Factors Determining the Adoption and Impact of a Postharvest Storage Technology

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Abstract

This paper evaluates the determinants and impact of adopting the metal silo - a postharvest storage technology for staple grains - which was disseminated by the Swiss Agency for Development and Cooperation (SDC) from 1983 to 2003 in four Central American countries. The aim of the SDC program was to diminish small farmers' postharvest losses by facilitating the manufacture and dissemination of metal silos and thereby to improve regional food security. Our empirical analysis is based on a unique data set obtained from a survey of 1,600 households from El Salvador, Guatemala, Honduras and Nicaragua. We employ a double-hurdle model to identify factors that contributed to the adoption of metal silos. We use tobit and standard regression models to assess the impact of adopting the metal silo on the food security and well-being of the considered households. Our estimation results show that both the household demand for metal silos and the impact of their adoption varied across the four considered countries. This finding points out the relevance of regional policies for the adoption of a technology, as well as its impact. Additionally, our results indicate that - in addition to the household self-sufficiency in maize - the main determinants of adoption were household socio-economic characteristics such as age, land ownership, completion of a training course and quality of basic infrastructure. Finally, when considering a group of economic and social indicators of household well-being, we found that, compared to the silo non-adopters, the adopter-households experienced a significantly higher improvement in their food security and well-being from 2005 to 2009.

Key words: food security, impact assessment, investment decision, postharvest grain losses, Central America

1. Introduction

Approximately 16 million people, or 47% of the total population of Guatemala, El Salvador, Honduras and Nicaragua, still live in rural areas (World Bank, 2008). Of this population, 62%, i.e. ca. 10 million people, are producers of staple grains (i.e. maize, beans, rice and sorghum) (Baumeister, 2010). The majority of staple grain producers are small to medium-sized family farms). Between 39% (Nicaragua) and 92% (Guatemala) of staple grain producers in the above-mentioned countries possess less than 2.1 ha (which corresponds to 3 "manzanas"[1]) of land (Baumeister, 2010). Poverty (defined as not having sufficient means to cover basic needs) is widespread for rural staple grain producer families, ranging from 56% in El Salvador to 91% in Honduras (Baumeister, 2010).

[1] Manzana is the local land measurement unit. One manzana is equal to approx. 0.7 hectare.

Staple grains, primarily maize and beans, play a crucial role for food security, income generation, as well as the livelihoods of rural inhabitants in Central America. Maize is the main staple food and beans are an important additional source of protein that complement the maize-based diet. While white maize is mainly used for human consumption, yellow maize is primarily used as fodder. Annual food requirements of a household with the average size of 5.4 persons amounts to about 810 kg of maize and 240 kg of beans, respectively (Baumeister, 2010).

Postharvest damage (i.e. physical alteration caused by biotic or abiotic agents) and loss (i.e. the difference between total damaged and recoverable damaged grain still fit for human consumption) of staple grains due to insect pests, rodents and birds are a common problem in developing countries. However, precise information on postharvest losses of maize and beans in Central America is rather scarce. A two-year study (production cycles 1980-81 and 1981-1982) conducted in Honduras by Raboud et al. (1984) assesses maize postharvest damage and losses to amount to 12.5% and 8.1% of the stored maize, respectively (on average, for two study years). Similarly, Abeleira et al., (2008) assess postharvest bean losses in Mexico to account for 10%.

Given the importance of the postharvest management of staple grains in Central America, the program “Postcosecha” (“postharvest” in Spanish) was launched in 1983 by the Swiss Agency for Development and Cooperation (SDC) in Honduras. Later, the program was extended to Guatemala (1990), Nicaragua (1992) and El Salvador (1994). The program consisted of the production and dissemination of a metal bin (silo) for the postharvest storage of staple grains. Between 1983 and 2009, almost 670,000 metal silos for postharvest grain storage were produced and disseminated in Central America (SDC, 2011). This postharvest technology was developed for the storage of maize and, to a more limited extent, beans. Currently, more than 400,000 mostly rural households, i.e. approximately 2.4 million rural people in Honduras, Guatemala, Nicaragua and El Salvador, use the metal silo for grain storage (Table 1); this number represents 24% of the rural households producing staple grains. Table 1 shows that 46% of the metal silos were disseminated after the direct support by SDC ended in 2003 (SDC, 2011), which confirms a successful continuation of the program, particularly in the case of Guatemala.

Table 1 around here

The modalities for disseminating the metal silo after 2003 have evolved differently in the four considered countries and need to be considered to explain the silo adoption pattern in each country. Most farmers either purchase the silo directly from tinsmiths or purchase it through a governmental program, or through non-governmental organizations (NGOs). In Honduras, the main acquisition modality has been direct purchase from tinsmiths (86%). In Nicaragua, besides directly purchasing from tinsmiths (57%), acquiring metal silos through NGOs is also important (23%). To increase food security in rural areas, in 2000 the Guatemalan government introduced a large subsidy program targeting rural poor families; the program subsidizes 62% of the fixed selling price of 58 USD (as of 2009) for a 12 quintal (545 kg) silo by providing the galvanized iron sheets to the contracted tinsmiths. Approximately 75% of the disseminated metal silos fall under the subsidy program, which explains the large increase of disseminated metal silos in recent years. In El Salvador, about 54% of the metal silos are handed over to farmers either as a donation (mostly through NGOs), or “in concession”, which implies that the farmer obtains the silo for free as part of an agricultural subsidization package including seeds, fertilizer, etc. However, the silo remains government property and the farmer is not allowed to sell the silo.

A metal silo is a cylindrical structure (one standard design), constructed from a high quality galvanized iron sheet (gauge No. 26 or 24) with a top inlet and a smaller bottom lateral outlet. The silos are locally constructed by trained artisanal tinsmiths with simple tools (for detailed descriptions and procedures how to fabricate the metal silo see (SDC, 2008a and Bravo, 2009). The metal silo generally holds between 100 and 3000 kg of grain. Rural families in Central America use most commonly the sizes of either 12 quintals[2] (545 kg) or 18 quintals (820 kg) corresponding to the annual grain consumption of an average family of 5-6 persons. The metal silo can be hermetically sealed, allowing farmers to fumigate the stored grain by using pellets containing phosphine compounds (e.g. aluminum phosphide, “phostoxin” (Bravo, 2009). An important aspect is that the grain must be dried properly dried (maximum of 13% grain moisture content) before filling it into the silo avoiding moulds. The metal silo technology has proven to be effective in protecting the harvested grains from attack not only from storage insects but also from rodent pests, birds, insects, and fungal invasion (moulds) (SDC, 2008b, Tefera et al., 2010). Users of the metal silo indicated that it is more effective in the control of postharvest losses than traditional storage methods (granaries, barns, sacks, metal and plastic barrels, etc.; Hermann, 1991; Coulter et al., 1995; Gladstone et al., 2003). The objective of the metal silo dissemination program was to improve the food security and

[2] 1 quintal (qq.) = 45.45 kg

livelihood of poor rural households, as well as create employment and income for artisanal tinsmiths that produce the metal silos (SDC, 2008b; Tefera et al., 2010).

There are several socio-economic studies which evaluate the Postcosecha Program considering such aspects as food security, livelihoods, and maize buying and selling, including price dynamics. According to the study by Raboud et al. (1984), the metal silo reduces storage losses to less than 1%, compared to an average of 10% loss in conventional maize facilities. Considering the dissemination dynamics of the metal silo since 1983 (Table 1), SDC (2011) assesses that the accumulated grain saved from potential postharvest loss in the four considered countries could account for up to 336,000 tons during the last 27 years. In 2009, the total storage capacity of metal silos in all four countries reached approximately 380,000 tons (SDC, 2011); this means that about 38,000 tons are saved annually from potential storage losses. This volume is equivalent to food for almost 50,000 families.

For a group of farms (N=60) in Honduras, Hermann (1991) reports that 20% of the surveyed farmers were metal silo users. 83% of non-users indicated they would not have enough stored grains (maize, beans) to cover their food needs till next harvest. The silo users indicated that they bought maize mainly during periods of low prices, whereas the non-users needed to buy mostly during the high price period from May to July. Coulter et al. (1995) report that due to the use of the metal silos, farmers stored more grain than previously (study conducted in El Salvador, Guatemala, Honduras, Nicaragua). Gladstone et al. (2002) found that among the farms surveyed in their study, 60% of the users still had some maize stored in the metal silo before the new harvest compared to 29% of the non-users. All abovementioned studies conclude that the use of metal silos has increased the food security of poor rural households.

Besides increasing food security, it is expected that farmers gain flexibility to decide when to sell the safely stored grain by taking advantage of seasonal price fluctuations due to changes in supply and demand (Florkowski and Xi-Ling, 1990). In Central America, prices are usually low during postharvest months (mid-August till February) when the supply is high, and peaks before the next harvest (from May till the beginning of August) when the available grain in the market becomes more scarce (Zappacosta, 2005; Hernández, 2008; Pérez et al., 2010). However, these recurring seasonal trends have also been distorted in Central America since 2007 due to the food price crisis (Pérez et al., 2010).

Hermann (1991) found that 67% and 40% of surveyed users and non-users of metal silos in Honduras sell maize. The users reported selling 66% of the stored maize before the new harvest during the high price period from May to August at an average price of 8.85

USD/quintal. The non-users stated they sold 50% shortly after harvest, i.e. from November to December, at an average price of 7.00 USD/quintal, but the rest was sold more evenly throughout the year. Additionally, the users reported selling 74% of the total maize to relatives or within the village, whereas the non-users were selling the bulk (87%) of their maize to intermediates or in the market. Coulter et al. (1995) found that the silo users have more freedom to sell maize when prices are better and to sell more within the community, thereby reducing dependence on intermediates. In addition, Gladstone et al. (2002) reported that in their study, 67% of the women silo users reported having more opportunities to sell any desired quantity of the stored maize at their convenience to cover household costs.

The abovementioned socio-economic studies state that the use of the metal silo also has a positive effect on the livelihoods of the families considering different aspects such as food security, workload, hygiene and health. Hermann (1991) found that 50% of the surveyed silo users in Honduras indicated they had a more balanced diet, i.e. the family consumed more rice, beans, meat, eggs, milk and milk products than prior to using the metal silo.

Another important aspect is related to a change in the postharvest workload of the family. The need to shell and remove the grains from the cob to fill the metal silo at once involves more men and hired labor, and the use of mechanized equipment if available. The grain stored in metal silos is ready for consumption and therefore there is no need for daily shelling and removal of grains from the cob, which is mostly done by women when a household uses a traditional storage system. Consequently, 77% of the women in the surveyed households confirmed that their workload in postharvest operations declined (Gladstone et al., 2002).

Finally, in the study by Hermann (1991) 93% of the silo-users indicated that their house is now cleaner compared to the before adopting the metal silo, i.e. when they used traditional storage methods only (less insect pests, rodents). Better nutrition and hygiene were also found to have a positive effect on health (especially for children). Moreover, farmers indicated they had less risks and health problems using aluminum phosphine in a hermetically sealed metal silo than when applying other storage pesticides in traditional storage systems (Gladstone et al., 2002)

All above-mentioned studies were conducted during the implementation phase of the Postcosecha Program and thus provide an interim evaluation of the program impact. In the present study we aim to give an ex-post assessment of the program impact. In particular, the present study’s objectives are: (i) to identify factors that significantly contributed to the adoption of the metal silo in the mentioned countries; and (ii) to assess the impact of the adoption of the metal silo storage technology on the food security and well-being of rural households. To evaluate the impact of the metal silo, a household survey and an examination of existing secondary data on the number of disseminated silos was conducted in 2009. Based on the survey data, this paper presents an in-depth analysis of selected aspects pertaining to the effect of metal silo adoption on food security, well-being and grain-selling dynamics of the staple-grain-producing households.

The remainder of the paper is organized as follows. Section 2 describes the methodology and the data employed to analyze factors of the technology's adoption and the effect of the adoption on household food security and well-being. Section 3 presents the estimation results, while Section 4 draws conclusions and policy implications.

2. Data and Methodology

2.1. Data

The study utilizes data from a survey conducted with 800 non-users and 800 users of metal silos. Each of the four considered countries was represented by 200 users and 200 non-users. However, after calibrating the data, the initial sample size was reduced to 1,535 households.

The selection of the interviewed households was carried out by applying a random sampling procedure with multi-stage cluster sampling. The main selection criteria were the following: farms have (i) to be situated in one of the main maize-producing zones in each of the four countries; (ii) to be small and medium-sized maize farmers with up to 15 manzanas (i.e. 10.5 hectares) of their own land were selected; (iii) to produce and store primarily maize grain (in metal silo or other storage methods).

The structured interview with the surveyed households considered the following aspects[3]:

- basic individual characteristics such as, e.g. household owner's sex, age, education level, and family size;
- production-related characteristics, e.g. area of self-owned and rented land, maize and beans production, number of hired workers, number of livestock, access to advisory services and credit, specialization, etc.;

[3] The complete questionnaire is available upon request.

- postharvest management characteristics, i.e. data on the acquisition of the metal silo (time, quantity), storage and use of grain in different storage systems, maize and beans sales and prices;
- impact indicators: income and employment, investments, food security, livelihoods, etc.

To assess the impact of adopting the metal silo, we focus on subsistence farms, i.e. small farms producing maize primarily for their own consumption. We define subsistence farms by selecting farms for which maize production does not exceed maize consumption by three times.[4] As a result, the number of sample farms was further reduced to a total of 1,195 farms in this part of the analysis.

The same (reduced) dataset is used to analyze determinants of the household decision to invest in a metal silo.[5] However, in the adoption analysis, we selected only those user-households that invested in a metal silo for first time between 2005 and 2009. This selection was dictated mainly by data availability.[6] Moreover, this timespan refers to the period after 2003 when the SDC stopped to provide direct support to the Postcosecha Program in all four considered countries. An additional selection criterion on the households used in the adoption analysis was that the farms had paid at least a part of the metal silo market price. This selection reduced the number of the user-households to a total of 179: 101 in Guatemala, 43 in Honduras, 21 in Nicaragua and 14 in El Salvador. The sample of 528 non-user-households consists of 141, 169, 92 and 126 households from Guatemala, Honduras, Nicaragua and El Salvador, respectively. Regarding an extremely small number of the user-households for El Salvador and their small share compared to non-user households, we decided not to consider them in further analysis.

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[4] This ratio was calculated based on the farm maize production and consumption data for 2008, which was more representative than 2009 considering weather conditions for grain production. We employ a relatively high upper limit of this indicator to consider that in bad harvest years maize production might drop substantially and thus seriously affect farm food security.

[5] We excluded from the sample farms with higher levels of self-sufficiency (i.e. maize production exceeds family consumption by three times), as the focus of our analysis is on small subsistence households. Additionally, considering that the adoption of metal silos might have been influenced for commercially-oriented farms by different factors than for subsistence farms, a joint estimation of the model for these two groups of farms might cause biased estimates.

[6] The farm responses refer to the situation in 2009, 2008, 2005 and also the year prior to metal silo acquisition, which is individual for each farm-adopter. Both periods, from 2009 to 2010 and from 2008 to 2010, were too short to form a sufficiently large sub-sample of farm-adopters. Accordingly, the period from 2005 to 2009 was the only available option for obtaining a sufficiently large sub-sample and also using the data corresponding to the same reference period for all farms.

2.2. Methodology

2.2.1.Investment decision model

To explain households' investment in metal silos, we employ a model which considers the investment decision as a two-stage process: first, the household has to decide to invest or not invest; second, if the decision is made to invest, it must decide how much to invest. To this end, the so-called double-hurdle model is employed (Cragg, 1971; Aramyan et al., 2007).

According the double-hurdle model, the households' investment decisions can be formulated as follows:

$$\mathbf{i}_j = \begin{cases} \mathbf{i}_j^* & if \quad \mathbf{i}_j^* > 0 \quad and \quad \mathbf{d}_j = 1 \\ 0 & if \quad \mathbf{i}_j^* \leq 0 \quad and \quad \mathbf{d}_j = 0 \end{cases} \tag{1}$$

where $\mathbf{i}_j$ is the observed level of investment (i.e. storage capacity of the metal silo(s) acquired by a household), $\mathbf{d}_j$ is a binary variable describing the decision to invest or not, and *j* is the household index and $\mathbf{i}^*_j$ is the latent value of the investment volume.

Crag's model consists of two regressions: a binary choice model is estimated in the first step, while the second step involves the estimation of a truncated regression model, viz:

1st step: $\mathbf{d}_j = \varphi' \mathbf{z}_j + \theta_j$ (2)

2nd step: $\mathbf{i}_j^* = \beta' \mathbf{x}_j + \varepsilon_j$ (3)

where $\theta_j \sim \mathrm{N}(0,1)$ and $\varepsilon_j \sim \mathrm{N}(0, \sigma_\varepsilon^2)$. Vectors $\mathbf{z}_j$ and $\mathbf{x}_j$ are the vectors of explanatory variables in binominal and truncated regression models, respectively.

Accordingly, in our empirical analysis we employ two dependent variables: a binary variable signaling whether or not a particular household acquired a metal silo in from 2005 to 2009, and a further variable which represents the capacity of the respective metal silo(s).[7] The vector of explanatory variables consists of different socio-economic characteristics of the sample households and is summarized in Table A1 (Appendix).

2.2.2.Modeling impact of metal silo adoption

The impact of using metal silos is investigated by focusing on 3 main aspects: a) food security; b) farmers' (and their families') well-being; and c) sales of maize. We employ linear

[7] In the truncated regression, we use the Box-Cox transformation of the dependent variable.

regression models to assess how the metal silo adoption influences food security and sales of maize.

Food Security

To assess differences between silo users and non-users with regard to food security, farmers were asked how many months they had to buy (i.e. in addition to their own production) maize and beans. These questions covered the years 2008 and 2009. The average value of both years is used in the subsequent analyses. The investigated hypothesis is that silo users need to buy less staple grains from the market and can use their own production due to better storage capacities (Hermann, 1991; Coulter et al., 1995; Gladstone et al., 2002). In a first step, empirical density functions of users and non-users are presented for each of the four countries (Guatemala, El Salvador, Honduras, Nicaragua). Because maize and bean production and consumption differ across these countries, we use a regression analysis to test if silo users in general need to buy less maize and beans.[8] Since the dependent variable is censored (by 0 from the left and 12 from the right), we use a tobit model, in which the numbers of months farms need to buy maize and beans ($Months_C$) are regressed against dummy variables for countries ($D_{Country}$, Guatemala is chosen as reference category), for silo non-use (the use of silos is the reference category), as well as interaction terms between both dummy variables, where β_0 is the regression intercept:

$$Months_C = \beta_0 + \beta_1 D_{Non-User} + \beta_2 D_{Country} + \beta_3 D_{Non-User} * D_{Country}. \qquad (4)$$

Livelihoods

To assess the impact of metal silos on non-economic factors (e.g. health, gender and education issues), as well as on factors that are difficult to quantify (e.g. income), farmers were asked how their situation changed from 2005 to 2009 with regard to the following variables: the family's food situation; the family's income situation; the workload of women; children's health situation, and the children's education situation. Thus, the questions covered aspects from various important fields, i.e. improvements in economic status, food security, gender and children's situation were considered. The answer scale ranged from 1 (high improvement) to 5 (severe worsening), while 3 indicates no changes. Category 6 was used if the interviewee indicated 'I don't know'. We test the hypotheses that silo users faced better economic and social development. This is motivated by the fact that silo adoption allows

[8] We included a control question regarding how many months farmers' own production of maize and beans was sufficient for family food provision. This variable confirmed the presented results.

adopters to generate more income and to reduce their workload, as well as that silo users are more resilient to certain shocks (e.g. price fluctuations, bad harvest). In a first step, cross tables and Pearson Chi-Square tests are used to identify whether significant differences between users and non-users exist. In a second step, regression analyses are used to also consider country-specific effects (and interaction terms) following the tobit regression approach described in Equation 4.

Sales of Production

We expect differences in the sale of stored grain and grain that is not stored (but sold immediately after harvest) with regard to the timing and location of sales as well as with regard to the distribution channel used. These differences are also expected to cause a variation in the received grain prices for different storage technologies. The analyses presented in this section are focused on maize because it is the most important crop for the interviewed households.

To investigate whether the location of maize selling is affected by storage technology, the questionnaire included a question asking where maize was sold. The answer categories were as follows: on (one’s own) farm; in the village; on the road; in the district town, others. Following the same structure, to whom the maize was sold was also asked. More specifically, the following answer categories were used: intermediates, retailers, super markets, farmers’ organizations, direct sales to consumers, others. Furthermore, farmers indicated in which month they sold most of the maize and what price they received, on average. These questions were asked separately for the different categories of maize storage, i.e. for i) maize that is not stored; ii) maize stored in metal silos; and iii) maize stored in other storage systems.

For maize that is sold mainly directly after harvest, no difference between metal silo users and non-users are expected regarding the selling location and time, purchaser and price. In contrast, we expect differences between maize that is not stored and stored maize, because maize storage in general enables farmers to decide tactically where, when and at which price maize is sold. Moreover, we expect that maize stored in metal silos can be kept longer than traditionally stored maize. Thus, the selling time as well as the price is expected to differ between these storage types. In order to test these hypotheses, we use cross tables and Pearson chi-square tests. In addition, group comparisons are conducted using the Mann-Whitney test. To test if maize prices from different storage systems lead to different prices, we use a regression analysis that also accounts for country-specific price differences:

$$Price = \beta_0 + \beta_1 D_{Storage\,Type} + \beta_2 D_{Country}. \quad (5)$$

The dummy variable for the storage type ($D_{Storage\,Type}$) uses maize that is not stored as a reference category, while Guatemala is used as a reference category for the country dummy ($D_{Country}$). Note that price data was only indicated by some farms, and interaction terms are thus not considered due to the lack of freedom in specific category combinations. All prices were given in local currencies and are converted into USD/qq in the presented results.

3. Empirical results

3.1. Investment decision analysis

Table 2 summarizes the estimation results of the double-hurdle model for three countries considered in this part of the analysis, i.e. Guatemala, Honduras and Nicaragua. We completed model estimations for the whole sub-sample, i.e. considering all three countries, and separately for Guatemala and Honduras. As the number of the relevant user-households for Nicaragua is rather small, we do not estimate the double-hurdle model for it separately. Additionally, as several farm characteristics have exhibited a substantial degree of correlation, we do not estimate the model employing all relevant farm characteristics, but only those which showed a low degree of correlation among each other and which have obtained significant parameter estimates.[9]

The first step model estimates (i.e. estimates of the logistic regression model) for three countries show that the decision to invest varies significantly across the countries considered in the analysis.[10] In particular, the adoption of metal silos has been more extensive in Guatemala (the reference country) than in Honduras and Nicaragua in recent years. On the one hand, this might be related to dynamics of the metal-silo adoption in single countries. On the other hand, the adoption rate might be strongly influenced by governmental policies. Considering that more governmental efforts have been undertaken to disseminate metal silos in Guatemala, our finding is indeed in line with the empirical evidence.

[9] For example, several farm characteristics representing farm size, e.g. crop land, number of employees, etc., had a rather high correlation with the household maize self-sufficiency indicator.

[10] This result might, however, be related to the sample composition in this part of the analysis, in particular the share of user-households in the total number of households are substantially lower for Honduras and Nicaragua than for Guatemala. If this composition of the sub-samples corresponds well to the real situation, then our finding is correct. Conversely, if the sample composition does not represent the actual stratification of the farmers, than this estimation result is biased due to inappropriate sampling.

Furthermore, according to our estimates significant differences in investment behavior exist regarding the age of the farm head, land ownership, completion of a training course, extent of maize self-sufficiency (calculated in months a household can cover its maize consumption by stored maize) and use of an alternative storage capacity such as metallic or plastic barrels, conical metal silos, etc. In particular, the estimation results show that the probability of the adoption decision declines with the age of the household head. This result is consistent with theoretical expectations (Rogers, 2003) and findings of other empirical studies for both developing as well as developed countries (Barham et al., 2004 Ersado et al., 2004), which suggests that older people are more reserved regarding the introduction and acceptance of innovations due to declining cognitive and learning abilities. The possession of an alternative storage system also diminishes the probability of metal silo adoption. This result is very rational – a household's need for storage capacity declines if it already possesses an acceptable alternative storage system (e.g. metal or plastic barrels, conical silos).

Though we did not obtain a significant parameter estimate for the variable characterizing the household head's education[11], the variable 'training' (access to training and advisory services for grain production) has a highly significant positive parameter estimate. The latter suggests that knowledge of production technology seems to spark the household's interest in metal silo acquisition. In our view, this result might be explained in two ways. First, training allows farmers to obtain new knowledge and thus become more aware of possibilities for more efficient utilization of their resources as well as farm organization. Second, training courses present an important communication channel for disseminating information about new technological solutions available on the market, and therefore play an important role in improving farmers' access to relevant markets and production factors.

A larger share of owned land in farm cropland also has a significant impact on the investment decision. On the one hand, farms that possess a larger portion of their cropland are wealthier and thus might more easily afford a metal silo than less wealthier farms.[12] On the other hand, they might be also more eager to invest in their farm in general, as they have less uncertainty regarding their land property rights, as well as a lower extent of agency costs due to potential information asymmetries between the land owner and tenant.

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[11] As can be seen from Table A1 in the Appendix, educational background does not vary sufficiently across household heads; most household heads are alphabetized or have completed primary school. This low variation in educational background can explain insignificant parameter estimates for this variable.

[12] Also, farms with a higher level of land ownership might more easily gain access to a credit for buying a silo, as they can use their own land as collateral.

Finally, the probability of metal silo adoption increases with a household's maize self-sufficiency. This result is in line with the empirical evidence provided by other studies (e.g. Hermann, 1991), in particular farms with lower levels of self-sufficiency often do not produce enough maize to fill a metal silo. Hence, metal silos present an effective instrument primarily for households with a higher level of self-sufficiency, while other policy instruments might be more effective for households with lower self-sufficiency levels. In particular, for the latter group of farms instruments aimed at an increase of productivity through access to more advanced production technologies might trigger a more significant shift in food security and well-being.

The separate estimation of the logistic regression models for Guatemala and Honduras shows that different socio-economic characteristics determine the adoption decision in these two countries. Whereas in Guatemala the decision to acquire a metal silo is influenced significantly by the completion of a training course and the use of an alternative storage system, the main determinants of silo adoption in Honduras are age and the extent of land ownership. The only variable which obtained a significant parameter estimate for both countries is maize self-sufficiency.

Table 2 around here

The second-step estimates (i.e. the truncated regression model estimates) also suggest the presence of significant differences in investment behavior of farms in different countries. Though none of the considered farm characteristics obtained a significant parameter estimate in the pooled truncated regression model, the overall significance of the model is high, which obviously pertains to the usage of the country dummies. In addition, the estimation results indicate that the investment extent is significantly higher in Honduras, i.e. the farms in this country invest in larger metal silos. This result presumably is related to the fact that farms in Honduras are on average larger than in Guatemala, and compared to farms in Nicaragua specialize more on maize that requires larger storage capacities than beans.

The extent of investment in Guatemala has been found to vary only subject to the provision of governmental subsidy, i.e. farms that receive a subsidy have a tendency to buy an additional silo thereafter. The estimates of the model for Honduras show that the extent of adoption (i.e. the storage volume) depends significantly on the age of the household. However, in contrast to the first-step model estimates, the parameter estimate for the age variable has a positive sign in the second-step model. Still, the results of the first- and second-step model estimates do not contradict each other. The first-step estimates show that in general, adopters are younger than non-adopters. The second-step estimation results indicate that among the adopters, older farmers tend to acquire larger storage capacities. Older farmers usually have larger families than their younger counterparts, and thus require more storage capacity. Our results also show that larger metal silos are usually requested by farms with a larger crop area. Access to electricity, which can be used as a proxy for infrastructure development, has a significant impact on investment volume; this suggests that farms with better access to markets, i.e. lower transaction costs, invest significantly more.

3.2. Impact assessment

4.2.1 Food Security

Figure 1 shows the empirical density functions of months per year the surveyed farm-households had to buy maize from the market. All interviewed farms produce maize and thus at least partially use their own production, while the majority of farms are rather independent from additional buying. For all countries, we find that metal silo users need to buy maize from the market in fewer months.

The results for beans, which are presented in Figure 2, contrast our findings for maize. It shows that in all countries, two groups of producers exist that either produce almost enough for their own consumption, or buy most of their beans from the market. The second group of farmers is well represented in Guatemala and El Salvador, while farms in Nicaragua are rather focused on their own bean production. The strongest differences between metal silo users and non-users are indicated for El Salvador, where users tend to rely much less on their own bean production and buy more beans from the market.

Figures 1 and 2 around here

The results of the tobit model estimation presented in Table 3 show that non-users need to buy maize in (significantly) more months than metal silo users. Country effects show that households in El Salvador need to buy (on average) less maize and beans (also for Nicaragua) than in Guatemala, which is the reference category in our analysis. For the number of months of beans purchasing, no general impact of silo use is found. However, the significant interaction effect of the dummy for silo non-use and the dummy for El Salvador shows that silo users in this country need to buy beans in fewer months (compared with those in Guatemala). The latter result is furthermore underpinned by the empirical density function presented in Figure 2, where the largest difference between metal silo users and non-users was indicated for El Salvador.[13]

For the interpretation of the presented results on the relationship between metal silo use and food security, it is important to take into consideration that metal silo users are usually characterized by a higher degree of self-sufficiency (cp. section 4.1). Thus, silo users already relied less on buying maize and beans before they acquired the metal silo. Therefore, the presented results are caused by the effect of the metal silo but also by higher general production levels of these farms.

Table 3 around here

4.4.2 Farmers' Well-being

Cross tables for all answer categories (i.e. on developments of the family's food situation, the family's income situation, the workload of women, children's health situation, and the children's education situation) show significant differences between metal silo users and non-users (not shown). In order to test whether metal silo users tend to assess their situation more positively than non-users, regression analysis was used. Table 4 shows the results of the regression analysis on the assessment of these economic and social aspects of well-being. Note that answer scales range from 1 (high improvement) to 5 (severe worsening), while 3 indicates no changes. Answers that indicated "I don't know" were not considered in the regression analysis.[14] The estimation results show that in all categories, households from Guatemala (reference category) indicated the smallest values, i.e. the best situation, because dummies for all other countries are significantly positive. More importantly, non-users had significantly higher (i.e. worse) responses compared to metal silo users. Thus, metal silo users assessed the development economic and social aspects more positively.

We also asked farmers to indicate the main reason for positive developments in their food security and income situation in an open question. Farmers frequently mentioned increased off-farm employment as a contributing factor for improved food security and income. The reduction in workload for women is explained by the change in postharvest operation, which also requires a different division of labor. Due to the need for shelling, removing the kernels

[13] We also included a control question in the survey on how many months households could cover their consumption from stored grain (maize and beans) production. These results confirmed the presented results: metal silo users indicated a higher degree of self-sufficiency.

[14] Furthermore, missing values are generated if the question did not apply for certain interviewed families (e.g. they had no children).

from the spindle and drying all the grain at once for filling the silo, men are more actively engaged in these operations and sometimes use machines, thereby considerably reducing the workload of women. In addition, the removal of grain from the silo for daily consumption, mainly done by women, is more convenient compared to the traditional method of daily shelling and kernel removal.

Table 4 around here

4.4.3 Selling of Maize

Table 5 shows the selling location for maize that is not stored, distinguished for metal silo users and non-users. It shows that after harvest, maize is mainly sold at the farm and the village. As expected, no difference for maize that is not stored is indicated between users and non-users of metal silos. The analysis of the purchaser of maize that is not stored and usually sold immediately after harvest also reveals no differences between users and non-users of metal silos: more than 75% of all considered farmers sell their maize that is sold immediately after harvest to intermediaries, while the rest is mainly sold directly to consumers (not shown).

Table 5 around here

In order to compare the selling location and purchaser of stored maize and maize that has not been stored, we focus our analysis on metal silo users.[15] Among the users, details of selling of maize that is not stored are reported from 225 farms, while 123 observations are available for maize stored in metal silos. Details on selling maize stored in other systems were reported by 89 farms. Table 6 shows relative frequencies (in %) for the selling location, purchaser, as well as main month of selling. It shows that stored maize is rather sold in the village (67%) compared to the on-farm selling (52%) of maize that has not stored. While the latter is mostly (76%) sold to intermediaries, direct selling to consumers is more important (50%) for stored maize. With regard to selling location and purchaser, maize stored in other systems ranges between maize that is not stored and maize stored in metal silos. It is also mainly sold in the village or the district's town, but is less often sold directly to the consumer compared to maize stored in metal silos.

Also, the time of selling varies significantly: the main selling month of maize that is not stored is directly after harvest, while 74% of the farmers indicated the period from November

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[15] This restriction on adopters is necessary to ensure that we compare farms at the same level of consumption and selling patterns.

to January as the main selling time. In contrast, metal-silo stored maize is mainly (73%) sold from March till July, which is the most critical period before the new harvest, when selling prices are highest. Maize stored in other systems is sold on average after maize that is not stored but before metal-silo-stored maize, with June and May being the main selling months[16].

Table 6 around here

In order to compare the received prices for maize from different storage systems, we used observations from all 1,195 sample farms. Figure 3 shows box plots of price levels, where all values are converted to USD/qq; it shows that stored maize generates, in general, higher prices than maize that has not been stored (and sold immediately after harvest). Moreover, prices for maize stored in metal silos seem to be on average higher than for maize from other storage systems.

Figure 3 around here

In order to also account for different price levels in the four considered countries, we conduct a regression analysis that uses dummy variables for countries and storage system terms (see Equation 5). The results presented in Table 7 show that maize price levels in El Salvador and Nicaragua are lower than in Honduras and Guatemala (the reference category of this analysis). Moreover, it shows that if these country-specific effects are considered, maize stored in metal silos leads to an average price markup of 1.85 USD/qq, while maize stored in other storage systems generates a price markup of 1.46 USD/qq compared to maize that has not been stored.

Table 7 around here

Conclusions

Postharvest yield losses are a major factor negatively affecting rural household food security in Central America. From 1983 to 2003, SDC implemented the Postcosecha Program, which aimed at reducing small farmers' postharvest losses by supporting the manufacture and use of metal silos. This study evaluates determinants of the adoption and impact of metal silo use on food security and well-being of rural households in in El Salvador, Guatemala, Honduras and Nicaragua from 2005 to 2009.

[16] Maize that is not stored is mainly sold in December and January, while metal silo-stored maize is mainly sold in May and July (not shown).

Our analysis is based on the survey data of 1,600 small grain-producing farmers in the abovementioned countries. As the focus of the study is on subsistence farms, the study utilizes data from those households for which the production of maize does not exceed its consumption by three times. We employ a so-called double hurdle model to analyze farm adoption decisions and standard regression models to evaluate the impact of the adoption.

Our estimation results show that both the demand for metal silos and the impact of their adoption was different across the four considered countries. According to the model estimates, the highest demand, as well as the highest impact of the metal silo adoption from 2005-2009 was observable in Guatemala. This result suggests that this country has apparently found a very effective policy for metal silo dissemination. In contrast to the other three examined countries, where the government might ad hoc disseminate metal silos free of charge, e.g. prior to an election, the government of Guatemala provides regular support in the form of a subsidy to small farmers interested in acquiring metal silos. Additionally, among the considered farms, farmers from Guatemala have reported more often that they have access to extension services in the form of training in a grain production subject.

Furthermore, our estimates indicate that household self-sufficiency in maize is an important factor for explaining farms' demand for metal silos. This result suggests that investment in a postharvest technology is most effective for subsistence farms with higher levels of self-sufficiency in maize, while alternative strategies such as, e.g. technological solutions for productivity improvements, might be more desired by subsistence farms with lower levels of self-sufficiency. Furthermore, the adoption of metal silos is influenced by a group of socio-economic characteristics of the households such as the household head's age, land ownership, access to extension services and quality of basic infrastructure.

Considering a group of economic and social indicators of household well-being, we found that compared to the non-adopters, the adopter households experienced a significantly higher improvement in their well-being from 2005 to 2009. For instance, our analysis shows that users experience a better situation with regard to the education and health status of their children, especially due to more financial freedom (due to buying less food and improved management of harvest selling). Thus, this instrument has direct spillovers (and multiplier effects) on future generations, ensuring sustainable long-term improvements. Furthermore, households indicated that the silo reduces women's workload due to the absence of daily shelling and removal of grains, which reduces gender inequalities. Therefore, the promotion of metal silos seems to provide a path for sustainable social and economic development, which should be considered when evaluating policy. Households were also asked to assess the development of their food security in this period; metal silo users indicated much better development than non-users.

Our results on maize-selling patterns showed that metal silo users are much more flexible regarding when and where to sell their harvest. Primarily, this provides higher economic returns for the users. However, this also has an indirect effect on other households. Because the supply of food from local producers is not limited to harvest periods, price peaks on local markets are expected to decline. Thus, this storage technique is expected to contribute to less variable prices and more affordable food for poor households.

The results of the analysis allow two important policy implications to be derived. First, more targeted policies are required. This aspect primarily concerns the design of policy instruments considering different households clusters. In particular, policy design should differentiate between the needs of and effective instruments for farms performing under and over the subsistence level. Additionally, as our results suggest that factors determining the adoption of an innovative technology might vary from country to country, when developing policy instruments more attention should be paid to regional specifics and should incorporate a careful examination of the main needs and limitations to development in each country. The example of the subsidy model in Guatemala targeting poor rural households is interesting in this respect. Second, regarding the relatively low educational level of farmers, more efforts should be carried out to improve farmers' professional skills, as well as their access to and awareness of innovative technological solutions.

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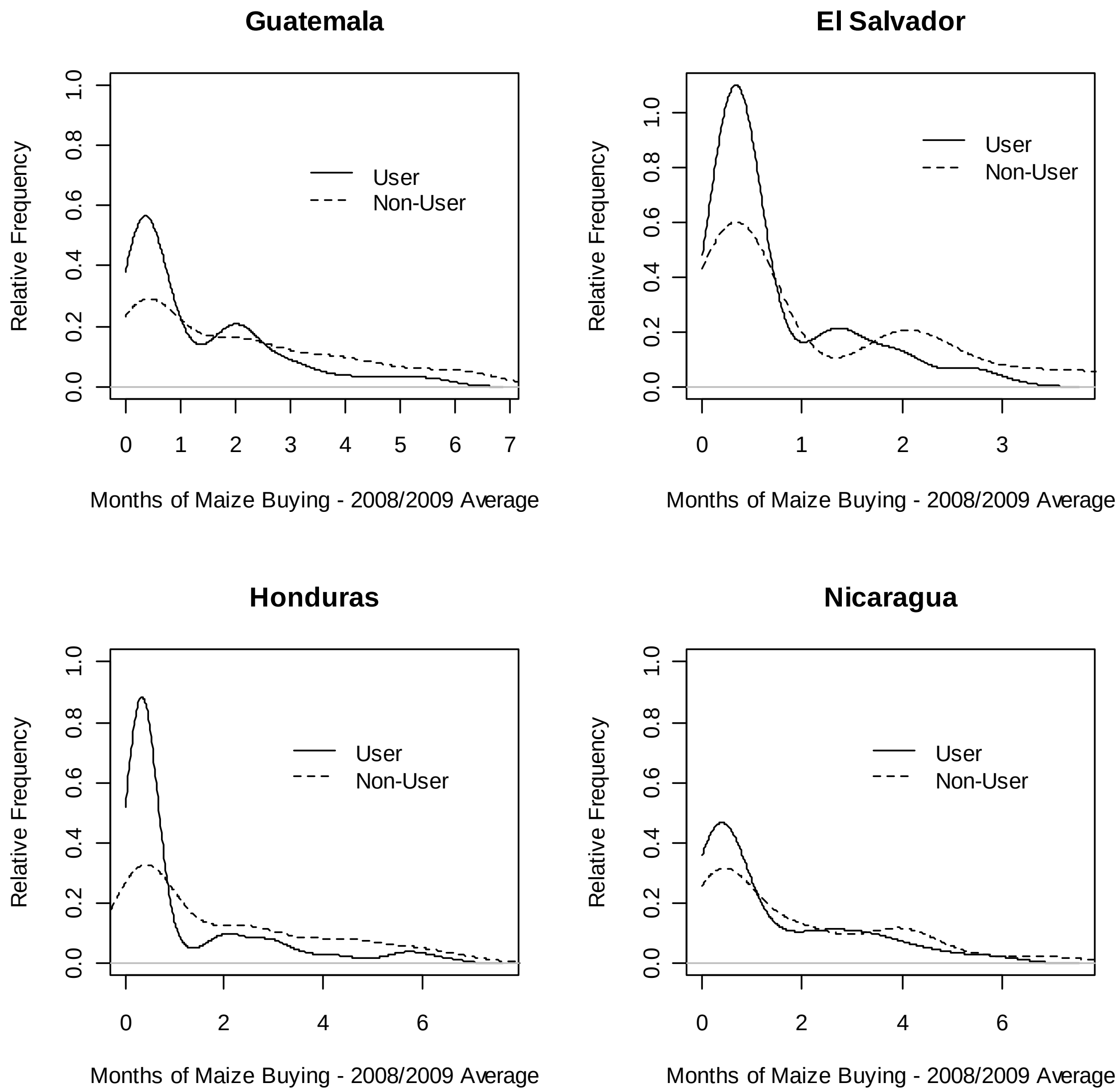

Figure 1. Months of the year the surveyed farm-households had to buy maize from the market.

Source: authors' estimates.

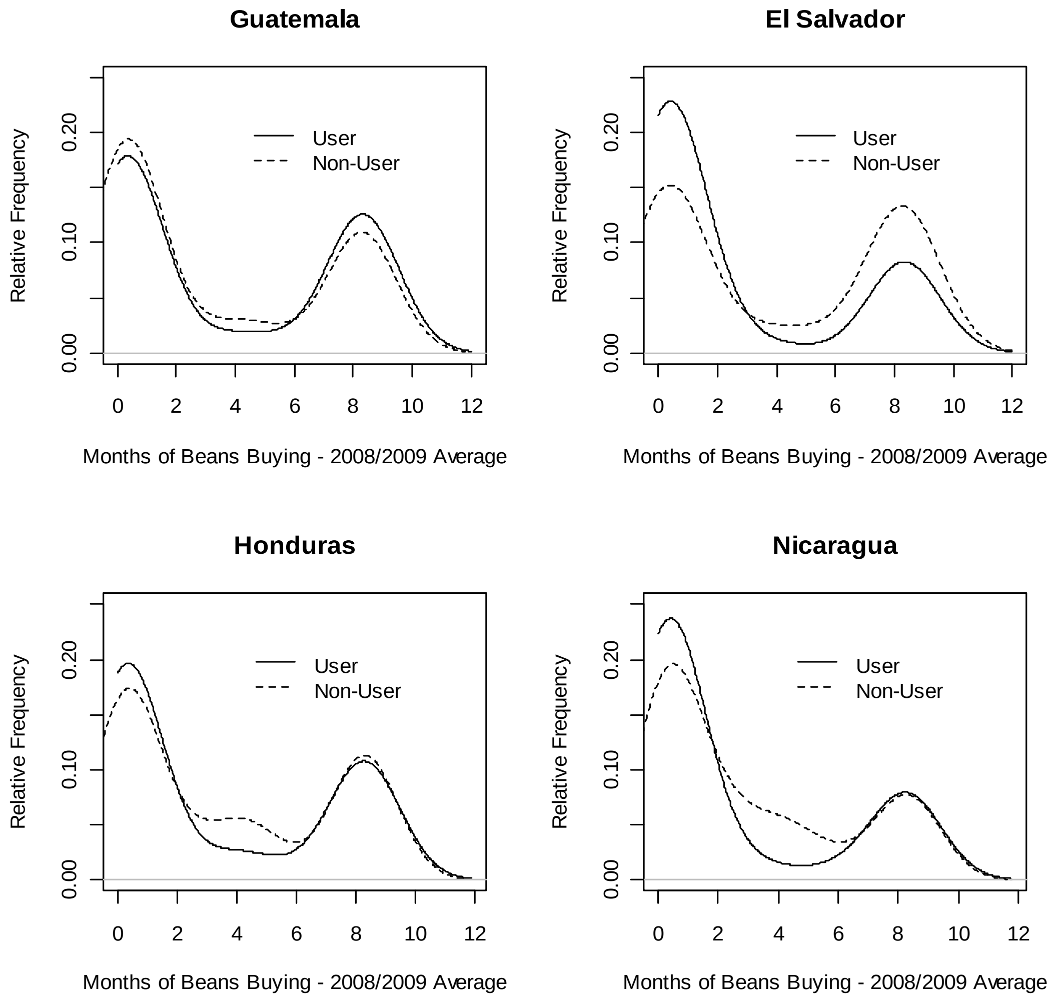

Figure 2. Months of the year the surveyed farm-households had to buy beans from the market.

Source: authors' estimates.

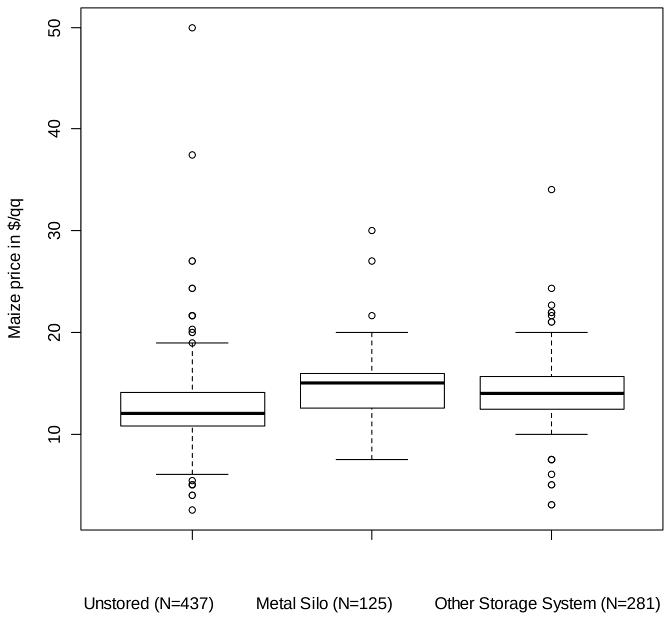

Figure 3. Maize price by storage system.

Source: authors' estimates.

Table 1. Adoption of plane metal silo for grain storage according to countries and periods

Country	Number of metal silos disseminated			Number of households using silos in 2009[2]
	1983-2003	2004-2009	Total 1983-2009	
Honduras (1983)[1]	147,427	81,381	228,808	133,850
Guatemala (1990)[1]	103,374	137,994	241,368	158,430
Nicaragua (1992)[1]	59,618	60,785	120,403	68,710
El Salvador (1994)[1]	46,190	30,188	76,378	52,880
Total	**357,339**	**310,348**	**667,687**	**413,870**

Notes: [1] Refers to the official start of the Postcosecha Program by SDC. Some pilot activities producing a small number of metal silos occurred beforehand. Official support by SDC ended in December 2003. [2] assessed considering: a) the number of the metal silos used per household; and b) a lifespan of 15 years for the metal silo.

Source: SDC, 2011

Table 2. Estimates of double hurdle model

Variables	All 3 countries		Guatemala		Honduras	
1. step						
dummy Honduras	-1.03	***	--		--	
dummy Nicaragua	-1.15	***	--		--	
age	-0.02	*	--		-0.11	*
age^2	--		--		0.00	
ownership	0.13	**	--		0.21	**
dummy training	0.62	***	0.74	**	--	
maize self-sufficiency	0.19	***	0.24	***	0.20	**
dummy altern. storage	-0.51	**	-1.05	***	--	
dummy coffee	--		2.11	**	--	
constant	-4.24	***	-2.95	***	-1.23	
Number of observations	566		241		212	
R2	0.10		0.11		0.08	
LR chi2	70.89	***	37.50	***	16.04	***
2. step						
dummy Honduras	0.35	***	--		--	
dummy Nicaragua	0.12		--		--	
age	--		--		0.01	***
crop area	--		--		0.06	**
dummy electricity	--		--		0.31	***
dummy subsidy	--		0.15	*	--	
constant	3.13	***	2.56	***	2.15	***
Number of observations	165		101		43	
Wald chi2	12.09	***	2.80	*	20.58	***

Note: *, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively.
Source: authors' estimates.

Table 3. Tobit regression analysis on the determinants of number of months when additional food buying was necessary (average values for 2008/2009).

	Number of months when maize has to be bought	**Number of months when beans has to be bought**
Intercept	-0.23***	3.69 ***
Dummy Non-User (vs. User)	0.44 ***	-0.35 (n.s.)
Dummy El Salvador[1]	-0.42***	-1.16***
Dummy Honduras[1]	-0.27**	-0.43 (n.s.)
Dummy Nicaragua[1]	0.02 (n.s.)	-1.20 ***
Dummy Non-User x Dummy El Salvador[1)]	-0.13 (n.s.)	1.90 ***
Dummy Non-User x Dummy Honduras[1)]	0.14 (n.s.)	0.70 (n.s.)
Dummy Non-User x Dummy Nicaragua[1)]	-0.17 (n.s.)	0.80 (n.s.)
Observations	1195	1195
Log-likelihood	-1534	-3212

Note: [1)] Country specific effects are evaluated against Guatemala as reference category.

Source: authors' estimates

Table 4. Regression analysis on the assessment of economic and social aspects of family well-being

	Food Aspects	**Family Income**	**Women Workload**	**Children's Health**	**Children's Education**
Intercept	2.27 ***	2.46 ***	2.70 ***	2.41 ***	2.48 ***
Dummy Non-User (vs. User)	0.50 ***	0.41 ***	0.28 ***	0.28 ***	0.18 **
Dummy El Salvador[1]	0.46***	0.37 ***	0.33 ***	0.26 ***	0.20 **
Dummy Honduras[1]	0.25 ***	0.18 **	0.19 ***	0.28 ***	0.11 (n.s.)
Dummy Nicaragua[1]	0.78 ***	0.57 ***	0.23 ***	0.57 ***	0.22 ***
Dummy Non-User x Dummy El Salvador[1]	-0.42 ***	-0.25 (n.s.)	-0.30 ***	-0.19 **	0.02 (n.s.)
Dummy Non-User x Dummy Honduras[1]	-0.28 **	-0.14 **	-0.17 **	-0.18 **	-0.11 (n.s.)
Dummy Non-User x Dummy Nicaragua[1]	-0.41 ***	-0.34 ***	-0.26 ***	-0.33 ***	-0.23**
Degrees of Freedom	1176	1163	1080	1150	1099
Adjusted R2	0.11	0.07	0.03	0.06	0.02

Note: [1)] Country-specific effects are evaluated against Guatemala as reference category.

Source: authors' estimates.

Table 5. Location of selling for maize that is not stored.

P_IV.2_1d	**Users**	**Non-Users**	**Row Total**
Farm	116	111	227
Village	87	87	174
Road	8	1	9
District town	10	8	18
Other	4	5	9
Column Total	225	212	437
Pearson's Chi-squared test statistic		5.50 (n.s.)	

Note: [1)] several households did not indicate sufficient details on maize selling and the total number of observations decreased from 1,195 to 437. *Source:* authors' estimates.

Table 6. Analysis for silo users: stored maize vs. maize that is not stored - location and time of selling and purchaser.

	Maize that is not stored (N=225)	Metal Silo Stored Maize (N=123)	Maize stored in other system (N=89)
Selling Location			
Farm	52%	24%	24%
Village	39%	67%	57%
Road	4%	1%	1%
District town	4%	7%	11%
Other	2%	2%	7%
Pearson's Chi-squared test statistic		49.26***	
Purchaser			
Intermediaries	76%	41%	54%
Commercial house, Supermarket, and Farmers' Organization	0%	2%	5%
Direct to consumer	20%	50%	34%
Others	3%	7%	7%
Pearson's Chi-squared test statistic		56.12***	
Month of Selling			
August- October	12%	7%	14%
November-February	79%	20%	36%
March-July	9%	73%	50%
Pearson's Chi-squared test statistic		302.85***	

Source: authors' estimates.

Table 7. Regression analysis: maize price for different storage systems.

	Maize Price in USD/qq
Intercept	13.70 ***
Dummy Storage Metal Silo (vs. maize that is not stored)	1.85 ***
Dummy Other Storage System (vs. maize that is not stored)	1.46 ***
Dummy El Salvador[1]	-1.38 ***
Dummy Honduras[1]	0.54 (n.s.)
Dummy Nicaragua[1]	-2.75 ***
Degrees of Freedom	837
Adjusted R2	0.14

Source: authors' estimates.

Notes: [1)] Country-specific effects are evaluated against Guatemala as the reference category.

Appendix

Table A1. Descriptive statistics of variables employed in the double hurdle model

Variable	Description	165 metal silo users				401 non-users			
		Mean	S.D.	Min	Max	Mean	S.D.	Min	Max
silosizesum	farm total metal silo storage capacity, quintals	15.82	7.62	0	68	0.00	0.00	0	0
age	household head age, years	44.09	14.53	18	86	45.13	14.04	18	82
education	educational background (1 - none, 5 - professional education and higher)	2.43	0.98	1	5	2.45	1.01	1	5
dummy training	1, if the household head completed a course in a grain production subject; 0 otherwise	0.32	0.47	0	1	0.15	0.36	0	1
family size	number of family members	5.27	2.46	1	13	5.14	2.26	1	14
dummy off-farm job	1, if one of the children left family to find an employment; 0 otherwise	0.22	0.42	0	1	0.26	0.44	0	1
crop area	farm crop area, manzanas	1.57	1.28	0.08	10	1.74	1.40	0.06	13
ownership	share of own land in farm crop area	1.35	1.81	0	10	1.33	1.75	0	20
dummy workers	1, if the farm employs permanent or temporal workers; 0 otherwise	0.49	0.50	0	1	0.49	0.50	0	1
dummy livestock	1, if the farm possesses livestock; 0 otherwise	0.30	0.46	0	1	0.24	0.43	0	1
cattle	number of cattle	0.58	1.30	0	6	0.74	3.34	0	50
pigs	number of pigs	0.16	0.46	0	2	0.31	1.15	0	15
dummy coffee	1, if the farm has a coffee plantation; 0 otherwise	0.07	0.25	0	1	0.05	0.22	0	1
maize self-sufficiency	number of months covering the family demand in maize from stored maize.	10.92	2.09	3	12	9.64	3.13	0	12
bean self-sufficiency	number of months covering the family demand in beans from stored beans	5.04	5.83	0	12	5.25	5.78	0	12
dummy altern. storage	1, if the farm possesses an alternative storage capacity; 0 otherwise	0.18	0.39	0	1	0.22	0.42	0	1
dummy subsidy	1, if the farm obtained a subsidy when purchasing a metal silo; 0 otherwise	0.51	0.50	0	1	0.00	0.00	0	0
dummy electricity	1, if the farm has access to electricity; 0 otherwise	0.70	0.46	0	1	0.50	0.50	0	1