Elasticity of Training[PS](
[(2014,0.008)-(2025,0.009)],(2014,0.009),(2015,0.009),(2016,0.009),(2017,
0.009),(2018,0.009),(2019,0.009),(2020,0.009),(2021,0.009),(2022,0.009),(2023
,0.009),(2024,0.009),(2025,0.009))
Table for Price Elasticity of Training[MMS](
[(2014,0.008)-(2025,0.009)],(2014,0.009),(2015,0.009),(2016,0.009),(2017,
0.009),(2018,0.009),(2019,0.009),(2020,0.009),(2021,0.009),(2022,0.009),(2023
,0.009),(2024,0.009),(2025,0.009))
Table for Price Elasticity of Training[LMS](
[(2014,0.008)-(2025,0.009)],(2014,0.009),(2015,0.009),(2016,0.009),(2017,
0.009),(2018,0.009),(2019,0.009),(2020,0.009),(2021,0.009),(2022,0.009),(2023
,0.009),(2024,0.009),(2025,0.009))
Units: Dimensionless

Table for Subsidized Inventory as a Fraction of Total Inventory[SG](
[(2014,0)-(2025,1)],(2014,1),(2015,1),(2016,1),(2017,1),(2018,1),(2019,0),
(2020,0),(2021,0),(2022,0),(2023,0),(2024,0),(2025,0))
Table for Subsidized Inventory as a Fraction of Total Inventory[PS](
[(2014,0)-(2025,1)],(2014,1),(2015,1),(2016,1),(2017,1),(2018,1),(2019,0)
,(2020,0),(2021,0),(2022,0),(2023,0),(2024,0),(2025,0))
Table for Subsidized Inventory as a Fraction of Total Inventory[MMS](
[(2014,0)-(2025,1)],(2014,1),(2015,1),(2016,1),(2017,1),(2018,1),(2019,0)
,(2020,0),(2021,0),(2022,0),(2023,0),(2024,0),(2025,0))
Table for Subsidized Inventory as a Fraction of Total Inventory[LMS](
[(2014,0)-(2025,1)],(2014,1),(2015,1),(2016,1),(2017,1),(2018,1),(2019,0)
,(2020,0),(2021,0),(2022,0),(2023,0),(2024,0),(2025,0))
Units: Units/Year