Willingness to Pay for Hermetic Grain Storage Bags in Malawi

W.A. Masters[1]; G. Guevara Alvarez[2]

1: Tufts University, Friedman School of Nutrition, United States of America, 2: Tufts University, Friedman School of Nutrition Science and Policy, United States of America

Corresponding author email: william.masters@tufts.edu

Abstract:

This study estimates willingness to pay (WTP) for hermetic grain storage bags in a sample of 116 very low-income farmers, about half of whom had attended bag-use demonstrations designed to demonstrate how these bags prevent damage from mold and insects. WTP was measured using Becker-DeGroot-Marschak (BDM) auctions, accompanied by a survey regarding respondents' education, household wealth and knowledge about aflatoxins that are released when mold is allowed to grow on the grain. We found a mean WTP of 311 Kwacha ($0.42) for one bag, well below the market price around 750 Kwacha, and no significant association between a respondent's WTP and their attendance at bag-use demonstrations, aflatoxin knowledge or education and wealth. At current market prices, we found no evidence that these bags would be commercially marketable in these communities, even after bag-use demonstrations. A systematic review of the literature suggests that commercial sales of hermetic bags may be possible for buyers in areas of less extreme poverty, where households are more able to make such investments in pursuit of longer-term payoffs in food safety and storage.

Acknowledegment: This report was funded by the American people through the United States Agency for International Development (USAID) via Cooperative Agreements AID-FFP-A-14-00006 and AID-OAA-A-15-00019 to Catholic Relief Services (CRS) for the UBALE project. We are grateful to all respondents, UBALE partners and CRS-Malawi staff for their help, and especially thank Angela Tavares and Juma Masumba for their guidance and support. Ethical approval was obtained from the Tufts University IRB as study #1703012, and from the Malawi National Commission for Science and Technology as Protocol P.06/17/181. Contents do not necessarily reflect the views of CRS, USAID or the United States Government.

JEL Codes: D12, O33

#1573

Willingness to Pay for Hermetic Grain Storage Bags in Malawi

Motivation

Malawi is among the world's poorest countries, ranked 170th out of 188 countries by the UN Human Development Index (UNDP, 2017). Rapid population growth and many other factors have contributed to persistent food insecurity, particularly in hungry seasons just before harvest, and extremely poor diet quality with little diversification away from maize, the lowest-cost starchy staple (FAO, 2016; Tefera, 2012; Oerke & Dehne, 2004).

On-farm storage of maize plays an important role in local food security, due to the seasonality of production and farmers' inability to buy from markets during periods of food scarcity (CIMMYT, 2011). Farmers who grow grain typically sell some after harvest to raise cash for non-food needs, and store as much as they can afford to keep for own consumption later in the year. Relatively few households are able to meet all their needs for the entire year, and must fall back on a variety of coping strategies especially in years of poor harvests.

This study focuses on opportunities for households to meet food and nutrition needs by reducing post-harvest loss, in terms of both volume and quality. The rate of loss depends on both initial conditions when grain is drying in the field, and the progression of damage that might occur after grain is removed and placed in a bin or other location where it may be exposed to microbes, insects, rodents and other harms (Schulten, 1975). Some losses affect only the volume and weight of grain, but most damage involves a loss of nutritional quality or economic value per unit (Tefera, 2012). In the Malawian context, the most common combination of harms is that grains are damaged by insects or rodents which then facilitates the mold growth (Nyambo, 1993).

The central policy initiative of the Malawian government to address food insecurity is the provision of subsidized fertilizer and maize seeds to raise production, with little attention to post-harvest losses. Tefera (2012) suggests that 14-36% of all maize is lost after harvest, from the combination of insect or rodent damage and microbial contamination. Damage levels vary widely with humidity and temperature as well as grain handling practices that either protect or expose the stock to pests and mold (Kaaya et al., 2006; De Groote, 2016). Crop variety also influences damage levels, as higher-yielding new varieties may have softer grains that are more susceptible to loss (Schulten 1975).

The most widespread traditional method to protect maize is to dry it on the cob, store the whole cob in a bin protected from rain and rodents, and then shell the grain off its cob just before its final end-use (Golob, 1988 and Schulten, 1982). Other longstanding methods include mixing the shelled grain with ash or sand; fumigating bags of grain with botanical or

chemical compounds such as phosphine (hydrogen phosphide); or heating grain to disinfect it using a solar device or other energy source (CIMMYT, 2011; Tefera, 2012).

A newer approach to post-harvest protection is hermetic storage, by which oxygen barriers limit the growth of insects or microbes inside the storage unit. The principal type of hermetic storage now being distributed to farmers in Africa through development assistance programs is the Purdue Improved Crops Storage (PICS) bags, developed at Purdue University in the 1990s and widely distributed across various African countries (Murdock, 2016). A somewhat different style of hermetic storage bag is designed and sold by GrainPro, a U.S.-based firm specialized in post-harvest handling whose manufacturing facilities are in the Philippines (GrainPro, 2017). Other hermetic bags sold in Africa include ZeroFly bags from Vestergaard, a Danish firm that also makes mosquito nets and water purification devices, AgroZ bags made by A to Z Textile Mills in Tanzania, and Elite Storage Bags from an agricultural input supplier in Kenya (KAAA, 2017).

A number of studies address the efficacy of hermetic storage bags, such as de Groote (2014) and Tefera (2012). A key feature of the approach is that bags are reusable and do not require purchase of chemical treatments. Murdoch (2016) points out that chemical free options like PICS instead of fumigants are important because grain is often stored within the home, including sleeping rooms. Hard-sided barrels or silos outside the home, whether or not they are hermetically sealed, are more durable and silos are more efficient for long-term, high-volume storage (CIMMYT 2011), but they involve much larger installation costs and not suited to the small volumes stored by individual farmers in Malawi and other African countries.

The rate of loss with PICS bags ranges from 0-5% after 5 months, depending on local conditions and the level of initial infestation; the most common pests are the maize weevil *Sitophilus zeamais* and the larger grain borer *Prostephanus truncatus* (Meikle, 2000; Tefera, 2012; IGENAES, 2016). As noted by CIMMYT (2011), the bags' hermetic seal can be broken by the larger grain borer and other pests, so longer term efficacy requires protection against perforation. Beyond loss of weight, grain quality is often compromised by mold growth, especially when grain is damaged by insects.

Hermetic storage limits growth of mold as well as insects, thereby limiting release of mycotoxins, especially aflatoxins produced by *Aspergillus flavus* and *Aspergillus parasiticus* (IARC, 2012). It is common for many types of toxin-producing mold to grow together on maize, groundnuts, and other crops, with the most common type in Malawi being aflatoxins (Matumba et al., 2009; Monyo, 2012; Matumba et al., 2014; Mwalwayo, 2016). For example, a study of stored maize in villages in Lilongwe detected aflatoxin in 45.3% of the samples analyzed (Matumba, 2009). Another study of processed foods produced in Malawi

examined locally produced instant baby cereals and found that 100% of the samples had levels of aflatoxin above the EU maximum tolerable level (Matumba et al., 2014).

Chronic aflatoxin consumption carries significant health consequences. The International Agency for Research on Cancer classifies aflatoxin as a Group-1 carcinogen based on strong evidence that aflatoxin causes liver cancer, especially in people with hepatitis B (IARC, 2012). Aflatoxin has also been linked to immunosuppression and increased disease susceptibility (Gong, 2016). Consumption of aflatoxin can be especially harmful for young children, and has been linked to child stunting (Gong, 2002; Smith, 2015). De Groote (2016) finds that consumers are notice mold and are willing to pay less for damaged grain.

The aim of this study is to elicit farmers' willingness to pay (WTP) for hermetic storage bags that would protect their grain from post-harvest losses. WTP is sometimes addressed directly, by asking respondents for their stated preferences using a variety of direct and open-ended questions. Hypothetical choices can be useful for ranking hypothetical scenarios, but responses often fail to predict actual choices in made in real life. The most successful way to elicit underlying preferences for specific products is to offer that item in an auction that mimics actual market conditions.

Method

This study elicited farmers' willingness to pay for hermetic grain storage bags using the random-price auction design of Becker, DeGroot and Marschak (1964). The Becker-DeGroot-Marschak (BDM) approach elicits WTP from individual respondents in a survey setting, and has been widely used to measure demand for many kinds of products around the world. The method mimics real-life markets by making the respondent's stated willingness to pay determine whether they actually obtain the product during the interview, at a given price that the buyer cannot influence. This reveals the maximum price at which the respondent would buy the product if it were for sale. To achieve this in an interview setting, respondents are invited to record a bid at which they are willing to buy the product, knowing that the interviewer then draws a random price which, if it is lower than the respondent's bid, triggers a purchase at that randomly drawn price.

The BDM auction process is known to predict actual market behavior more accurately than other types of surveys, because it is always in the respondent's self-interest to state the highest value they can actually afford to pay. Once respondents learn how the BDM auction works, they realize they want to avoid stating a bid higher than what they are willing and able to pay, since that would lead to a regretted purchase if the randomly drawn price falls between that bid and their true WTP. They also realize that they want to avoid stating a lower bid, since that would lead to missing a bargain if the randomly drawn price falls

between that lower bid and their true WTP. It is always in the respondent's interest to bid their actual WTP, whatever that may be.

For the BDM auction in this study, we conducted practice rounds offering a low-cost bar of laundry soap, and allowed respondents to bid for the storage bags only if they could answer basic comprehension questions about how the auction works. Soap is an effective practice instrument because it is routinely purchased by all surveyed households, at varying prices on the order of USD 0.05-0.10 per bar depending on convenience, quality and other aspects of the retail transactions. Some respondents usually buy soap in bulk at the lowest-cost retailers that may be far from home, while others must pay more for smaller units close by when they most need it and can afford to buy. In the practice auction, it was clear to each respondent what would have been the opportunity cost to them of not buying during the interview, and almost all could quickly obtain the very small amount of cash needed to buy the soap if they wish. After the practice auction, participants were asked the basic comprehension questions and all but one demonstrated clear understanding, thereby establishing the ethical nature and validity of the process.

The auction for PICS bags was identical to the auction for soap, except that a bag's market value is an order of magnitude higher. The market price in town of the PICS bag at the time of our interview was on the order of one US dollar. Respondents had varying degrees of familiarity with the bag and its value, depending in part on whether they attended a bag-use demonstration at which its efficacy was described. Respondents also had varying degrees of knowledge and concern about aflatoxins, and different cash flow situations that could influence whether they can buy the bags on the date of the interview. When interview dates were set and informed consent was obtained through a pre-survey visit to the household, respondents were informed that the survey would include an opportunity to purchase one or more PICS bags for cash on the spot if they wished to do so. This ensured that respondents who might be able and willing to buy could plan ahead to have the cash on hand. Prior to the auction, respondents were asked if they had sufficient cash to cover any bids they might choose to make, and were invited to continue only if they were able and willing to have the required funds on hand. Respondents were also free to end their participation in the interview and not participate in the auction for any other reason.

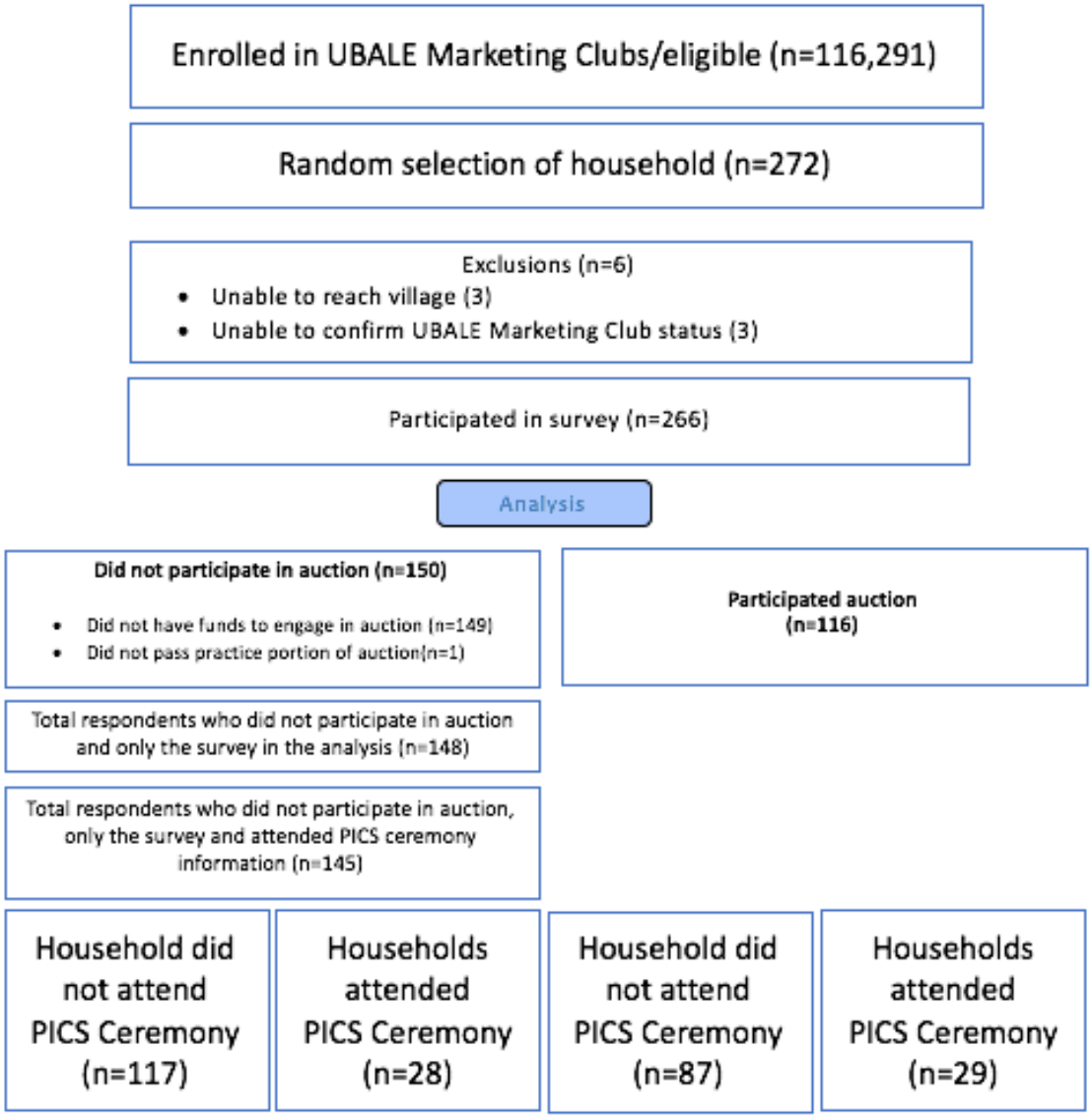
The specific PICS bag being auctioned could hold 50 kg of grain, which is a typical storage volume for convenient handling in this context. Respondents whose bids led to a purchase were offered the opportunity to bid again, and participate in the auction up to three times and thereby purchase a maximum of three bags. The specific script we use was modeled on the BDM auction being conducted at approximately the same time on Grain Pro bags in India (Shukla, 2017), for comparability between the two results.

The auction was conducted in three districts of the country, Nsanje, Chikwawa, and Blantyre Rural, among participants in a development program providing maternal and child health services including education about the nature of crop damage, including especially the hidden health consequences of toxins from mold growth. Our data will be used to guide future interventions aimed at the subsidized or commercial distribution of hermetic bags and other storage options, as well as related work in populations like our survey respondents to improve food security and food safety after harvest.

Data

Our data were obtained in June and July 2017, from a survey with a two-stage cluster sampling design. The population of interest is individuals who are enrolled in the marketing clubs of the UBALE program managed by Catholic Relief Services with funding from the US Agency for International Development, in collaboration with different local implementing partners in each of the three districts. Sample size in each district is proportional to the total number of such individuals (one per household) in each district: Blantyre Rural 26%, Chikwawa 52%, and Nsanje 22%. Total magnitude was dictated by budget and logistical constraints. For this survey, we were able to conduct 4 interviews each day in a given village, have surveyors visit 4 different villages each day, and remain in the field for 17 working days, giving a maximum sample size of 272. Within each district, villages are organized into groups under the administrative leadership of a Group Village Head (GVH), spanning several villages each with a roster of enrolled individuals. We assigned each a random number, ordered from smallest to largest, and selected each GVH, village, and household accordingly. The selection process is illustrated in Figure 1.

Figure 1. Sampling frame and sample size (CONSORT diagram)



Not all sampled individuals were able or willing to participate in the auction. Of the 272 selected potential respondents, 3 were in villages that were entirely inaccessible due to flooding, and 3 had marketing club registrations that could not be verified. Of the 266 remaining survey respondents, 149 were unable or unwilling to have cash on hand for the auction, and of the 117 potential auction participants, one was unable to answer the practice-round comprehension questions, leaving a sample size of 116 for WTP estimation. Their location is shown in Table 1, revealing that participation rates were lowest in Chikwawa (42 of 121 respondents, or 35%) and highest in Nsanje (46 of 92, or 50%).

Table 1. Summary of survey sampling frame and sample size

	Total	Blantyre Rural	Chikwawa	Nsanje
Total farmers in sample	272	55	121	96
Farmers available to participate	266	53	121	92
Agreed to participate in auction	116	28	42	46

Our survey was aimed at measuring demand for hermetic storage bags, which we hypothesized might be influenced in part by respondent characteristics such as wealth and aflatoxin knowledge, and also by having attended a bag-use demonstration. To measure wealth, we asked respondents if people in their household owned any of a list of nine durable assets commonly found in the area. Given their very different and unknown value, we used those nine variables to construct a standardized wealth index using principal components analysis (PCA). To measure aflatoxin knowledge, we asked a set of 12 true/false questions of roughly equal importance, from which we construct a knowledge score defined as the number of correct answers. Other information of potential interest is that, of the 266 respondents, their average age was 43 years, 248 (93%) reported growing some crops in the previous year, 166 (62%) were female, and 140 (53%) reported being the head of their household.

Attendance at bag-use demonstrations prior to our survey is summarized in Table 2. About half of all auction participants had done so, primarily in Blantyre Rural and Nsanje districts. Attendance was not randomly assigned, and although these differences were not statistically significant, the average attendee was older (46.5 vs. 42.2 years), wealthier (index value of .32 vs. -0.7), and more likely to be a woman (64% vs. 57%) than auction participants who had not attended a demonstration. The survey data also suggests the possibility that having attended a demonstration is linked to auction participation: the bottom row of Figure 1 reveals that 51% of those who attended a demonstration subsequently did the auction (29 vs. 28), as opposed to only 43% among those who had not attended a demonstration (87 vs. 117).

Table 2. Auction participants who had previously attended a bag-use demonstration

	Total	Blantyre Rural	Chikwawa	Nsanje
All auction participants	**116**	**28**	**42**	**46**
Of these: Hhld heads	63	10	27	26
Women	66	23	21	22
Men	50	5	21	24
Participants who had attended a demonstration	**59**	**21**	**15**	**23**
Of these: Hhld heads	29	10	7	12
Women	38	14	10	14
Men	21	7	5	9

In summary, our survey provides suggestive but not statistically significant evidence for important differences between survey respondents in general and those who attended a demonstration or participated in the auction. People who were more willing and able to buy a bag, meaning a higher potential willingness to pay, could have been more likely to attend a demonstration, and also more likely to participate in the auction. The demonstrations could also have had a causal effect, raising the bids of attendees and making them more likely to participate in the auction. Without random assignment, we cannot separate one cause from another. Our auction results, like market demand itself, come from the combination of preexisting factors such as household wealth with successive choices such as attending a product demonstration. Our primary objective in this study is to measure overall WTP, so as to predict what fraction of the population might choose to buy now at any given market price. A secondary objective is to provide suggestive evidence for the causes of differences in WTP, such as the potential impact of having attended a product demonstration.

Results

Our measure of interest is willingness to pay, defined as the final bid offered for a PICS bag by a respondent in the auction. Of the 116 auction participants, only 8 respondents drew a price below their bid and consequently obtained a bag at that price. These included 6 of the 46 auction participants in Nsanje district, 2 of the 42 in Chikwawa, and none of the 28 in Blantyre Rural.

Bids were made in Malawian Kwacha (MWK), and range from a minimum of 50 to a maximum of 1000. Their distribution is shown in Figure 2 for the sample as a whole, with a mean of 311 and a standard deviation of 184. Figure 3 shows that the distributions are quite similar across the three districts, with most observations falling between 200 and 400 MWK per bag.

Figure 2. Distribution of willingness to pay (n=116)

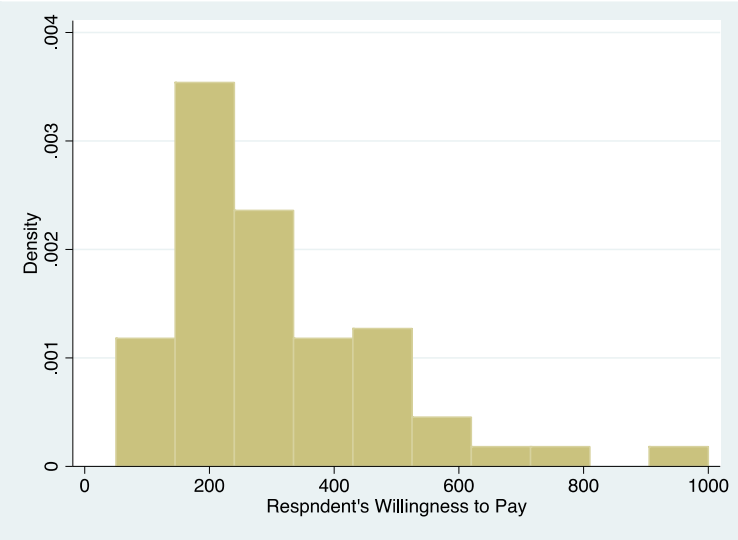
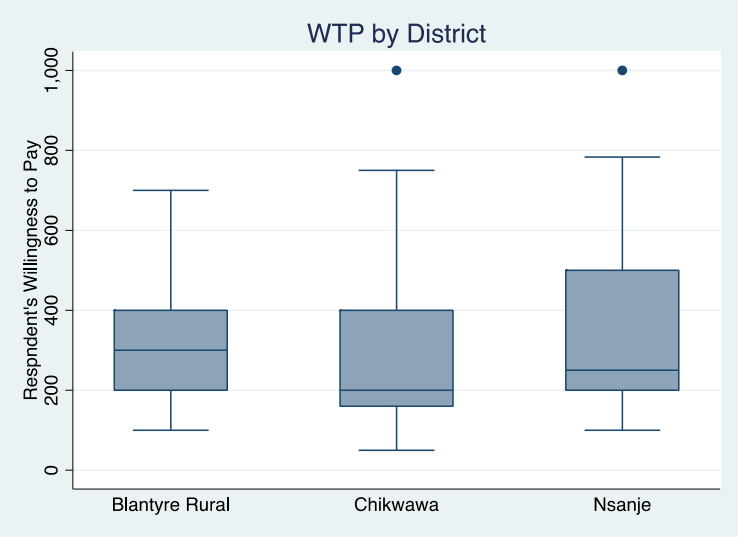
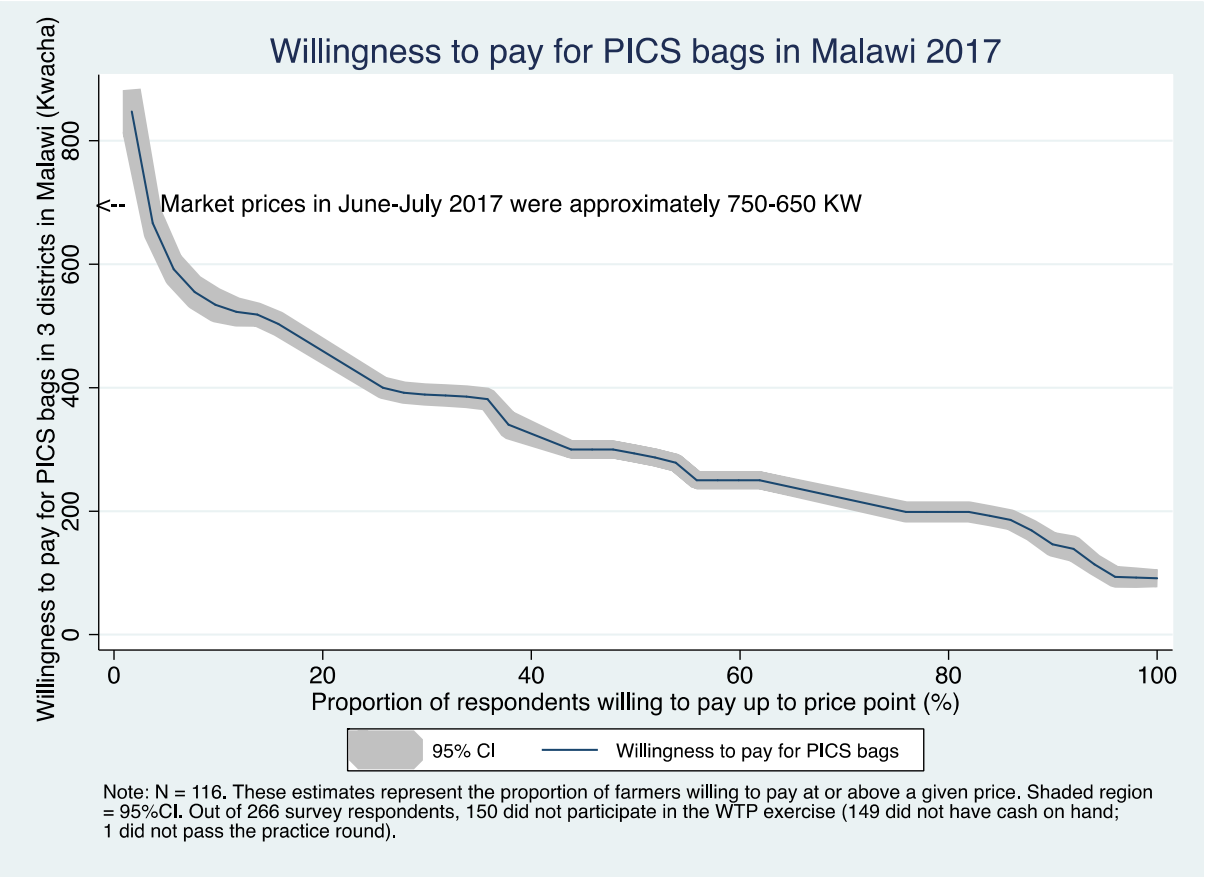


Figure 3. Willingness to pay by district



The market price for these bags, where available, is typically 750 MWK. Only four of our 116 respondents gave a WTP above that price. With subsidized distribution or cost reduction over time, prices could fall far below 750 MWK. To estimate the fraction of respondents whose WTP implies they would purchase at each price level, Figure 4 provides a smoothed version of the distribution shown in Figure 3 arrayed by price, in the form of a demand curve. For more than 80% of respondents to buy, prices would need to fall below about 200 MWK.

Figure 4. Estimated demand curve



A key question for the introduction of any technology is how information about its value spreads to potential new adopters. The value of a hermetic storage bag depends on the damage it prevents, which cannot be directly observed. For the launch of PICS bags in Malawi, selected marketing club farmers were offered free bags to store their grain. The club organized small ceremonies to watch them fill and seal the bag, and organized bag-opening ceremonies some months later. To test whether these product demonstrations are associated with higher demand, we asked survey respondents whether they attended either type of ceremony.

Table 3 shows WTP for respondents by district for respondents who did or did not attend one or more bag-use demonstrations. The mean bid among the 29 respondents who attended at least one ceremony is 375 MWK, compared to 290 MWK among the 87 respondents who did not. Across districts, the largest gap is in Nsanje, and the principal difference is at the bottom of the distribution: among those who did not attend, the lowest bids were 50 or 100 MWK, whereas no respondent who did attend bid less than 200 MWK.

Table 3. Willingness to pay by Attended and District

	Total	Blantyre Rural	Chikwawa	Nsanje
All respondents	*116*	*28*	*42*	*46*
Lowest bid	50	100	50	100
Mean bid	311	307	290	333
Highest bid	1000	700	1000	1000
Attended demonstration	*29*	*11*	*6*	*12*
Lowest bid	200	200	200	200
Mean bid	375	364	250	449
Highest bid	1000	700	300	1000
Did not attend demonstration	*87*	*17*	*36*	*34*
Lowest bid	50	100	50	100
Mean bid	290	271	297	292
Highest bid	1000	700	1000	600

The descriptive statistics presented earlier (Table 2) address possible differences in socioeconomic characteristics among auction participants who attended demonstrations versus those did not. We found suggestive but not statistically significant evidence that attendees were older, from wealthier households, and more likely to be female. These pre-existing characteristics, rather than attendance, could have accounted attendees' higher bids. We tested a variety of regression specifications and found that none of these characteristics are significantly associated with the differences in WTP across individual respondents. The specifications tested in those exploratory regressions are provided in the annex of Supplemental Information; further tests, including pooling our data with results of other studies, could potentially yield additional insights.

Discussion

Our results add to a small but rapidly growing literature on the spread of hermetic storage bags, as part of the larger interest in controlling post-harvest losses for food security and food safety. Previous literature has focused on demand for specific attributes of crops to be stored, and on cost-benefit analysis of programs to distribute new kinds of storage bags. That literature has pointed to concern about farmers' valuation of the bags, which depends on many factors including their valuation of the losses to be averted, their confidence in the effectiveness of the bags, and their ability or willingness to make even a small investment whose payoffs are delayed and uncertain.

To place our results in context, we conducted a systematic review to find previous estimates for the level of WTP for hermetic storage bags, relative to the market cost of those bags and

their path to commercial sales in various settings. As with any new technology, economies of scale in production and marketing makes cost per unit decline with initial growth in market size, even as the spread of knowledge from experienced users shifts demand. For hermetic storage, we found literature on both the timeframe of commercialization, and barriers to scaling up distribution though either the public or private sector.

Detailed results of our systematic review are provided in the annex of supplemental information. In summary, we found only three precedents that actually measure WTP for hermetic storage bags. Mwaijande (2017) reported the WTP for PICS bags in Tanzania was close to market value at Tsh 4000 ($1.80) for 74% of respondents in their study, but the two others found results similar to ours: Stein (2016) found WTP for PICS bags in Kenya was well below market price, and Goentzel (2017) found over two-thirds of survey participants were willing to pay a low, subsidized price; about a quarter were willing to pay a bit more than 60% of the unsubsidized cost, and no one was willing to purchase at the unsubsidized cost.

Another five studies focus only on quantities distributed or sold, without addressing WTP or the magnitude of subsidy needed for commercialization. Moussa (2014) states that, in West and Central Africa, the cost of a PICS bags was cited as a barrier to purchase by only a small number of respondents. The biggest barrier to adoption cited was the unavailability of bags in their local area. Nouhoheflin (2017) states that 5 million PICS bags were manufactured and sold in West and Central Africa. That study uses distance traveled as a metric of willingness to pay, finding a maximum distance of 7 km that farmers were willing to travel to obtain a bag. Ayedun (2017) also cites local availability of bags as the major barrier to adoption in Northern Nigeria, along with agricultural extension. Baributsa (2014) states that the number of PICS bags ordered by the private sector rose sharply from 2007 to 2010 across West and Central Africa. As distribution of the bags shifted from public to private channels, public-sector extension continued to play a role by informing farmers and supporting the supply chain to reach over 30,000 villages. Baoua (2014) references an unpublished report from 2013 that 2.5 million bags had been sold in West Africa.

USAID (2016) describes the situation in Kenya, stating that the national distributor, Bell Industries, finds PICS bags profitable to sell and that quantity demanded has risen over time. Bell Industries appears to be maintaining high profit margins in a context of high and rising volumes, and the study concludes that farmers' awareness and willingness to buy the bags is high in maize-growing areas of Kenya. Supply of the bags is expected to reach 1 million units in 2016, from under 52,000 in 2014. Several contextual factors have supported expansion, including solid transportation and manufacturing capacity, widespread awareness and use of modern agricultural inputs, a dense presence of competent civil society actors in the agricultural space, and especially having an established, well-functioning agricultural distribution system including farmers' associations that both promoted the bags and arranged bulk purchases for their members.

Once the market for hermetic bags is established, Coulibaly (2012) suggests that demand might be highly inelastic and price could have little effect on quantity sold. Whether or not farmers want to buy depends in part on what they know of the bags' efficacy in controlling post-harvest losses, and also on how they value the uncertain and delayed payoff of having more and safer grain in the future. Ndegwa (2016) considers several combinations of grain prices and post-harvest losses that changes the break-even points of GrainPro bags and concludes that for small losses over its three-year life span the bag is not profitable enough to be attractive to farmers. Adoption would be likely only for farmers who risk large losses due to poor initial conditions and long storage periods, and have relatively little discounting of the uncertainty and delay in whether and when those benefits are obtained. GrainPro and other suppliers of both flexible bags and hard-sided barrels or silos have found scale economies to be important on the buyer's side, as traders and stockholders who specialize in storage and transport handle larger volumes at lower cost per unit than individual farmers. In this study, we focus specifically on demand for the bags among individual farmers, for whom the quantity and duration of storage is relatively limited.

Conclusion

The aim of this study is to measure farmers' valuation of hermetic grain storage bags, as part of a project to improve food security, food safety and nutrition in Malawi, and a more general effort to improve the handling of maize, groundnuts and other crops that suffer high post-harvest losses. Hermetic storage bags preserve grain by limiting the oxygen supply needed for reproduction of any insects and micro-organisms that may be present when the bag is sealed. The efficacy of this technique relies on using sufficiency strong and impermeable plastic, and keeping the bag completely sealed until the grain is removed.

The specific kind of hermetic storage used in this project are PICS bags designed to hold 50 kg of grain, and actually used primarily for maize. Hermetic bags were introduced to this area for the first time during the year before our survey, through product demonstrations at which participating farmers were given a bag to fill and seal, with follow-up demonstrations later at which the bags were opened.

To measure farmers' demand for bags we use random-price auctions, designed to obtain the highest price at which each respondent would be able and willing to purchase a bag if it were available at a local shop. These Becker-DeGroot-Marshak auctions are widely used to predict consumer behavior and elicit a community's demand curve for new products. What we find is that only 4 of 116 auction participants would now purchase a bag at its current market price of about 750 Malawian Kwacha (about one US dollar), and their mean willingness to pay is less than half of that price (about $0.42).

Farmers' willingness to pay for these bags could be low partly due to their lack of familiarity with the technology. We find suggestive evidence that farmers who had observed at least one of the bag-use demonstrations had higher demand for bags, as revealed by greater participation rates and higher bids in the auction, but these differences were not statistically significant. It is possible that more knowledge of how the bags preserve grain and limit harm from toxins would lead to higher demand, but other constraints might also apply. Most farmers have low and variable harvests, which they store for short periods of time before needing to consume or sell the grain. And almost all of their households are in extreme poverty, forced by urgent unmet needs to discount the value of uncertain future payoffs such as the damage avoided when grain is stored in hermetic bags.

From farmers' responses to our survey we conclude that commercial sales of hermetic bags in this population are unlikely to succeed without large subsidies, until and unless there is a large shift in demand. A similar conclusion was found in two of the three comparable previous studies that we found, and is also consistent with a range of other evidence about the spread of hermetic bags described in our literature review. Commercial sales are possible now among the few farmers who are most able and willing to pay for storage bags, and bags might also be sold to grain traders who engage in off-farm storage and transport, but subsidized distribution remains the primary channel by which this innovation can reach the poorest farmers in Malawi.

References

Becker, G.M., DeGroot, M.H., Marschak, J. (1964). Measuring utility by a single-response sequential method. Behav Sci. 9 (3): 226–32.

Caswell, J.A., Noelke, C.M., & Mojduszka, E.M. (2002). Unifying two frameworks for analyzing quality and quality assurance for food products. Chapter 3 (pp. 43-61) in B. Krissoff, M. Bohman, and J.A. Caswell (eds), Global Food Trade and Consumer Demand for Quality. Boston: Springer.

CIMMYT (2011). Effective grain storage for better livelihoods of African farmers: project completion report. Mexico DF, Mexico: International Maize and Wheat Improvement Center.

Cunningham, C. F. (2003). The impact of information on willingness-to-pay for bison. M.Sc. thesis. Saskatchewan, Canada: University of Saskatchewan.

Donaldson, C., Thomas, R., & Torgerson, D. J. (1997). Validity of open-ended and payment scale approaches to eliciting willingness to pay. Applied Economics, 29(1): 79-84.

Golob, P. (1988). Current status of the larger grain borer Prostephanus truncatus (Horn) in Africa. International Journal of Tropical Insect Science, 9(06), 737-745.

Gong, Y., Cardwell, K., Hounsa, A., Egal, S., Turner, P., Hall, A. & Wild, C. (2002). Dietary aflatoxin exposure and impaired growth in young children from Benin and Togo. BMJ, 325:20.

Gong, Y. Y., Watson, S., & Routledge, M. N. (2016). Aflatoxin exposure and associated human health effects: A review of epidemiological studies. Food Safety, 4(1): 14–27.

HELVETAS (2016). Farmers' access to postharvest technologies: Final Report. Bern, Switzerland: HELVETAS.

KAAA (2017). Hermetic storage technology. Nairobi: Kenya Agribusiness and Agroindustry Alliance (http://kaaa.co.ke/hermetic-storage-technology).

Kaaya, A. N., & Kyamuhangire, W. (2006). The effect of storage time and agroecological zone on mould incidence and aflatoxin contamination of maize from traders in Uganda. International Journal of food microbiology, 110(3), 217-223.

Matumba, L., Monjerezi, M., Chirwa, E., Lakudzala, D., & Mumba, P. (2009) Natural Occurrence of AFB1 in Maize and Effect of Traditional Maize Flour Production on AFB1 Reduction in Malawi. African Journal of Food Science, 3(12), 413-425.

Matumba, L., Monjerezi, M., Biswick, T., Mwatseteza, J., Makumba, W., Kamangira, D. & Mtukuso, A. (2014). A Survey of the Incidence and Level of Aflatoxin Contamination in a Range of Locally and Imported Processed Foods on Malawian Retail Market. Food Control, 43, 87-91.

Meikle, W. G., Holst, N., Degbey, P., & Oussou, R. (2000). Evaluation of sequential sampling plans for the larger grain borer (Coleoptera: Bostrichidae) and the maize weevil (Coleoptera: Curculionidae) and of visual grain assessment in West Africa. Journal of economic entomology, 93(6), 1822-1831.

Monyo, E., Njoroge, S., Coe, R., Osiru, M., Madinda, F., Waliyar, F., Thakur, R., Chilunjika, T. & Anitha, S., (2012). Occurrence and Distribution of Aflatoxin Contamination in Groundnuts (Arachis hypogaea L) and Population Density of Aflatoxigenic Aspergilli in Malawi. Crop Protection, 42, 149-155.

Matumba, L., Monjerezi, M., Kankwamba, H., Njoroge, S.M., Ndilowe, P., Kabuli, H., Kambewa, D. and Njapau, H. (2016). Knowledge, attitude, and practices concerning presence of molds in foods among members of the general public in Malawi. Mycotoxin Research, 32(1), pp.27-36.

Monyo, E. S., Njoroge, S. M. C., Coe, R., Osiru, M., Madinda, F., Waliyar, F., ... & Anitha, S. (2012). Occurrence and distribution of aflatoxin contamination in groundnuts (Arachis

hypogaea L) and population density of Aflatoxigenic Aspergilli in Malawi. Crop Protection, 42, 149-155.

Mwaijande, F. (2017). Farmers' adoption and willingness to pay for post-harvest technologies in Tanzania: policy implication for enhancing food security. Journal of Postharvest Technology, 5(1), 1-6.

Mwalwayo, D. & Thole, B. (2013). Prevalence of aflatoxin and fumonisins (B1 + B 2) in maize, rice and ground nuts consumed in rural Malawi. Toxicology Reports, 3, 173-179.

Ndegwa, M. K., De Groote, H., Gitonga, Z. M., & Bruce, A. Y. (2016). Effectiveness and economics of hermetic bags for maize storage: Results of a randomized controlled trial in Kenya. Crop Protection, 90, 17-26.

Oerke, E. C., & Dehne, H. W. (2004). Safeguarding production losses in major crops and the role of crop protection. Crop protection, 23(4), 275-285.

Schulten, G.G.M. (1975). Losses in stored maize in Malawi (Central Africa) and work undertaken to prevent them. European and Mediterranean Plant Protection Organization, EPPO Bulletin, 5(2), pp.113-120.

Shukla, P. (2017). Promoting Food Safety through Mycotoxin Awareness: Evidence from a Randomized Control Trial with Farmers in India. Presentation at Tufts University, April 2017.
Smith, L. E., Prendergast, A. J., Turner, P. C., Mbuya, M. N. N., Mutasa, K., Kembo, G., & Stoltzfus, R. J. (2015). The potential role of mycotoxins as a contributor to stunting in the SHINE Trial. Clinical Infectious Diseases, 61(suppl 7), S733–S737.

Tefera, T. (2012). Post-harvest losses in African maize in the face of increasing food shortage. Food Security, 4(2), 267-277.

USAID (2017). INGENAES: Integrating Gender and Nutrition within Agricultural Extension Services. Washington, DC: United States Agency for International Development (https://agrilinks.org/activities/ingenaes-integrating-gender-and-nutrition-within-agricultural-extension-services).

USAID (2016). Scaling up of hermetic bag technology (PICS) in Kenya. Washington, DC: United States Agency for International Development (https://agrilinks.org/library/scaling-hermetic-bag-technology-pics-kenya-review-successful-scaling-agricultural).

UNDP (2017). Human Development Report 2016. New York: United Nations Development Programme. (http://hdr.undp.org/en/countries/profiles/MWI).

SUPPLEMENTAL INFORMATION

Annex 1. Regression specifications

To describe links between each respondent's WTP and their individual or household characteristics, we used the following specifications for ordinary least-squares regression. None of these initial analyses revealed any significant associations.

$$Y_{WTP} = WealthQuintiles + Attended + Amtstored + Aflaknow + e \quad (1)$$

$$Y_{WTP} = WealthQuintiles + Amtstored + Aflaknow + PICSmessages + e \quad (2)$$

$$Y_{WTP} = WealthQuintiles + Amtstored + Attended + AflaknowQuestions + e \quad (3)$$

$$Y_{WTP} = WealthQuintiles + Amtstored + Attended + Aflaknow + Livestock + e \quad (4)$$

In these specifications,

Y_{WTP} is a continuous variable that ranges from the lowest WTP to the highest WTP, captured in Malawian Kwacha, 50-1000 MKW.

WealthQuintiles is an index constructed through principal component analysis based on an index of household durable goods assets.

Attended is a binary variable for attendance at a product demonstration.

Amtstored is a categorical variable that records the amount of grain respondents want to store between harvests in increments of 50kg starting with 50kg and ending with more than 300kg.

Aflaknow is a composite score of how many correct aflatoxin knowledge questions (1 to 12) a respondent answered correctly.

PICSmessages is one of five binary variables for each specific message provided at the bag-use demonstrations, with specifications tested for each on its own and as a group.

AflaknowQuestions is each of 12 binary variables for each specific question related aflatoxin knowledge included in the *Aflaknow* index, used on their own and as a group.

Livestock is a binary variable that recorded if respondents owned any livestock yes or no.

Annex 2. Evidence map of previous studies estimating demand for hermetic storage bags

Citation	Location	Period	Study Design	Study evidence for commercialization
Abifarin, 2010	Nigeria		N/A	Quantity of bags sold is 4000.
Abdoulaye 2012	Nigeria		N/A	"Key factors influencing adoption of PICS bags include: being from a demonstration village (P = 5%), attendance of village demonstration (P = 1%), and other information variables such as being a member of an association (P = 1%), having access to radio messages (P = 1%), and cowpea production (P = 1%). The major problem across the board was that the bag was not readily available in the villages."
Coulibaly, 2012	West Africa	2007-2012	A broad-based consultative process with key informative interviews with project staff and supply chain participants in each of the ten PICS countries.	"Data also suggest that price does not significantly impinge upon the average farmer's willingness to invest his or her limited resources in PICS technology."
Moussa, 2014	West and Central Africa; ten countries		Qualitative cross sectional; Interviews	"Cost of bags was cited as a key constraint by a small number of respondents; key reasons for not using PICS bags include unavailability of bags in their local area...46% of respondents use some type of hermetic storage for cowpeas."

Citation	Location	Period	Study Design	Study evidence for commercialization
Baributsa, 2014	West and Central Africa; ten countries	2007-2012	Documenting market building, supply chain development and ag extension activities (awareness building, demonstration, follow-up visits, bag opening ceremonies, training)	"Bags ordered by the private sector went from 0% in 2007 to 200% in 2010, proving that it is possible to commercialize a new agricultural technology in developing countries in a relatively short time." Farmers' willingness to pay the market price of PICS bags has helped to build incentives along the supply chain by providing margins to all actors, including manufacturers, distributors and vendors. By 2010 (three years since the project launched in 2007), all PICS bags ordered for sales were fully financed by the private sector and no project funds were involved in ordering; (PICS) technology has been disseminated in 30,896 villages in 10 different countries in West and Central Africa from 2007 to 2012; Large-scale extension activities substantially increased the demand for the technology and helped establish the supply chain.
Baoua, 2014	West Africa		Experimental	This item references an unpublished report in 2013 that cites 2.5 million bags sold in West Africa.
Stein, 2016	Kenya		Survey, Becker-DeGroot Maschak mechanism.	"Overall high self-reported interest in PICS. However, most bids for PICS bags well below market price of 250 Ksh; Average bid: 83 Ksh among all bids, 125 Ksh among non-zero bids; 38% gave bid of zero, indicating non-interest in buying PICS bag at time of survey; Prior PICS awareness has a positive effect on WTP bid price (20 Ksh increase) and likelihood to recommend PICS1." No significant effects found for any other variables examined

Citation	Location	Period	Study Design	Study evidence for commercialization
USAID, 2016	Kenya		N/A	"The Kenyan national wholesale distributor at the summit of the value chain, Bell Industries in Nairobi, has found PICS bags to be profitable, and demand is continually rising. The company is expanding production of PICS bags..."; Production can be outsourced, while the option of in-house production is being explored; Existing distribution chains can be used; Profit margins for the company are high in a context of high and rising volumes; Demand is increasing rapidly in response to promotional activities; The three-year life of the PICS bags offers potential for sales of 4 million units per annum through repurchases; and PICS bags do not conflict with the company's existing product lines, which are in the domain of pre-harvest crop protection; These promotional campaigns led to early scaling up of hermetic bag technology in Kenya and adoption by farmers who then not only increased their own orders but also spread the information to their communities, which led to more interest and higher demand. Hence: PICS bags are widely known throughout the maize-growing areas of Kenya; Farmers are eager to obtain them;
Ndegwa, 2016	Kenya		Randomized control trial	"Not 100% insect free storage but reduced losses due to insects; comparison between hermetic bags and farmer practices, marginal cost between using hermetic bag (3yrs) and farmer practice of bag/insecticide combo."
Mwaijande, 2017	Tanzania		Cross sectional survey and focus groups	"Willingness to adopt 100kg bag at Tsh4000 ($1.8) below market price of Tsh4,483 ($2.02); range of market price Tsh3,600-6,000. Willingness to adopt higher in farmers with PICS awareness."

Citation	Location	Period	Study Design	Study evidence for commercialization
Nouhoheflin, 2017	West and Central Africa		Research case study; Key informant interviews.	" An early PICS adoption study showed that farmers were reluctant to travel more than about 7 km to buy PICS bags projects in the sense that from the beginning it treated African farmers as customers, not as charity cases. Other than a few bags used in village demonstrations, almost all of the 5 million PICS bags that were manufactured were sold through commercial channels; African manufacturers were eager to find new products in high demand by their customer base and national extension services and NGOs were quite effective at implementing farmer training programs; bottleneck was development of supply chains down to the village level; Data also suggest that retail price does not significantly impinge upon the average farmer's willingness to invest his or her limited resources in PICS technology."
Goentzel, 2017	Uganda		An in-house model as an alternative of a static score informed by field research.	This study finds 70% of survey participants were willing to pay the subsidized price of a hermetic bag, about 25% were willing to pay a bit more that 60% of the unsubsidized price, and no one willing to purchase at the unsubsidized price.

Citation	Location	Period	Study Design	Study evidence for commercialization
USAID, 2017	Kenya		Systems dynamics methodology	"However, competitors such as the U.S.-based multinational GrainPro have entered the market with similar products, and metal silos are also available. Hence, the success of PICS bags in demonstrating the effectiveness of hermetic storage has resulted in competition that should produce benefits for end-user farmers. Supply of the bags is expected to reach 1 million units in 2016, from under 52,000 in 2014. Several contextual factors supported the scaling of PICS bags in Kenya, including solid transportation and manufacturing capacity, widespread awareness and use of modern agricultural inputs, a dense presence of competent civil society actors in the agricultural space, and especially having an established, well-functioning agricultural distribution system; Fifth, the experience with PICS bags – rapid enthusiasm and take-up of the product accompanied by the early entry of competitors into the market – demonstrated the need for donors to prepare for the unexpected, which may imply additional costs; PICS bags were among the cheapest of all the innovations reviewed, and many farmers interviewed who adopted them emphasized this [end-user affordability] as a major advantage; In Kenya, farmers' associations both promoted PICS bags and arranged bulk purchases for their members. This brought the bags within the reach of very poor rural households that would not otherwise have been able to access them because of the small quantity they could afford and the cost of transport to the supplier; In these cases (e.g., PICS bags and Kuroilers), demand can expand very rapidly. "