Storage as a determinant of market participation: Evidence from northern Ghana

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1. Introduction

Accurate estimation of the supply response of smallholder agricultural farmers in the developing world has been a subject of continued refinement since the first description of the canonical agricultural household model with non-seperable production and consumption decisions by Singh, Squire, and Strauss (1986). Understanding the particular constraints and risks faced by these households under imperfect labor, credit, and insurance markets is key for policymakers to understand the food security implications of agricultural shocks and policies (see de Janvry and Sadoulet (2006) for a useful overview of the agricultural household literature). For instance, a positive price shock for a staple food item may be beneficial or disastrous for a household depending on its status as a net consumer or supplier of that staple in a given year. For the autarkic household, the price shock may be irrelevant. Aggregate supply elasticies are determined not only by the continuous change in supply due to the households which always supply, but also the number of households which switch from autarky to market participation as a seller. So that accurate estimations in these changes in aggregate supply can be made, it is necessary that we understand the model elements upon which the household makes its market regime decision. At the same time, encouraging smallholder participation in markets has been an ongoing policy goal in the developing world both, as a way to improve household welfare via gains from specialization Manda et al. (2020), and to promote agricultural productivity growth Barrett (2008).

From the empirical literature, important factors affecting market participation are distance to markets (Miteva et al., 2017) and market information (Ouma et al., 2010). Bellemare and Barrett (2006) used an ordered Tobit model to study the choice process of market participation among livestock pastoralists in Kenya and Ethiopia, finding evidence of sequential decision making, where the household first decides whether to sell, then contingent on that decision determines amount.

One of the elements needed to understand of household supply response is its decision to store grain for later sale, consumption, or use as an agricultural input in future production. Saha and Stroud (1994) develop a household model of optimal storage under price uncertainty with the goal of examining evidence for three explanations for the prevalence of household storage: 1. Speculative price arbitrage motivations, 2. Risk-averse consumptive insurance and 3. Convenience yield. They find that their model and data reject risk-neutral household preferences, providing strong evidence for storage as a risk-reducing activity. Park (2006) develops an infinite-time horizon dynamic stochastic household model that includes storage and proportional transaction costs but not fixed transaction costs. He calibrates the model to Chinese maize production data, and also finds that households store grain as a precaution since it is also consumed. He does not estimate anything empirically, but rather simulate his model using parameters calibrated for a particular setting. He finds a relatively narrow price band where the household's net purchases of grain is zero, and a non-monotonic storage response to price, with low storage at high and low prices, but high amounts storage at moderate prices. Cardell and Michelson (2023) find that, while there is significant price variability between rainy and dry seasons, the risk that the high price in the dry season may not rise above the price at harvest often enough that even moderately risk averse households may not be motivated to store, even when facing apparent price arbitrage opportunities. Luo et al. (2022) ask a similar question to ours, estimating the effect of losses in maize storage on market participation using a fractional logit model with cross-sectional data. They find that maize losses increases sales volume, and reduces time to sale for stored maize.

Key, Sadoulet, and Janvry (2000), to whom we owe our conceptual framework, develop a household model based on the canonical agricultural household model, with the addition of fixed and proportional transaction costs. They show that these transaction costs result in a "price band", which is a range of prices over which a household will optimally remain autarkic rather than engage in the market as either a net buyer or seller. Using data on maize production in Mexico, they find that transaction costs do indeed have statistically significant effects on the threshold at which a household will sell.

As described below, we use this model and include the choice of storage for one period, focusing on the impact that stored grain from the previous period has on the household's market participation decision in the current time period. This motivates our empirical estimation, and provides theoretical basis for our instrument for endogenous storage. Our hypothesis is that the inclusion of storage widens the "price band" over which the household remains autarkic, and that storage in the current time period will be negatively related to the choice to sell, but that previously stored grain will make a household more likely to enter the market as a seller. Relative to Park (2006), we contribute to the literature by testing this hypothesis using a household-level panel of yield, sales and input data from Northern Ghana. Using prices as instruments for endogenous past storage and rainfall data as an instrument for endogenous yield, we estimate a two stage least squares model with household fixed effects, finding that storage in the previous period has a positive and statistically significant effect on market participation in the current period. Our estimated coefficient on storage in the current period is negative, but no statistically significant effect on market participation as a seller.

This result suggests that policymakers in similar agricultural economic settings to northern Ghana should household consider stocks of grain commodities when attempting to estimate households agricultural supply responses, and that household level storage is an important determinant in household market participation that should be considered by institutions working to integrate smallholder farmers into wider agricultural commodity markets.

2. Model

2.1 Partial equilibrium

We use the household production model with transaction costs by Key, Sadoulet, and Janvry (2000) to describe the impact of storage in the previous period on selling. In contrast to the original model, we include storage and consider interrelated decisions over 2 periods. For simplicity, we assume no proportional transaction costs as in Renkow, Hallstrom, and Karanja (2004) and focus on a single commodity. We also focus on the interior solution so that our constraints are binding. The household faces the following utility maximization problem:

$$\max_{c_t, m_t, q_t, s_0} U(c_t; z_h)$$

s.t.

$$p_0 \delta_0^S m_0 - w_0 x_0 + T_0 - tf_0 = r\left(p_1 \delta_1^S m_1 - w_1 x_1 + T_1 - tf_1\right) = 0 \tag{1a}$$

$$q_0 - c_0 - m_0 - s_0 = 0 \tag{2a}$$

$$q_1 - c_1 - m_1 + s_0 = 0 \tag{2b}$$

$$G(q_0, x_0; z_h) = 0 \tag{3a}$$

$$G(q_1, x_1; z_h) = 0 \tag{3b}$$

$$q_t, c_t, x_t, s_t > 0 \tag{4a}$$

Here p_0 and p_1 are the market prices for the commodity for period 0 and 1, respectively; δ_0^S and δ_1^S are indicator variables of whether a household sold on the market in a given period; c_0 and c_1 indicate consumption; s_0 is storage in the first period; q_0 and q_1 are the quantities produced in each period, and x_0 and x_1 are inputs into production purchased at factor prices w_0 and w_1 respectively; T_0 and T_1 are exogenous wealth endowments in each period; tf_0 and tf_1 are the fixed transaction costs associated with reaching the market; $G()$ is a production function that is assumed to be constant across time given inputs; z_h are the household characteristics which would shift household consumption and the production function. These are assumed constant given the short study period. m_0 and m_1 are the quantities sold on the market in each period, and can be positive for a net seller, zero for an autarkic household or negative for a net consumer. r is an interest rate by which the second period income constraint is multiplied. (1a) defines the income constraint, (2a) and (2b) the resource constraints, and (3a) and (3b) the production constraints.

The Legrangian becomes:

$$
\begin{aligned}
L &= u(c_0; z_h) + \delta u(c_1; z_h) \\
&+ \lambda \left(p_0 \delta_0^S m_0 - w_0 x_0 + T_0 - t f_0 - r p_1 \delta_1^S m_1 + r w_1 x_1 - r T_1 + r t f_1 \right) \\
&+ \mu_0 \left(q_0 - c_0 - m_0 - s_0 \right) + \mu_1 \left(q_1 - c_1 - m_1 + s_0 \right) \\
&+ \gamma_0 G(q_0, x_0; z_h) + \gamma_1 G(q_1, x_1; z_h)
\end{aligned}
\tag{5}
$$

with the following first order conditions that hold for an interior solution (ignoring the partial derivatives with respect to the Legrangian multipliers):

$$\frac{\partial L}{\partial c_0} = \frac{\partial U}{\partial c_0} - \mu_0 = 0 \tag{6a}$$

$$\frac{\partial L}{\partial c_1} = \beta \frac{\partial U}{\partial c_1} - r\mu_1 = 0 \tag{6b}$$

$$\frac{\partial L}{\partial x_0} = -\lambda w_0 + \gamma_0 \frac{\partial G}{\partial x_0} = 0 \tag{6c}$$

$$\frac{\partial L}{\partial x_1} = -\lambda w_1 + \gamma_1 \frac{\partial G}{\partial x_1} = 0 \tag{6d}$$

$$\frac{\partial L}{\partial m_0} = \lambda(p_0 \delta_0^S) + \mu_0 = 0 \tag{6e}$$

$$\frac{\partial L}{\partial m_1} = r\lambda(p_1 \delta_1^S) + \mu_1 = 0 \tag{6f}$$

$$\frac{\partial L}{\partial s_0} = \mu_0 + r\mu_1 = 0 \tag{6g}$$

Substituting (6e) and (6f) into (6g), we have that $\frac{\partial L}{\partial s_0} = -\lambda(p_0 \delta_0^S) + r\lambda(p_1 \delta_1^S) = 0$. This implies that the decision of how much of the good to store at time $t = 0$ depends on the prices from the current and future period as well as the discount rate. That is, when the present value of the difference in prices, $p_1 - p_0$ increases, the households should increase their storage. This is important in our estimation, as it informs our choice of instruments for endogenous storage using current and future prices.

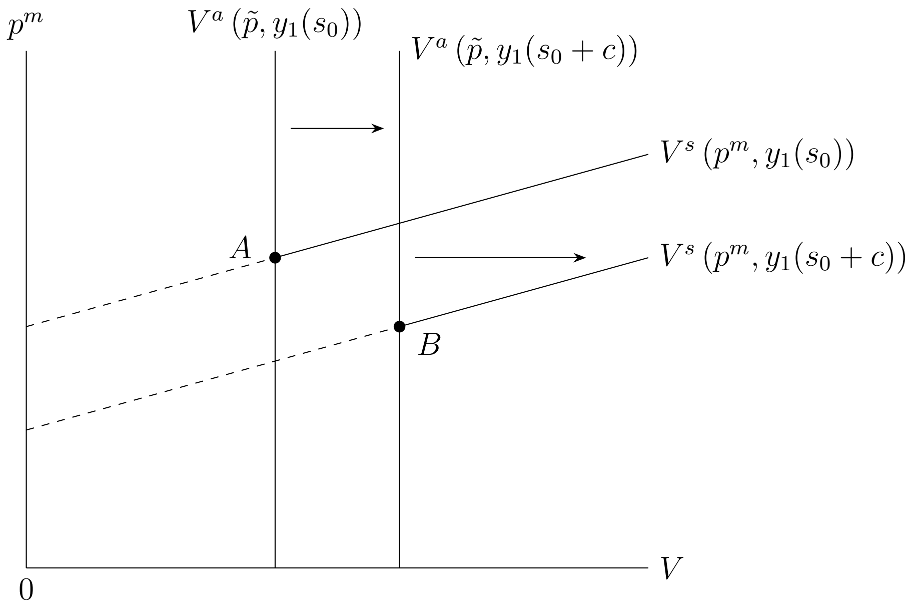

Figure 1: Indirect utility is increasing in previous storage. *Ceteris paribus*, an increase in previously stored grain lowers the price at which a household enters the market as a seller.

We omit consideration of the buyer market decision, since our interest is at the threshold of autarky and market participation. Following Key, Sadoulet, and Janvry (2000), the income constraints are

$$p_0^d c_0 = y_0 = p_0^d(q_0 - s_0) + T_0 - tf_0 \tag{7a}$$

$$r(p_1^d c_1) = y_1 = r\left[p_1^d(q_1 + s_0) + T_1 - tf_1\right] \tag{7b}$$

Where p_t^d is the market price for the seller and $\tilde{p}_t = \mu_t/\lambda$ for the self-sufficient household. The maximum utility that can be achieved given prices, income and household characteristics in each market participation regime can be written as the indirect utility function, $V(p, y, z_h)$. Thus, the utility levels of selling can be compared to autarky. It is clear that income in the second period is increasing in storage in the previous period. Figure 1 illustrates that, since the indirect utility of the seller is upward sloping in prices, an exogenous shock to storage would lower the threshold price at which households switch from autarky to market participation as sellers, since this threshold occurs at the point where the autarkic and selling indirect utilities are equal. Thus, we hypothesize that prior storage increases the likelihood of market participation as a seller. This motivates the empirical work in later sections.

2.2 Potential general equilibrium effects

It is possible that in a small, poorly integrated market there may be general equilibrium effects by which sellers are not price takers. The analytics for the general equilibrium are similar, but require an additional expression

$$m_{ti} + \sum_{i \neq j}^{J} m_{tj} = 0$$

Where i indicates a household and t the time period. Including this into the income constraint (constraint 1a) and acknowledging that price p becomes a function of m, we end up with a differential equation for each time period (time indexes suppressed since the expressions over time are equlivalent):

$$p + \frac{\partial p}{\partial m} m = \frac{\mu}{\lambda}$$

Rearranged:

$$p = \frac{\mu}{\lambda} - \frac{\partial p}{\partial m} m$$

For sellers, $m > 0$ and $\frac{\partial p}{\partial m} < 0$, implying that the price threshold needed to induce selling increases, making the area under autarky larger relative to the area of autarky under partial equilibrium, *ceteris paribus*. This result is consistent with previous findings in the literature (de Janvry, Fafchamps, and Sadoulet, 1991; de Janvry and Sadoulet, 2006). Under general equilibrium, the prices depend on the quantity sold on the market. Storage indirectly may lower prices, thereby reducing the probability of selling. Yet, it increases income at the current time. The net effect on the probability of selling is an empirical question, which depends on the increase in storage, the size of the market, and the size of the self-inflicted negative externality via the effect on price.

3. Empirical model

We want to test the hypothesis that prior storage positively impacts participation in the market as a seller. From our model, we posit that the seller decision at each period is a function of storage in the previous period, current prices, and household fixed effects, which include fixed transaction costs such as distances to major markets. Due to the relatively short time period of our data, we assume fixed costs are time invariant and are captured by the household fixed effects. Our main equation of interest is given by

$$SoldAny_{it} = \beta_0 + \beta_1 StoredKg_{t-1} + \beta_2 Yield_{it} + \beta_3 Price_t + \beta_4 Year_t + \alpha_i + u_{it} \tag{8}$$

Where α_i is an individual fixed effect and u_{it} is the idiosyncratic error term. Since storage is endogenous, we instrument for it using community averaged current and future prices in some specifications, and district-level prices in others (see Angrist and Krueger, 2001). This is in keeping with the rational expectations literature of commodity storage, which holds that the price of storage is determined as a function current prices and expectations about future prices, but not past prices (see Wright and Williams, 1982).

Therefore, we use community level prices in the previous period to instrument for storage in the previous period. Since yields are partly determined by household inputs, we must consider them to be endogenous as well. The estimation of equations with multiple endogenous variables has precedent in the literature when justified by the underlying model (for example, Acemoglu and Angrist, 2000). We use rainfall over the growing season as an instrument for yield, since rainfall is one of the primary determinants of maize yield in our study area Baffour-Ata et al. (2023). Recent literature suggests that two-way fixed effects estimators, such as the one we employ may not be ideal when heterogeneous treatment effects are possible, since the linear regression estimand may be negative even while all of the average treatment effects are positive de Chaisemartin and D'Haultfœuille (2020). Without accounting for endogeneity, we find that only 15 of 1350 switchers have a negative local average treatment effect, which gives us mild confidence that this issue is not occurring in our case.

4. Study Area

Our study area spans roughly 1,300 square kilometers in northern Ghana (see figure 2), where agricultural scale ranges from less than subsistence farming to commercial enterprises. The climate is semi-arid, with a rainy growing season that lasts 5 to 6 months starting in May, followed by a dry season. It has an average annual temperature of 28°C and annual rainfall of 900 to 1040 mm (de Jager, Giller, and Brouwer, 2018). Rainfall based yield risk is an important factor (Ankrah et al., 2021). Maize is an important staple crop, and makes up a significant portion of many households' diets (de Jager, Giller, and Brouwer, 2018). In our sample, 3,145 of the 3,178 households for which we had data grew at least some maize over the study period. While maize is an important crop, many other crops are cultivated such as rice, beans, groundnuts, soy beans, millet, okra and yams. Crops are grown both for household consumption and sale to others. One motivation for planting multiple crops is to smooth labor inputs over the growing season. There are significant differences in the mechanization employed by farmers in this region, with some communities having a tractor that is used for field preparation and planting, and others hiring tractor operators from outside the community during planting season. Many communities do not use mechanization at all.

Not all households engage in maize selling, with less than half the sample engaging in selling in each period. Households who sell primarily sell to traders who come to the community and purchase grain to transport to a market, which may be either a local market or a larger city market. Sometimes farmers deliver their grain to the market themselves, but it is rare for farmers to deliver grain to a larger city for sale. Other common buyers are others in the same community, and buyers in adjacent communities. These local prices were highly correlated with one another ($r \approx 0.95$). In keeping with our model, the farmers in this region are semi-subsistence farmers, growing in part for the consumption needs of their household.

5. Data

Our data come from the Disseminating Innovative Resources and Technologies to Smallholders in Ghana (DIRTS) project Udry (2019), and is a four year panel conducted between 2014-2017.

Figure 2 shows a map of the plot level data relative to the landscape of northern Ghana, with Tamale being the largest city in the region. These data include plot level information on crop sales, storage, prices, yields, and inputs, as well as plot location, which we aggregate to the household level. There are 162 communities across 9 districts in the Northern Region of Ghana. This project was implemented as a multi-armed randomized control trial to test the effects of increased access to inputs, rainfall index insurance grants, weather forecasts, and extension information. Fifty of the communities were treated with insurance only, fifty-two with insurance and extension information, thirty-one with the input and insurance treatments, and twenty-nine with extension, inputs and insurance. We do not have access to the treatment variables. Within each community, twenty households were selected for inclusion in the study, and ten were selected for the designated treatment combination for that community. Fortunately for the purposes of this research, the researchers found no detectable effect for any of the interventions with two exceptions. They implemented an input marketing intervention in the first two years of the study, where they worked with input suppliers to ensure community level access to key inputs in the 31 treatment communities. All households in the treatment community had access to these inputs. Do to this intervention, they saw a reduction in labor use, an increase in improved seed use, resulting in an overall increase in profits. This is especially troubling since we have motivated our choice of empirical model by arguing that in increase in indirect utility via income lowers the market participation price threshold. This intervention was discontinued before the 2016 growing season, but is a troubling potential source of bias in our fixed effects estimator. As a robustness check against this problem, we estimate the same instrumental variables fixed effects model with community fixed effects, and find no substantial difference in our results. The project also employed community members to deliver extension information on best farming practices. This resulted in improved test scores on extension information for the treated, but did had not statistically significant effect on yield, output or profits. The authors of the study reported no other relevant and statistically significant effects of their interventions. Though we control for yield with in our analysis which is the primary channel through which the input marketing intervention would work, we acknowledge that these data as a shortcoming of our research.

We dropped observations with key missing variables as well as unrealistically high values for yields. Since not every farmer grew maize in every year, our panel is unbalanced. Since we had price information for each type of buyer, we assigned the price paid by the buyer who purchased the highest volume from the household as that household's primary price of sale. We averaged these primary sale prices at the community level to get the community prices. District prices were calculated from the DIRTS data, since they had used district level prices to create a variable denoting the total harvest value in terms of district prices. Our rainfall measure comes from WorldCover, a crop insurance provider working in Northern Ghana. We used the average daily rainfall over the maize growing season.

Figure 3 shows the community averaged prices by year. Figure 4 shows harvest volume, yield, storage, sales volume, number of sellers and sales price over time. We see significant price variability, with no clear correlation between prices and yields. In 2016, we see a significant increase in yield, coinciding with a relatively high price, which may explain the increase in the number of sellers that we see in that year. Table 1 reports descriptive statistics grouped by whether the household ever sold. We note that households who sold farmed more acres, saw higher yields, and stored more.

6. Results

We test for general equilibrium effects on price at the community level by regressing prices on yields, number of sellers and the district level price with year and community fixed effects. Column 1 of table 2 reports the results of this OLS regression, and column 2 reports the fixed effects model. Here, distance to a major market, which could be used as a proxy for fixed costs, is contained in the community fixed effect. We find that neither community level yields nor community number of sellers are statistically significant in determining the prices face on average at the community level, with the district level price explaining much of the variation. In the FE model, the district level price variable had high collinearity with the year fixed effect, so these results should be taken with caution. The OLS regression suffers from lower collinearity, and has the same qualitative result.

In our main specification, we use a two-way fixed effects linear probability model with instruments for storage and yield, with results reported in table **??**. In column one, we see that, in keeping with the predictions of our model, storage in the previous period causes an increased likelihood of market participation as a seller, though the effect is quite small. In column two, we see that the estimated coefficient on storage in the current period is not statistically significant, though it does have a positive sign which is also in keeping with our model. Columns 3 and 4 report the equivalent estimations, but with district level prices as instruments for storage. Finally, we report the results of our robustness check against potential omitted variable bias due to the DIRTS input marketing treatment. Since the treatment effectively occurred at the community level, community fixed effects should control for this potential source of bias.

The previously reported results are promising, but require some caveats. First, while our data contains information on storage, we only observe one period of time per year, and cannot say anything about the seasonal dynamics which often characterize prices in these types of settings. We also focus only on maize, when in reality most farmers are diversifying their crops to smooth labor, manage risk, and vary consumption. Though we believe we have controlled for the most serious potential cause of bias due to the study from which they come, we are not able to control for possible violations to our assumptions in the fixed effects model.

There have been recent concerns that conventional two-way fixed effects may be difficult to interpret due to the possibility of many negatively weighted estimands while having a positive overall treatment effect (de Chaisemartin and D'Haultfœuille, 2020). We conducted a test of this issue, albeit with out instruments for endogenous yield and storage, and found minimal negative weights. de Chaisemartin and D'Haultfoeuille (2022) suggest that the two-way fixed effects estimator results are often quite similar to those of the newer DID estimators.

Our research suggests that increasing the viability of storage for smallholder households may increase their market participation. Policymakers attempting to predict supply response should consider household storage stocks, and increasing access to storage may be a way to induce higher rates of market participation. Participation in markets has often led to to well-being and development throughout history, and is a continued challenge in a context with the missing markets described in the literature. Increased participation in markets by smallholders is likely to lead to higher household welfare (Barrett, 2008) and national food security (Poole, 2017).

7. Tables and Figures

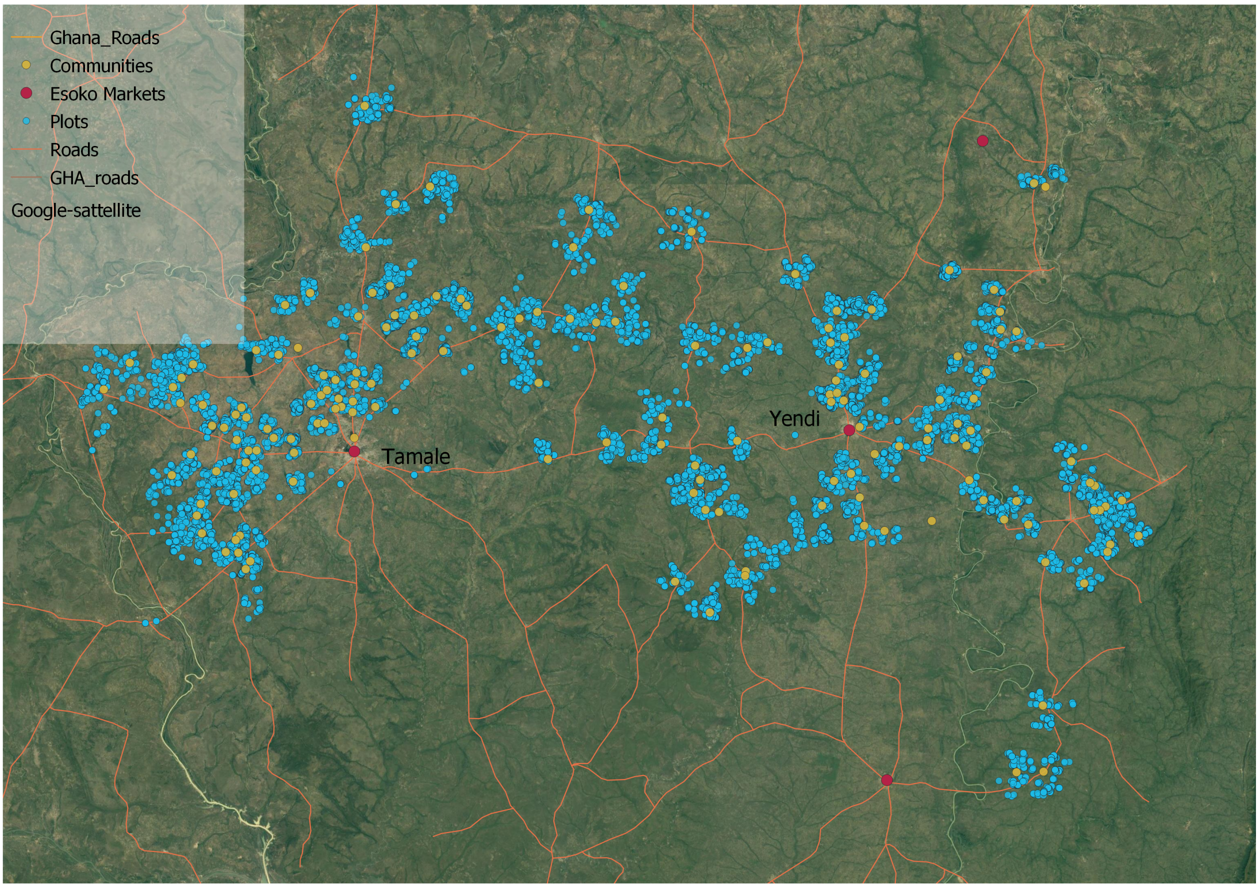

Figure 2: Plots in the DIRTS data in blue, community centers in yellow, and major regional markets in red.

Table 1: Descriptive statistics by whether or not the farmer was ever a seller.

Ever Sold	(1) N	(2) mean	(3) sd	(4) min	(5) max
Harvest (Total Kg)	6,863	1,461	1,520	0	21,000
Yield (Kg/Ha)	6,863	829.8	873.6	0	9,810
Total Area (Acres)	6,863	9.315	10.75	0	300
Stored now (Kg)	6,857	477.4	722.5	0	10,000
Primary price (Kg)	3,879	0.791	0.384	0	5
Community avg. price	6,851	0.796	0.232	0.225	2.267
Never Sold	N	mean	sd	min	max
Harvest (Total Kg)	2,654	826.7	1,014	0	22,100
Yield (Kg/Ha)	2,654	647.6	724.7	0	9,661
Total Area (Acres)	2,653	6.483	7.857	0	97
Stored now (Kg)	2,651	276.1	533.6	0	10,000
Avg. price	2,632	0.792	0.232	0.225	2.267

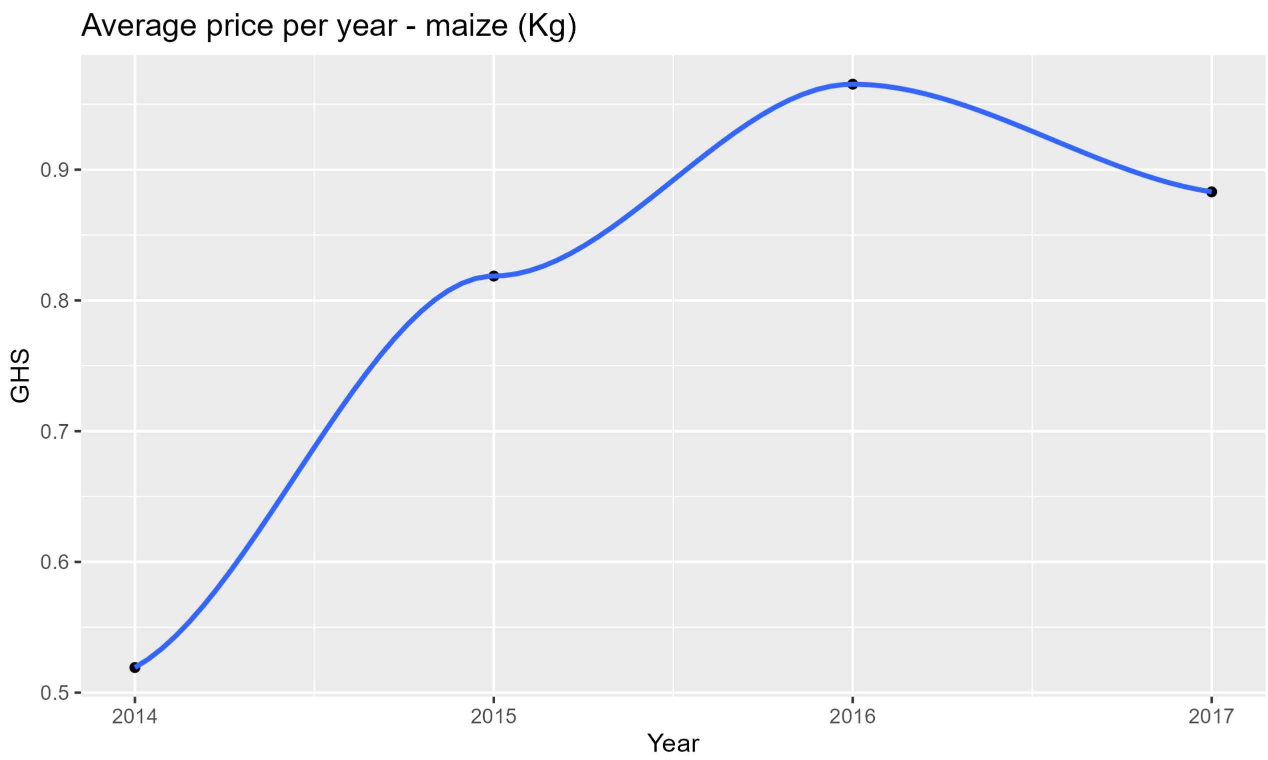

Figure 3: Average harvest volume, yield, storage, sales volume, number of sellers and price by year.

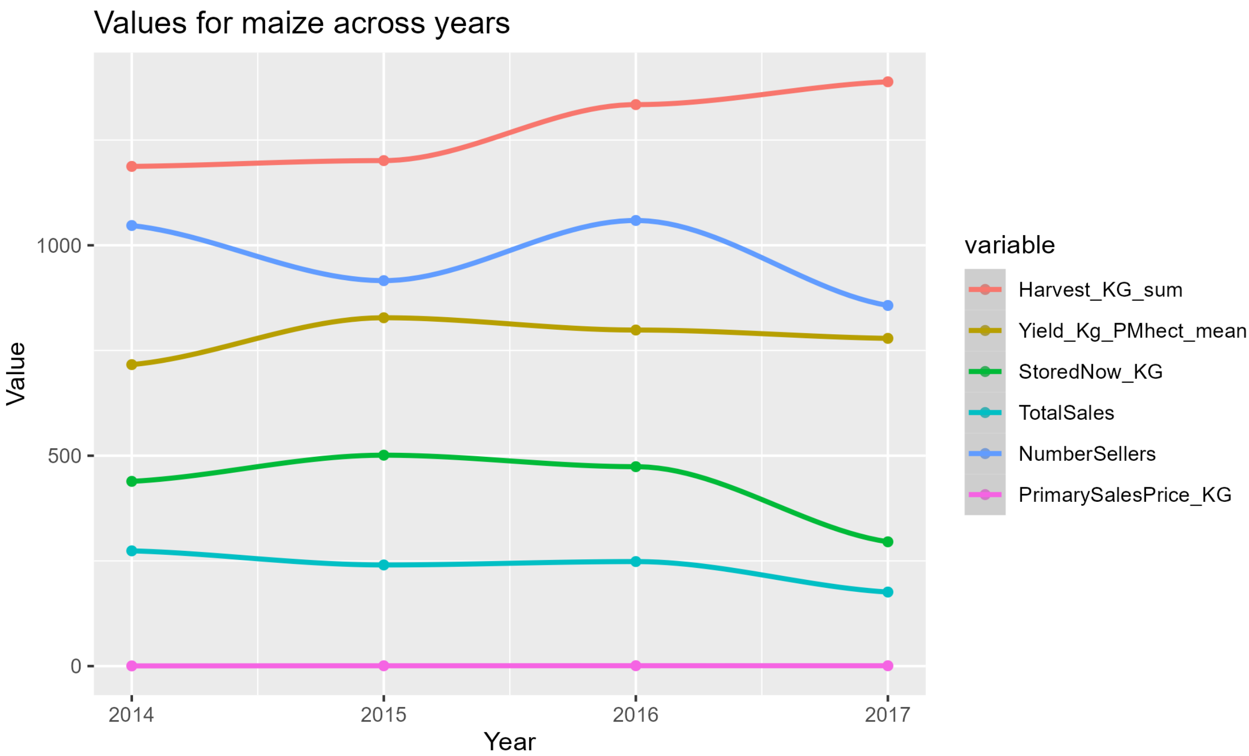

Figure 4: Average realized price per Kg by year.

Table 2: Community averaged prices regressed on potential price determinants in order to test for partial equilibrium.

	(1) OLS	(2) FE
Community Average Yield (Kg/Ha)	0.0000193 (0.341)	0.0000485 (0.185)
Number of sellers in community	0.00132 (0.545)	-0.00350 (0.307)
District level price	0.764*** (0.000)	0.577*** (0.000)
2015	0.0618 (0.109)	0.110** (0.021)
2016	0.0629 (0.275)	0.153** (0.041)
2017	0.127*** (0.001)	0.172*** (0.000)
Constant	0.119* (0.051)	0.224*** (0.005)
Observations	640	640
R^2	0.502	0.561

p-values in parentheses
* p<0.10, ** p<0.05, *** p<0.010

Table 3: Two stage least squares with fixed effects. Columns 1 and 2 use community level prices to instrument for storage, and columns 3 and 4 use district level prices. Standard errors clustered at the household level.

	(1) Seller	(2) Seller	(3) Seller	(4) Seller
Stored previous period (Kg)	0.000547**		0.000452**	
	(0.031)		(0.018)	
Stored now (Kg)		0.000737		0.00139
		(0.607)		(0.198)
Yield (Kg/Ha)	0.000432	0.000564	0.000345	-0.000828
	(0.567)	(0.844)	(0.480)	(0.559)
2015	-0.122**	-0.105	-0.0993***	-0.0194
	(0.028)	(0.563)	(0.008)	(0.795)
2016	-0.133***	-0.0503	-0.111***	0.0168
	(0.003)	(0.714)	(0.002)	(0.810)
2017	-0.253***	-0.0700	-0.228***	0.114
	(0.000)	(0.859)	(0.000)	(0.640)
Constant	-0.0283	-0.287	0.0621	0.436
	(0.956)	(0.848)	(0.851)	(0.487)
Observations	9442	9445	9401	9404

p-values in parentheses
* p<0.10, ** p<0.05, *** p<0.010

Table 4: Two stage least squares with household and community fixed effects. This estimation is a robustness check against potential contamination by an input marketing treatment in 31 of the sample communities.

	(1) Seller	(2) Seller
Stored previous period (Kg)	0.000716	
	(0.574)	
Stored now (Kg)		0.000627**
		(0.015)
Yield (Kg/Ha)	-0.00165***	-0.000101
	(0.000)	(0.859)
Constant	1.420***	0.218
	(0.000)	(0.697)
Community-year effects	Yes	Yes
Observations	9401	9404

p-values in parentheses
* p<0.10, ** p<0.05, *** p<0.010

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