Does Access to Storage Protectant Increase Smallholder Adoption of Improved Maize Seed? Insights from Malawi

Jacob Ricker-Gilbert
Purdue University

Michael Jones
Purdue University

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Abstract

To date there is limited knowledge on the role that post-harvest storage protectants, chemical or otherwise, play in a smallholder farmer's decision to adopt of high-yielding improved maize varieties. This is a key issue because higher yielding varieties are often more susceptible to storage pests than lower yielding traditional varieties. We present novel evidence from Malawi which shows that access to storage chemicals has a positive and significant effect on both farmer adoption of improved seed and the area that households plant to improved maize. Results have important implications for input support programs because failing to account for small holder storage challenges may reduce a farmer's incentive to adopt modern seed varieties that can enhance staple crop production and food security.

Introduction

Increasing adoption of modern inputs such as improved seeds and chemical fertilizer is essential for boosting staple crop production and improving smallholder food security in Sub-Saharan Africa (SSA). In addition to increasing production, it is essential to recognize that food security does not simply end at harvest because susceptibility to pests during storage can cause tremendous post-harvest dry weight losses of up to 30% in six months of storage for grains (Boxall 2002). Previous work confirms common rural knowledge that higher yielding dent hybrids, the most commonly promoted improved maize varieties in SSA, offer less natural protection against storage insects such as maize weevil and larger grain borer than do lower yielding traditional flint varieties (Smale Heisey, and Leathers 1995; Adda et al. 2002). Smallholder perceptions of greater storage pest damage in improved vs. local maize varieties has also been recently verified in Malawi (Jones, 2012). Therefore farmers face a rational trade-off at planting time between choosing an improved variety that may boost production but where the harvested maize is more susceptible to pests when stored vs. choosing a traditional variety that is lower yielding but less vulnerable to pests in storage. Nevertheless issues related to post harvest loss are often overlooked in studies that model smallholder improved seed adoption behavior.

The objective of this study is to determine how access to storage chemicals, sometimes locally grouped under the name "actellic", affects a smallholder's decision to adopt improved maize seed in Malawi.[1] In doing so this study makes an empirical contribution to both the input subsidy literature and the technology adoption literature in SSA. Malawi received has wide recognition for scaling up a large inorganic fertilizer subsidy program in 2005 and a subsidy for improved maize seeds in 2006 (Dugger 2007). However less attention has been paid to the fact that Malawi implemented a subsidy for maize storage chemicals in 2008/09 growing season as a compliment to the fertilizer and seed subsidy.

[1] In this study improved maize seeds are defined as hybrid varieties and open pollinated varieties (OPV). Although smallholder farm households in Malawi report that more than 95% of the improved maize seed they acquire is hybrid, anecdotal evidence from Malawi indicates that most farmers refer to *any* improved seed as hybrid.

There is a growing literature measuring the impact of input subsidy programs on smallholder behavior and wellbeing in Africa. One related study in Malawi finds that households who acquire subsidizes seed and fertilizer plant a significantly larger share of their land to maize and tobacco, the crops targeted by the country's input subsidy program, than do other households (Chibwana et al. 2011). Another study uses household-level panel data from Malawi and Zambia and finds that in both countries households who acquire subsidized maize seed purchase significantly less seed on the commercial market (Mason and Ricker-Gilbert 2012). The present study adds to the literature on input subsidies by estimating the impact of storage chemicals on farmer improved seed adoption decisions.

To our knowledge, there is little research investigating the relationship between investment in storage protection and adoption of improved maize varieties. One previous study in Ghana (Gyasi et al. 2005) and one study in Zambia (Langyintuo and Mungoma 2008) consider how a farmer's perception of hybrid maize storability affects his or her decision to adopt it. Both studies estimate hybrid maize adoption and include "storability" as a dummy variable equal to one when a farmer perceives that hybrid maize stores better than local varieties and the authors do not consider a farmer's ability to protect maize stocks in their model. One limitation of this approach is that there is likely limited variation in the storability dummy, as evidence from Malawi suggests that most farmers believe local varieties to store better than hybrid (Smale 1995). Therefore, the simple use of a dummy variable of a farmer's perception may not be the most rigorous manner to investigate the effect of hybrid storage vulnerability on adoption decisions.

Understanding how investment in storage protection affects adoption of improved maize varieties is important because the economic consequences of hybrid susceptibility to storage pests are significant. The consequences of pest damage to grain include (i) increased dry weight losses expediting the need to purchase, (ii) early sale at low post-harvest prices to avoid storage losses, and/or (iii) later sale of damaged maize at reduced prices. Market price data from the Malawian Ministry of Agriculture shows that prices routinely increase 50-100% within six months of the harvest season (Malawian Ministry of Agriculture, Chapoto and Jayne 2010). Households with ruined stores must buy maize later at these elevated prices. Also, marketing producers wishing to store into the lean season may face price discounts for insect-damaged grain which significantly erode storage returns (Compton et al. 1998, Jones 2012).

Therefore, by considering how storage inputs that reduce post-harvest pest damage affect a household's decision to adopt improved maize varieties at planting, this study adds an important dimension to the adoption literature in Africa. Previous adoption studies vary greatly in their explanations of why hybrid adoption and cultivation are low. Using panel data from Kenya, Suri (2011) argues that many producers who do not adopt hybrid maize are operating as economically rational actors. Suri finds that heterogeneity in producer returns and high transaction costs of acquiring seed explain the behavior of most non-adopters. Simtowe, Zeller, and Diagne (2009) argue that high seed costs and credit constraints explain why hybrids still compose less than 50% of maize cultivation in Malawi. Simtowe et al. (2006) add production risk as a factor in Malawian non-adoption. Langyintuo and Mungoma (2008) use a double-hurdle model with household data from Zambia to show that household wealth positively affects both the probability of adoption and intensity of hybrid planting.

Data for the present study come from a nationally representative cross section of 1,375 rural households in Malawi collected as part of the Second Agricultural Input Subsidy Survey (AISS2) in Malawi during the 2008/09 growing season. In this article we first set up a model of smallholder maize adoption decision making, where the farmers choice to adopt improved maize varieties is estimated via probit to account for the binary nature of that decision. Second we model the farmer's decision of how much area to planted to improved maize varieties. This variable is estimated via tobit to account for the corner solution nature of that decision.[2] The key variable of interest in this study is whether or not the household used maize storage chemicals after the previous two harvests. We test whether or not households who had access to storage chemicals in the past are more likely to adopt improved maize seed the following year and plant larger areas of land to improved maize varieties. We also compliment this by estimating another model where we assume that farmers have perfect foresight. This allows us to test whether farmers who acquire storage chemicals after the 2009 harvest are more likely to adopt improved maize at planting time in the 2008/09 season.

In order to establish the causal impacts from acquiring storage chemicals on household improved maize adoption decisions, we need to deal with several modeling challenges. The first issue is that households have different levels of ability to acquire storage chemicals. This is especially true after Malawi implemented a subsidy for storage chemicals in the 2008/09 season. With the advent of the storage chemical subsidy any farmer can visit an extension office and purchase storage protectants at a discounted price. To deal with potentially uneven access to storage chemicals by households, we include variables such as assets, distance to the local extension office and number of private input suppliers in the village in our empirical models.

A second modeling challenge is that in Malawi households who acquire storage chemicals may also acquire subsidized fertilizer and or subsidized seed, which could in turn affect their decision to plant improved maize seed. Access to subsidized seed and fertilizer is different than access to storage chemicals because they are restricted to certain individuals chosen by village leaders. Furthermore, at least officially selected households can only acquire certain amounts of subsidized seed and fertilizer at a reduced price. Therefore access to subsidized seed and fertilizer may be correlated with unobservable factors in the error term of our improved maize adoption model. We deal with potential endogeneity

[2] Corner solution variables, sometimes called censored variables, have a relatively continuous distribution over a range of values, but take on one or two focal points with positive probability (Wooldridge, 2010). In our context many household do not plant improved maize, but for those who do the area that they plant is relatively continuous.

caused by this problem using instrumental variables (IV). The IV's used in this study are 1) the official quantity of subsidized seed distributed in a household's district and 2) whether or not the ruling party won the previous presidential election in the household's district. Since the dependent variables in our models of improved maize adoption and the potentially endogenous variables (kilograms of subsidized seed and fertilizer acquired) are both non-linear in nature, we use the control function approach rather than two-stage least squares to deal with this issue.

Results from this study indicate that access to storage chemicals are a highly positive and significant driver in both the decision to adopt improved maize seed as well as the decision of how many hectares of improved maize seed a household decides to plant. These results have important policy implications for programs which facilitate access to production and post-harvest inputs, because failing to account for small holder storage challenges may reduce the incentive for farmers to adopt modern seed varieties that can enhance staple crop production and food security. Our findings from Malawi where pest damage is a major issue may also be applicable to other nations with similar improved maize variety characteristics and storage pest complexes.

Background

Post-Harvest Loss in Malawi

Post-harvest storage losses in Southern Africa are predominately caused by molds, rodents, and insect pests (World Bank, 2011). The main harvest in Malawi is followed by a long dry season so mold damage to grain is not a significant storage problem for smallholders. Nevertheless, post-harvest grain damage due to pests is a major issue. While producers have always dealt with the maize weevil as a dominate pest, improving smallholder maize storage practices in Africa have become increasingly more important over the past twenty five years since the larger grain borer (LGB) was accidentally introduced in Africa from Central America in the 1980's (Golob, 2002). Lacking natural predators, the LGB's nearly simultaneous initial infestation in Tanzania and Togo have since expanded throughout both Eastern and Western Africa. As a result farmers have had to abruptly and fundamentally shift storage practices in this time to avoid inevitable stock destruction as the threat from the larger grain borer has increased (Addo, Berkinshaw, and Hodges 2002). The LGB supposedly entered Malawi in 1991/92 through trade shipments from Tanzania through the northern district of Chitipa. Since this time, the LGB is now prevalent in almost every district of Malawi and poses an enormous constraint on smallholder maize storage (Singango, Nkhata, and Mhango 2008).

In the past many farmers throughout the continent preferred to store husked maize on cob, though the husk provides the LGB with a more stable brace to penetrate grains. Shelled maize creates a less stable environment to mitigate losses, though admixing insecticides is universally recommended in grain borer infested zones (Dales and Golob 1997, Golob 2009). Previously, insecticides such as Actellic contained only a pirimiphos-methyl compound which effectively controls the maize weevil. The LGB is impervious to this compound, however, and heavy research investments led to the release of new chemicals based on permethrins or deltamethrins (Golob 2002). The Actellic Super or Shumba Super labels are two widely available brands which combine the lethal chemicals for both pests, used in Malawi and elsewhere on the continent.

Use of Improved Maize Varieties in Malawi

In this article improved maize varieties by farmers refers to seeds for both hybrid and open pollinated varieties. The spectrum of improved varieties available for Malawian farmers has changed greatly over the last several decades. Smale (1995) documents a structural shift in the 1990s as national research institutions began a push away from traditional improved dent varieties to improved semi-flint varieties. The flinty texture allowed farmers to increase yields while better maintaining desirable post-harvest qualities such as high flour-to-milling ratios, and better natural resistance to maize weevils. However this has evolved into a present-day reversion to largely dent varieties, including selections from multinational corporations like Pioneer and Monsanto. While the reasons driving this reversion to more storage susceptible varieties is not the subject of this study, the farmer is ultimately left with little choice outside of dent varieties when sourcing improved seed. Grain damage in storage is thus a large concern for all dent-growing producers who must later cope with pests like LGB and maize weevil.

Storage Chemical Subsidies in Malawi

Beginning in the 2008/09 season, the Malawian government introduced subsidized storage chemicals in acknowledgement of the growing constraint posed by storage pests (Dorward and Chirwa, 2011). In the 2011/12 season, the price of subsidized storage chemicals was 100MK per 200g bottle of Shumba Super dust, as compared to prices of 250-350MK per bottle in retail outlets (author's observation). Following recommended application doses of 25g/50kg maize grain, this bottle would protect 400kg of maize[3]. Distinct from the improved seed and fertilizer subsidy program, no vouchers are required. Any farmers is free to purchase as many subsidized bottles as they need from Extension Planning Area (EPA) offices while stocks remain, although extension agents have authority to regulate this quantity as they deem appropriate. Stock shortages are common and anecdotally vary by region since allocation is determined by district maize production[4].

Fertilizer and Seed Subsidies in Malawi

Fertilizer subsidy programs have existed in almost every year for decades in Malawi. However, after a drought-affected poor harvest in the 2004/05 growing season, the government decided to greatly expand its subsidized fertilizer program and continue subsidizing improved maize seeds. Since 2005/06, the Malawian government has utilized input vouchers to target farmers who meet certain criteria. These targeted farmers can then redeem the vouchers for inorganic fertilizer at a reduced price and improved maize seed for free. During the 2008/09 growing season (the year of the data used in

[3] It is reported that application rates vary greatly by farmer. Some may overdose for longer protection, while others apply less due to financial constraints.
[4] Author's observations through interactions with officials in Blantyre, Zomba, Thyolo, Lilongwe, Nkhotakota, and Mzimba offices in June/July 2011 and Jan/Feb 2012.

this study), the government of made 202,000 metric tons of subsidized fertilizer and 5,365 tons of subsidized seed available to farmers. The program cost an estimated US $265 million (Dorward and Chirwa 2011). The government paid greater than 90% of fertilizer cost in that year, as recipient farmers were officially required to pay the equivalent of US $5.33 for a 50 kg bag of fertilizer that cost between US $40 and $70 at commercial prices, while vouchers for improved maize seed could be redeemed at no charge. In 2008/09 all subsidized fertilizer vouchers had to be redeemed at government depots, while households could redeem their maize seed vouchers at a wide range of large and small input suppliers' stores.

Officially each targeted household was supposed to receive two coupons good for two 50-kilogram bags of fertilizer at a discounted price, and one coupon for a two kilogram bag of hybrid maize seed or a four kilogram bag of OPV seed. In reality, the actual amount of subsidized fertilizer and seed acquired by households varied greatly. For example, based on the survey data used in this study, in 2008/09 subsidy participants in Malawi received a median of 50 kg of fertilizer and 2 kg of hybrid maize seed. Five percent of participants received less than 50 kg while 49% of participants received more than 50 kg of fertilizer. For households receiving maize seed through the subsidy, the 25th and 90th percentiles were 2 kg and 6 kg of maize seed, respectively.

Throughout the years of the subsidy's implementation, the process of determining who received coupons for fertilizer and seed was subject to a great deal of local idiosyncrasies. At the regional level, coupons were supposed to have been allocated based on the number of hectares under cultivation. At the village level, subsidy program committees and the village heads were supposed to determine who was eligible for the program. In more recent years open community forums were held in some villages where community members could decide for themselves who should receive the subsidy. The general program eligibility criteria was that beneficiaries should be "full time smallholder farmers who cannot afford to purchase one or two bags of fertilizer at prevailing commercial prices as determined by local leaders in their areas" (Dorward et al., 2008). However, numerous unofficial criteria may have been used in subsidized seed and fertilizer application, such as households' relationship to village leaders, length of residence, and social and/or financial standing of the household in the village.

Empirical Approach

Consider the two part decision of household i in region r during the 2008/09 season where the farmer first decides whether to adopt improved maize seeds. The farmer then decides to plant a certain amount of available land to improved maize seed. That decision is a function of the following factors:

1) $H_{ir} = \beta_0 + \beta_1 C_{ir} + \beta_2 S_{ir} + \beta_3 A_{ir} + \beta_4 X_{ir} + \beta_5 \rho_{ir} + \beta_6 R_{ir} + \varepsilon_{ir}$

where H represents the household's binary decision in 2008/09 whether or not to adopt improved maize seed in the first step. This variable takes on a value of 1 if the household decides to adopt improved maize seed and zero otherwise. In the second step H represents the number of hectares planted to improved maize varieties.

The variable for whether or not the household acquires storage chemicals in each of the previous two growing seasons is represented by C. First we use a variable equal to 1 if the household used storage chemicals after the 2008 harvest and 0 otherwise. Second we use a variable equal to 1 if the household used storage chemicals after the 2007 harvest and 0 otherwise. We treat C as a binary variable rather than a continuous variable representing the kilograms of storage chemicals acquired because thorough analysis of the data combined with discussions in the field confirm that many households do not know the quantity of storage chemicals that they acquire, and apply. Furthermore some households acquire storage chemicals in liquid form, while others acquire it in powder form making it hard to convert to equivalent measures. Therefore to eliminate mis-measurement we model storage chemical access as a binary decision.

In equation 1) The kilograms of subsidized fertilizer that the household acquires and the kilograms of subsidized improved maize seed that households acquire in 2008/09 are denoted by S. Access factors that may affect a household's decision to plant hybrid seed are represented by A. These factors include 1) distance to paved road in kilometers, 2) distance to the main market in kilometers, 3) distance to extension services in km, and 4) number of input suppliers in the village. Household demographics that affect improved seed adoption are represented by X. These factors include 1) value of household assets, 2) household landholding, 3) adult equivalents, 4) if the household is female headed, and 5) if there has been a death of the household head or spouse and 6) education of the household head. A vector of prices that affect the decision to adopt hybrid seed are represented by ρ. Relevant prices are 1) commercial price of fertilizer (NPK & urea), 2) agricultural wage rates in the community, 3) previous year hungry season maize price (January to March) and harvest season maize prices (May to July). Average rainfall over the previous growing season and the coefficient of variation on average rainfall over the growing season are represented by R. The error term in equation 1 is represented by ε. The corresponding parameters are represented by β_0 through β_6.

By including access to storage chemicals in the past two years, the model presented in equation 1) implicitly assumes that farmers are backwards looking. For robustness we also estimate a model where C represents a binary variable equal to 1 if the household acquires storage chemicals for after the 2009 harvest and 0 otherwise. This model assumes perfect foresight on the part of the farmer and takes into account the possibility that he or she may be confident at planting that they will be able to acquire storage chemicals after the coming harvest. This could in turn affect his or her planting decision during 2008/09 in a different way than having acquired storage chemicals in the past would. Estimating a model that considers the effect of acquiring storage chemicals after the 2009 harvest is also important because as mentioned earlier, the storage chemical subsidy was implemented during that year in Malawi.

Identification Strategy

In order to argue that the effects of acquiring storage chemicals has a causal effect on a household's decision to adopt improved maize seed there are several modeling issues that need to be addressed. The first challenge is that households may have different levels of access to storage chemicals and this could in turn affect their level of use. To deal with this issue we set up a model to examine the factors that affect storage chemical use in 2008 as a function of the following factors:

2) $C_{ir2008} = \gamma_0 + \gamma_1 C_{ir2007} + \gamma_2 S_{ir} + \gamma_3 A_{ir} + \gamma_4 X_{ir} + \gamma_5 \rho_{ir} + \gamma_6 R_{ir} + v_{ir}$

Where C_{ir2008} equals 1 if the household acquired storage chemicals in 2008 and zero otherwise. In addition, C_{ir2007} also equals 1 if the household acquired storage chemicals in the 2007 season and zero otherwise. The other factors denoted by S, A, X, ρ, and R are the same as in equation 1) and γ represents the corresponding parameters. The error term is denoted by v.

Equation 2) is estimated in order to understand factors affecting household access to storage chemicals. Storage chemical access is treated as exogenous in equation 1 conditional on observable factors in that model. The reason that C_{ir} is treated as exogenous is because even after the storage chemical subsidy was scaled up in the 2008/09 season, households who could get to an extension office were able to acquire as much storage protectant as they needed or could afford. Since the storage chemical subsidy was not targeted, after considering factors like assets, distance to extension offices, and number of input dealers in a village it is safe to assume that C is uncorrelated with ε in equation 1).

While we can safely consider C to be exogenous conditional on observables in equation 1) , S is likely not exogenous even after conditioning on observables. The reason is because subsidized seed and subsidized fertilizer are not distributed randomly in Malawi, so S may be correlated with ε in equation 1). For example, due to relatively unclear targeting guidelines government officials in some areas may distribute subsidized inputs to households who are more productive, while in other areas the inputs may go to less productive households. Furthermore, although subsidized seed and fertilizer are officially distributed in standardized “packs”, in reality, the quantities received vary substantially across households, and the majority of households receive no subsidized inputs. In other words, the two potentially endogenous explanatory variables take on corner solution properties. Therefore we use the control function (CF) approach rather than two stage least squares (2SLS) to test and control for endogeneity of subsidized seed and fertilizer in equation 1).

The CF approach entails estimating separate reduced form Tobit models for subsidized improved maize seed and subsidized fertilizer. The explanatory variables in these models are all of the exogenous variables from the structural model equation 1) and at least one instrumental variable (IV) for each suspected endogenous variable (Rivers & Vuong, 1988; Vella, 1993). The full set of IVs is included in both reduced form models (Wooldridge, 2010). The reduced form Tobit residuals are then generated and subsequently included as additional regressors in the structural model of commercial improved maize seed demand. If the residual for the suspected endogenous explanatory variable (SEEV) is statistically significant ($p<0.10$), then we reject the hypothesis that the SEEV is exogenous. However, inclusion of the residual controls for that endogeneity. If we fail to reject the hypothesis that the SEEV is exogenous, then the Tobit residuals for that SEEV can be excluded from the structural model. Because the Tobit residuals are generated via first stage regressions, valid inference requires that the standard errors for the structural model parameter estimates be obtained via bootstrapping (Wooldridge, 2010).

The IV’s used in this study are 1) the official quantity of subsidized seed distributed in a household’s district and 2) whether or not the ruling party won the previous presidential election in the household’s district. It is logical that official district-level subsidized seed allocation per rural household affects how much subsidized seed that a household acquires. The locality election variable is also likely a strong instrument as it reflects the political nature of the subsidy programs in Malawi. Similar variables have been used in other applications that address input subsidy targeting issues across Africa (Banful, 2011; Mason and Ricker-Gilbert 2012). The argument for the IV’s being exogenous is that they are determined at an administrative level that is high above the rural household. Therefore, we maintain that the IVs used in this analysis should be exogenous in the structural equation of household adoption of improved maize seed, particularly after controlling for observed covariates and time invariant unobserved heterogeneity ε in equation 1).

Data

Data from this study come from the 2009 Agricultural Inputs Support Survey II (AISS2) conducted after the 2008/09 growing season in Malawi. The data are nationally representative and draw from 14 districts in Malawi. The AISS2 survey builds upon two earlier surveys, the Second Integrated Household Survey (IHS2) in Malawi collected during the 2002/03 and 2003/04 growing seasons, and the 2007 Agricultural Inputs Support Survey (AISS1) conducted after the 2006/07 growing season. Unfortunately, questions related to household storage decisions were only asked during the AISS2 survey and not in any of the earlier surveys. Therefore we have to treat the data as a cross-section in 2008/09, however we use inverse probability weights (IPW) multiplied by the survey weights to deal with household attrition and ensure that our sample which remains in the AISS 2 is still nationally representative. The IPW technique involves three steps: (i) use probit to measure whether observable factors in one wave affect whether a household is re-interviewed in the next wave; (ii) obtain the predicted probabilities (Pr_{it}) of being re-interviewed in the following wave; (iii) compute the IPW = ($1/Pr_{it}$) and apply it to all models estimated. For households originally sampled in IHS2, the IPW for household i in AISS1=$1/Pr_{iAISS1}$ and the IPW in AISS2= $1/(Pr_{iAISS1}*Pr_{iAISS2})$. (For more information on IPW see Wooldridge 2010). We multiply the IPW by the survey sampling weights in the first wave to control for the probability of the household being selected for interview from the population.

Fertilizer Prices

Fertilizer prices used in the study are calculated from the survey as Malawian kwacha per kilogram of commercial maize fertilizer. The price is calculated as an average of urea and Nitrogen/Phosphorus/Potassium (NPK) prices, which are the primary fertilizers applied to maize in Malawi. These prices are based on what respondents in the survey say they pay for commercial fertilizer during the planting season, generally from October to December in Malawi. For those buying fertilizer commercially we use the observed price that they paid, while for those who do not buy commercially we use the district median price to proxy for the price that the household faces for the input.

Maize Prices

Data for the variable representing the median hungry season maize price in the household's district during the previous year, and the variable representing the median harvest season maize price in the household's district during the previous year both come from district level data on maize retail sales, collected by the Malawian Ministry of Agriculture.

Wage rate calculations

Agricultural wage rates are calculated as the average of total income from off-farm agricultural labor earned by the household divided by total days of off-farm labor that they supply. Households are also asked in the survey to monetize the value of any in kind payment. For households who supply off-farm labor, we use the wage rate that they obtain, while for households who do not supply off-farm labor we use the district median wage to proxy for the wage rate they would receive.

Rainfall

The rainfall variables come from district-level experiment station records.

All other explanatory variables are constructed from the household survey.

Results

Table 1 presents the means and medians of the variables used in the analysis. The descriptive statistics for the dependent variables used in the analysis indicate that 64% of households plant improved maize seed in the 2008/09 growing season. Households allocate 0.32 hectares of land to improved maize seed on average, and 0.20 hectares to improved maize seed at the median during that year. The average household has 1.07 hectares, while at the median landholding stands at 0.81 hectares. The storage chemical access variables indicate that 44% of households acquired storage chemicals after the 2009 harvest, 43% of households acquired them after the 2008 harvest, and 24% of households acquired them after the 2007 harvest. In 2008/09, the average household acquires 2.67 kilograms of improved maize seed from the subsidy, while the median household acquired 2 kilograms. The average household acquires 55 kilograms of subsidized fertilizer in 2008/09 while the median household acquires 50 kilograms of subsidized fertilizer.

Table 2 presents the factors that affect whether or not a household acquires storage chemicals after the 2008 harvest. The table operationalizes equation 2) and is estimated via probit. The coefficients presented in table 2 are the average partial effects (APE). Results from table 2 demonstrate that acquiring storage chemicals in 2007 increases the probability that a household will use storage chemicals in 2008 by 47.4 percentage points. The coefficient is highly significant with a p-value of (0.00). It is also evident that having access to inputs significantly effects whether or not a household acquires storage chemicals after the 2008 harvest. An additional dealer in the village who supplies subsidized inputs increases the probability that a household will use storage chemicals by 0.6 percentage points on average, while an additional dealer who sells commercial inputs in the village increases the probability that a household uses storage chemicals by 2.7 percentage points. In addition the data displays that the higher the value of household livestock and durable assets, the more likely they are to use storage chemicals. A one percent increase in the value of household assets makes the household 5.3

percentage points more likely to use storage chemicals on average. Another interesting finding is that having a higher price of maize during the previous harvest season decreases the probability that a household will adopt storage chemicals. This result may indicate that when prices at harvest are high, households are more likely to sell and thus have less need for storage protectants.

Table 3 presents the results of the reduced form models of factors affecting the kilograms of subsidized improved maize seed that households acquire (column 1), and the kilograms of subsidized fertilizer that households acquire (column 2) during the 2008/09 season. Both models are estimated via tobit to account for the corner solution nature of the variables and the coefficients are APEs. Results in columns 1 and 2 indicate that the IV for the number of kilograms of subsidized maize seed distributed to the household's district is statistically significant at the 1% level. The other IV, whether or not the ruling party won the previous election is close to marginally statistically significant at the 10% level in the subsidized fertilizer model presented in equation (2). Therefore, the government seed allocation IV can be used to identify the model in equation 1), while the ruling party IV is marginally able to identify equation 2). Note that at this time, we are unable to identify a second IV that is more effective at identifying equation 2).

Column 2 of table 3 indicates that acquiring storage chemicals after the 2008 harvest makes the average household acquire 11.63 more kilograms of subsidized fertilizer for the 2008/09 season. In addition, column 1 shows that households with less land and fewer assets do not acquire significantly more subsidized seed than larger farms. Conversely, households with more land and assets acquire significantly more subsidized fertilizer. It is also interesting to note that households where the head has completed upper primary school acquires significantly more subsidized seed and fertilizer than households where the head has no education. However households where the head has a post-secondary degree receive significantly less subsidized seed and fertilizer. This may indicate that government officials may target the inputs towards people with some education and ability to use the inputs effectively, but they do not target towards people with very high levels of education who may be engaged in other activities and/or be able to buy inputs through commercial channels. Columns 1 and 2 both indicate that female-headed households do not acquire significantly more subsidized inputs than other households in Malawi, even though they are officially supposed to be targeted beneficiaries of the subsidy program.

Table 4 presents the results for factors affecting the use of improved maize seed among households in our sample. The results in table 4 assume that subsidized seed and subsidized fertilizer acquisition is exogenous conditional on the other covariates in our model. Column 1 presents the factors that affect the probability that a household adopts improved maize seed in the 2008/09 growing season. This model is estimated via probit because the choice is binary, and the coefficients are the APEs. Column 2 presents the results for factors affecting the number of hectares households devote to hybrid maize. This model is estimated via tobit because the variable is continuous, but there are a significant number of zeros. The coefficient estimates in column 2 are also the APE.

Results from column 1 of table 4 indicate that acquiring storage chemicals over the past two years individually have a statistically significant effect on the probability that a household adopts improved maize seed in the 2008/09 season. Acquiring storage chemicals after the 2008 harvest makes the household 10.5 percentage points more likely to adopt improved maize in 2008/09 on average. Acquiring storage chemicals after the 2007 harvest makes the household 8.4 percentage points more likely to adopt improved maize seed during 2008/09 on average. Acquiring subsidized fertilizer also has a statistically significant effect on the probability of adopting improved maize seed, as an additional kilogram of subsidized fertilizer in 2008/09 makes the household 0.2 percentage points more likely to adopt improved maize in that year on average.

Other variables in column 1 of table 4 that are statistically significant have the expected sign. For example the number of commercial input dealers in a village makes the household more likely to adopt improved maize seed. Female headed households are 7 percentage points less likely to adopt improved maize seed than male headed households. Larger households with higher adult equivalents are more likely to adopt improved maize seed, and higher average rainfall over the past 5 growing seasons makes the household more likely to adopt improved maize seed.

Column 2 of table 4 indicates that acquiring storage chemicals after the 2008 harvest causes the average household to plant 0.065 hectares more land to improved maize varieties (p-value=0.00). Acquiring storage chemicals after the 2007 harvest causes the average household to plant 0.079 more hectares to improved maize varieties (p-value=0.00). An additional kilogram of improved maize seed causes the average household to plant 0.001 hectares to improved maize (p-value=0.00), while an additional kilogram of subsidized fertilizer also causes the household to plant 0.001 hectares more improved maize seed on average (0.00). It is also interesting to note that an extra hectare of land causes the average household to devote 0.11 hectares more land to improved maize. In addition larger households with higher adult equivalents plant larger areas to improved maize, probably because they have more labor available.

Table 5 presents the results for factors that affect household adoption of improved maize seed and the numbers of hectares planted to improved maize seed. Subsidized seed and subsidized fertilizer are assumed to be endogenous in table 5. However we test for endogeneity using the control function method where the reduced form residuals generated by the equations in table 3 are included as covariates in the model presented in table 5. After bootstrapping to obtain valid standard errors that account for the two stage estimation process, we find that the reduced form residuals are not statistically significant for subsidized seed or subsidized fertilizer in either column 1 or column 2 of table 4. These results indicate that in this context, it is safe to assume that endogeneity of subsidized seed and subsidized fertilizer is not an issue, and the results from table 4 can be treated as consistent estimates of factors affecting adoption and area planted to improved maize seed during the 2008/09 growing season.

Table 6 is included as a robustness check and considers the fact that farmers may be forward looking with their storage chemical and maize planting decision. In this model we include a dummy variable for whether or not the household acquires storage chemicals after the 2009 harvest. This model assumes that farmers have perfect foresight and know at planting time during the 2008/09 season whether or not they will be able to acquire storage chemicals for the coming harvest. This table is also important because the storage chemical subsidy was implemented during the 2008/09 season in Malawi. Results from column 1 indicate that acquiring storage chemicals after the 2009 harvest makes the household 17 percentage points more likely to adopt improved maize seed during the 2008/09 season (p-value=0.00). Column 2 demonstrates that acquiring storage chemicals after the 2009 harvest causes the average household to devote 0.131 hectares more land to improved maize varieties on average (p-value=0.00). These findings provide robust and consistent evidence that acquiring storage chemicals has a statistically significant and positive economically meaningful effect on both the probability that a household adopts improved maize varieties and the total area that a household devotes to improved maize varieties. These findings hold up when we consider the fact that storage chemical access in the past may affect planting decisions in the current year, and when we consider that availability of storage chemicals during the coming harvest may affect a household's current year planting decisions.

Conclusions

This study identifies how access to storage chemicals affects the decision of farmers in Malawi to adopt improved maize varieties that while being higher yielding, may also be more susceptible to pest than traditional maize varieties. The implications of this study are important as food security does not end at harvest, and the challenges faced by Malawian farmers in maize storage exemplify this reality. As destructive pests like the larger grain borer change the face of post-harvest grain management in many regions of Sub-Saharan Africa, the consequences also extend even to the planting decisions of producers.

The key finds from this study from this study are as follows: first when considering the fact that access to storage chemicals in the past may influence improved maize seed adoption in the future, we find that acquiring storage chemicals after the 2008 harvest makes the average household 10.5 percentage points more likely to adopt improved maize seed during the 2008/09 season. In addition the average household who acquires storage chemicals after the 2008 harvest plants 0.065 hectares more land to improved maize varieties in the 2008/09 season. Furthermore the average household who acquires storage chemicals after the 2007 harvest is 8.4 percentage points more likely to adopt improved maize seed during the 2008/09 season, and the average household who acquires storage chemicals after the 2007 harvest plants 0.079 hectares more land to improved maize varieties in the 2008/09 season. These results demonstrate a clear relationship between acquiring storage chemicals in the past and planting improved maize varieties in the future.

The second main finding is that our results still hold when we consider the possibility that farmers who plant during the 2008/09 season may be forward looking and expect to have access to storage chemicals after the 2009 harvest. Our results indicate that households who end up acquiring storage chemicals after the 2009 harvest are 17 percentage points more likely to adopt improved maize varieties during 2008/09 than other households on average. In addition those same households plant 0.13 more hectares to improved maize seed than other households. It is important to note the storage chemical subsidy was scaled up during the 2008/09 season. This finding provides robustness, because our estimates are consistent regardless of whether we consider access to storage chemicals in the past or access to storage chemicals in the coming year as the key variables of interest.

This study demonstrates that having access to storage chemicals in the past and having access to storage chemicals in the future significantly affects both a farmer's adoption and area planted decisions. We demonstrate this key relationship while controlling for possible endogeneity of subsidized seed and fertilizer access, as well as accounting for key demographic, financial, and geographic factors that affect access to storage chemicals, as well as access to subsidized seed and fertilizer. Ultimately policies and programs that facilitate access to storage inputs, chemical or otherwise, can thus present an important step to advance the adoption if improved maize varieties that can enhance staple production and food security goals for smallholder producers. Only partially accounting for the production and post-harvest biological constraints which farmers face may result in sub-optimal input use among smallholders. While the evidence presented in this study applies to Malawian farmers, this relationship likely applies to small farmers in other regions which may face destructive storage pests like the larger grain borer.

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Table 1. Descriptive Statistics of Variables Used in the Analysis

	Mean	Median
Dependent Variables		
=1 if household plants improved maize seed in 2008/09 season	0.64	
Hectares of improved maize seed planted in 2008/09 season	0.32	0.20
Covariates		
Kgs. of subsidized seed acquired	2.67	2.00
Kgs. of subsidized fertilizer acquired	55	50
=1 if HH used storage chemicals after 2009 harvest	0.44	
=1 if HH used storage chemicals after 2008 harvest	0.43	
=1 if HH used storage chemicals after 2007 harvest	0.24	
=1 if farm credit organization in village	0.32	
distance to paved road (km)	17	8
distance to main market (km)	40	35
distance to extension services (km)	5.46	4.68
number of dealers who sell subsidized inputs in village	0.86	0.26
number of commercial input sellers in village	0.50	0.00
value of household assets ('000 kwacha)	56.41	13.80
landholding (in ha)	1.07	0.81
=1 if household headed by female	0.29	
household adult equivalents	4.26	4
=1 if death in the family over past two years	0.09	
=1 if primary (grades 1 to 4)	0.26	
=1 if upper primary (grades 5 to 8)	0.34	
=1 if secondary (grades 8 to 12)	0.12	
=1 if post-secondary	0.01	
past year hungry season maize price (kwacha/kg)	71	72
past year harvest season maize price (kwacha/kg)	40	40
price of NPK & Urea fertilizer (kwacha/kg)	133	130
agricultural wage rate (kwacha/day)	414	405
average rainfall, past five growing seasons (in cm)	913	850
coefficient of variation on past rainfall (in cm)	0.26	0.27
=1 if household in northern region	0.14	
=1 if household is in central region	0.36	
IV: Gov't-subsidized maize seed allocated to HH's district (kg/rural HH)	86	76
IV: =1 if ruling party won HH's constituency in last pres. election	0.46	

Note: N=1,375
1 US$ = 150 Malawian Kwacha at the time of the survey

Table 2. Factors Affecting Access to Storage Chemicals after 2008 Harvest (Probit Estimator)

	Dep. Var: =1 if Household Acquired Storage Chemicals	
Covariates	**Coeff.**	**P-value**
=1 if HH used storage chemicals after 2007 harvest	0.474***	0.000
=1 if farm credit organization in village	-0.019	0.512
distance to paved road (km)	0.000	0.523
distance to main market (km)	0.000	0.475
distance to extension services (km)	0.000	0.766
number of dealers who sell subsidized inputs in village	0.006***	0.004
number of commercial input sellers in village	0.027**	0.011
log value of household assets	0.053***	0.000
landholding (ha)	0.013	0.378
=1 if household headed by female	-0.014	0.627
log of household adult equivalents	-0.025	0.300
=1 if death in the family over past two years	-0.029	0.553
=1 if primary (grades 1 to 4)	0.046	0.175
=1 if upper primary (grades 5 to 8)	0.078**	0.022
=1 if secondary (grades 8 to 12)	0.051	0.252
=1 if post-secondary	0.009	0.943
past year hungry season maize price	0.002	0.561
past year harvest season maize price	-0.010**	0.027
price of NPK & Urea fertilizer	0.000	0.312
agricultural wage rate (kwacha/day)	0.000	0.917
average rainfall, past five growing seasons	0.000	0.141
coefficient of variation on past rainfall	0.158	0.727
=1 if household in northern region	-0.128	0.386
=1 if household is in central region	-0.186**	0.013
N	1,375	
R^2	0.32	

Note: *, **, *** indicates that corresponding coefficients are statistically significant at the 10%, 5%, and 1% level respectively; coefficients are Average Partial Effects (APE) estimated via the *margins* command in Stata.

Table 3. Factors Affecting Subsidized Seed and Subsidized Fertilizer Acquisition During the 2008/09 Season

	(1) Kilograms of Subsidized Improved Maize Seed Acquired by HH TOBIT		(2) Kilograms of Subsidized Fertilizer Acquired by HH TOBIT	
Covariates	**Coeff.**	**P-value**	**Coeff.**	**P-value**
IV: Gov't-subsidized maize seed allocated to HH's district (kg/rural HH)	0.039***	0.002	0.608***	0.000
IV: =1 if ruling party won HH's constituency in last pres. election	0.245	0.778	6.077	0.106
=1 if HH used storage chemicals after 2008 harvest	0.594	0.410	11.630***	0.000
=1 if HH used storage chemicals after 2007 harvest	0.973	0.219	2.837	0.425
=1 if farm credit organization in village	-1.123	0.120	5.030	0.114
distance to paved road (km)	-0.017	0.217	-0.024	0.706
distance to main market (km)	0.001	0.889	-0.026	0.544
distance to extension services (km)	-0.076	0.190	-0.173	0.500
number of dealers who sell subsidized inputs in village	0.004	0.982	0.276	0.694
number of commercial input sellers in village	0.269	0.455	-1.842	0.234
log value of household assets	0.245	0.218	3.379***	0.000
landholding (ha)	0.480	0.186	6.099***	0.000
=1 if household headed by female	0.400	0.574	1.604	0.611
log of household adult equivalents	-0.822	0.190	2.108	0.445
=1 if death in the family over past two years	-1.178	0.248	-3.630	0.414
=1 if primary (grades 1 to 4)	0.502	0.543	3.930	0.280
=1 if upper primary (grades 5 to 8)	1.473*	0.061	6.378*	0.068
=1 if secondary (grades 8 to 12)	-0.167	0.877	0.300	0.950
=1 if post-secondary	-8.371**	0.045	-30.990**	0.025
past year hungry season maize price	0.032	0.631	0.115	0.697
past year harvest season maize price	-0.240**	0.043	-0.179	0.736
price of NPK & Urea fertilizer	-0.006	0.559	-0.150***	0.001
agricultural wage rate (kwacha/day)	-0.001	0.473	0.001	0.848
average rainfall, past five growing seasons	0.005	0.203	0.004	0.842
coefficient of variation on past rainfall	2.119	0.855	-78.886	0.118
=1 if household in northern region	-0.850	0.816	-20.075	0.209
=1 if household is in central region	-0.124	0.944	2.506	0.750
N	1,375		1,375	
R^2	0.01		0.03	

Note: *, **, *** indicates that corresponding coefficients are statistically significant at the 10%, 5%, and 1% level respectively; coefficients are Average Partial Effects (APE) estimated via the *margins* command in Stata.

Table 4. Factors Affecting the Probability of Adoption and The Number of Hectares Planted to Improved Maize Varieties During the 2008/09 Season (All Covariates Assumed Exogenous).

	(1) **Dep var:** = 1 if HH Adopts Improved Maize Seed		(2) **Dep var:** Ha of Improved Maize Seed that HH Plants	
	PROBIT		**TOBIT**	
Covariates	**Coeff.**	**P-value**	**Coeff.**	**P-value**
Kgs. of subsidized seed acquired	0.002	0.511	0.001**	0.033
Kgs. of subsidized fertilizer acquired	0.002***	0.000	0.001***	0.000
=1 if HH used storage chemicals after 2008 harvest	0.105***	0.000	0.065***	0.009
=1 if HH used storage chemicals after 2007 harvest	0.084***	0.000	0.079***	0.004
=1 if farm credit organization in village	-0.022	0.623	0.025	0.295
distance to paved road (km)	-0.002	0.118	0.000	0.648
distance to main market (km)	0.001	0.292	0.000	0.319
distance to extension services (km)	-0.001	0.486	0.003*	0.100
number of dealers who sell subsidized inputs in village	-0.002	0.545	-0.005	0.340
number of commercial input sellers in village	0.034***	0.000	0.038***	0.001
log value of household assets	0.000	0.996	0.010	0.132
landholding (ha)	0.010	0.595	0.110***	0.000
=1 if household headed by female	-0.070**	0.044	-0.040	0.105
log of household adult equivalents	0.059**	0.031	0.069***	0.001
=1 if death in the family over past two years	-0.039	0.321	-0.041	0.244
=1 if primary (grades 1 to 4)	0.009	0.818	-0.027	0.345
=1 if upper primary (grades 5 to 8)	0.050	0.125	0.030	0.278
=1 if secondary (grades 8 to 12)	-0.025	0.511	-0.020	0.597
=1 if post-secondary	-0.004	0.959	-0.001	0.990
past year hungry season maize price	-0.004	0.247	-0.003	0.214
past year harvest season maize price	0.000	0.992	0.007*	0.053
price of NPK & Urea fertilizer	0.000	0.488	0.000	0.710
agricultural wage rate (kwacha/day)	0.000	0.721	0.000**	0.018
average rainfall, past five growing seasons	0.001***	0.003	0.000	0.395
coefficient of variation on past rainfall	-0.190	0.716	-0.440	0.244
=1 if household in northern region	-0.068	0.688	-0.170	0.138
=1 if household is in central region	-0.067	0.374	-0.104*	0.083
N	1,375		1,375	
R^2	0.14		0.12	

Note: *, **, *** indicates that corresponding coefficients are statistically significant at the 10%, 5%, and 1% level respectively; coefficients are Average Partial Effects (APE) estimated via the *margins* command in Stata.

Table 5. Factors Affecting the Probability of Adoption and The Number of Hectares Planted to Improved Maize Varieties During the 2008/09 Season (Subsidized Seed and Fertilizer Endogenous).

	(1)		(2)	
	Dep var: = 1 if HH Adopts Improved Maize Seed		**Dep var:** Ha of Improved Maize Seed that HH Plants	
	PROBIT		**TOBIT**	
Covariates	**Coeff.**	**P-value**	**Coeff.**	**P-value**
Residuals from subsidized seed reduced form tobit	-0.357	0.863	-0.378	0.458
Residuals from subsidized fertilizer reduced form tobit	0.047	0.837	0.050	0.518
Kgs. of subsidized seed acquired	0.002	0.952	0.001	0.823
Kgs. of subsidized fertilizer acquired	0.002***	0.000	0.001***	0.000
=1 if HH used storage chemicals after 2008 harvest	0.271	0.962	0.240	0.851
=1 if HH used storage chemicals after 2007 harvest	-0.706	0.763	-0.756	0.493
=1 if farm credit organization in village	1.404	0.753	1.526	0.487
distance to paved road (km)	0.014	0.797	0.017	0.514
distance to main market (km)	-0.002	0.974	-0.003	0.711
distance to extension services (km)	0.061	0.701	0.069	0.453
number of dealers who sell subsidized inputs in village	0.012	0.984	0.009	0.947
number of commercial input sellers in village	-0.366	0.757	-0.383	0.463
log value of household assets	-0.022	0.983	-0.013	0.960
landholding (ha)	-0.071	0.978	0.023	0.956
=1 if household headed by female	-0.357	0.948	-0.343	0.858
log of household adult equivalents	1.014	0.687	1.077	0.253
=1 if death in the family over past two years	0.901	0.808	0.956	0.518
=1 if primary (grades 1 to 4)	-0.237	0.925	-0.287	0.544
=1 if upper primary (grades 5 to 8)	-1.006	0.777	-1.085	0.420
=1 if secondary (grades 8 to 12)	0.160	0.962	0.179	0.935
=1 if post-secondary	6.343	0.870	6.717	0.454
past year hungry season maize price	-0.029	0.960	-0.028	0.853
past year harvest season maize price	0.225	0.847	0.246	0.652
price of NPK & Urea fertilizer	-0.003	0.939	-0.004	0.776
agricultural wage rate (kwacha/day)	0.001	0.879	0.001	0.633
average rainfall, past five growing seasons	-0.004	0.895	-0.005	0.833
coefficient of variation on past rainfall	-7.560	0.936	-8.293	0.643
=1 if household in northern region	-0.597	0.967	-0.736	0.937
=1 if household is in central region	0.156	0.980	0.133	0.982
N	1,375		1,375	
R^2	0.15		0.13	

Note: *, **, *** indicates that corresponding coefficients are statistically significant at the 10%, 5%, and 1% level respectively; coefficients are Average Partial Effects (APE) estimated via the *margins* command in Stata; p-values obtained via bootstrapping at 500 repetitions.

Table 6. Factors Affecting the Probability of Adoption and The Number of Hectares Planted to Improved Maize Varieties During the 2008/09 Season; with Storage Chemical Access During the 2009 Harvest Included (All Covariates Assumed Exogenous).

	(1)		(1)	
	Dep. Var. = 1 if HH Adopts Improved Maize Seed		**Dep. Var.** = Ha of Improved Maize Seed that HH plants	
	PROBIT		**TOBIT**	
Covariates	**Coeff.**	**P-value**	**Coeff.**	**P-value**
Kgs. of subsidized seed acquired	0.002	0.529	0.001**	0.029
Kgs. of subsidized fertilizer acquired	0.002***	0.000	0.001***	0.000
=1 if HH used storage chemicals after 2009 harvest	0.170***	0.000	0.131***	0.000
=1 if farm credit organization in village	-0.014	0.769	0.032	0.178
distance to paved road (km)	-0.002	0.124	0.000	0.695
distance to main market (km)	0.000	0.295	0.000	0.342
distance to extension services (km)	-0.001	0.489	0.003*	0.093
number of dealers who sell subsidized inputs in village	-0.004	0.346	-0.007	0.217
number of commercial input sellers in village	0.035***	0.000	0.040***	0.001
log value of household assets	-0.001	0.903	0.009	0.167
landholding (ha)	0.009	0.640	0.110***	0.000
=1 if household headed by female	-0.073**	0.016	-0.041	0.098
log of household adult equivalents	0.057*	0.052	0.066***	0.002
=1 if death in the family over past two years	-0.035	0.391	-0.036	0.306
=1 if primary (grades 1 to 4)	0.010	0.800	-0.027	0.347
=1 if upper primary (grades 5 to 8)	0.039	0.205	0.021	0.442
=1 if secondary (grades 8 to 12)	-0.022	0.574	-0.018	0.620
=1 if post-secondary	-0.007	0.935	0.003	0.975
past year hungry season maize price	-0.005	0.160	-0.004*	0.091
past year harvest season maize price	0.001	0.883	0.008**	0.034
price of NPK & Urea fertilizer	0.000	0.405	0.000	0.840
agricultural wage rate (kwacha/day)	0.000	0.734	0.000**	0.022
average rainfall, past five growing seasons	0.001***	0.002	0.000	0.324
coefficient of variation on past rainfall	-0.164	0.755	-0.460	0.222
=1 if household in northern region	-0.082	0.632	-0.192*	0.090
=1 if household is in central region	-0.073	0.352	-0.115*	0.054
N	1,375		1,375	
R^2	0.15		0.12	

Note: *, **, *** indicates that corresponding coefficients are statistically significant at the 10%, 5%, and 1% level respectively; coefficients are Average Partial Effects (APE) estimated via the *margins* command in Stata.