Smallholder Behavioral Responses to Marketing Board Activities in a Dual Channel Marketing System: The Case of Maize in Zambia

Nicole M. Mason, T.S. Jayne, and Robert J. Myers
Department of Agricultural, Food, & Resource Economics
Michigan State University

Corresponding Author: Nicole M. Mason
446 W. Circle Dr. Rm. 207
Agriculture Hall
East Lansing, MI 48824-3755
masonn@msu.edu

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Abstract: This paper develops a conceptual model of farmers' production decisions in the context of dual output marketing channels (e.g., government and private sector) when prices at harvest time and the availability of one of the channels are unknown at planting time. It then uses the operationalized model to estimate the marginal effects of Food Reserve Agency (FRA) policies on smallholder behavior in Zambia. Results suggest that increases in the FRA farmgate maize price influence smallholders' production decisions by raising their expected maize price. Smallholders respond to an increase in the FRA price by both intensifying and extensifying their maize production.

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More than two decades after the initiation of agricultural market reforms in eastern and southern Africa (ESA), most governments in the region continue to participate directly in staple food marketing (Jayne et al. 2002; Jayne, Chapoto, and Govereh 2007; World Bank 2008). In recent years, parastatal grain marketing boards (GMBs) and strategic grain reserves (SGRs) have re-emerged as important players in grain markets in ESA, yet little is known about how these scaled-up activities are affecting fertilizer use and crop production among smallholder farmers.

The existing literature on the impacts of GMBs in the region focuses mainly on the decades prior to structural adjustment and on the effects of the dismantling or downsizing of these entities during the 1980s and 1990s (e.g., Jansen 1991; Krueger 1991; Schiff and Valdés 1991; Masters and Nuppenau 1993; Krueger 1996). Although this literature is relevant to the recent revival of GMBs in ESA, a key difference between grain markets prior to structural adjustment and grain markets today is that grain trade is now mostly *legal* in countries with GMBs/SGRs. Prior to structural adjustment, parallel grain markets existed in many countries with GMBs but private grain trade was officially *illegal*, though often tolerated to some extent. Further analysis is needed to understand the effects of GMBs/SGRs in the context of legal dual marketing channels.

A second gap in the existing literature on the effects of GMBs/SGRs is that most previous studies are based on aggregate data.[1] Few have used household-level survey data to investigate the micro-level processes through which GMBs/SGRs affect smallholder behavior. Moreover, despite the widespread understanding that African farmers are highly heterogeneous, there have been few investigations of how GMB/SGR operations differentially affect smallholders with varying levels of land or other productive assets.[2]

This article helps to fill these two knowledge gaps by first developing a conceptual model of smallholder factor demand and output supply in the context of dual output marketing channels when harvest time prices in both channels and the availability of one of the channels are unknown at planting time. To our knowledge, this article is the first to develop a conceptual framework of farmer behavioral responses that explicitly takes into account dual output marketing channels with such characteristics. We then apply the conceptual model to the case of Zambia and use nationally-representative household-level panel survey data to estimate the marginal effects of the Food Reserve Agency (FRA), the government parastatal strategic food reserve/maize marketing board, on smallholder fertilizer use and crop production.[3]

Zambia provides a useful case study of how smallholders are responding to the increased role of the state in grain marketing. In recent years, the Government of the Republic of Zambia (GRZ) through the FRA has become the dominant single buyer of smallholder maize in the country. During the 2006/07 and 2007/08 agricultural marketing

[1] Two recent examples are Jayne, Myers, and Nyoro (2008) and Mason and Myers (2011), which use time series data to estimate the effects of GMB activities on maize market prices in Kenya and Zambia, respectively.
[2] A key exception is Mather and Jayne (2011), which is a companion piece to this article and examines the effects of the National Cereals and Produce Board (NCPB, a GMB) on smallholder behavior in Kenya. Another exception is Kutengule, Nucifora, and Zaman (2006), which estimates the effects of proximity to Agricultural Development and Market Corporation (ADMARC, a GMB) facilities on household per capita expenditures in Malawi.
[3] The Zambian case differs markedly from the Kenyan one because the FRA buys mainly from smallholders whereas the NCPB buys almost exclusively from large-scale farmers. As a result, smallholders have two potential maize marketing channels in Zambia but only one in Kenya. This leads to major differences between the conceptual and empirical models used here, and those used by Mather and Jayne (2011).

years, the FRA purchased nearly 400,000 metric tons (MT) of maize from smallholders, or more than 50% of the maize marketed by this group. Then the FRA more than doubled its purchases in 2010/11 and bought 878,570 MT of maize amounting to 83% of estimated smallholder maize sales. The FRA buys maize at a pan-territorial price that often exceeds market price levels in major maize producing areas. Private trade is legal and private buyers are allowed to buy maize at prices above or below the FRA price. Together, FRA activities and GRZ fertilizer subsidies accounted for over 90% of the GRZ budget allocation to agricultural sector Poverty Reduction Programmes in budget years 2006 to 2011.

The household-level panel survey data used in this study cover the 1999/2000, 2002/03, and 2006/07 agricultural seasons, and therefore capture years before and during the recent scale-up of FRA maize purchases. We hypothesize that FRA policies (namely, the FRA's past maize purchase price and maize quantities purchased) affect smallholders' expected maize price, which in turn affects their fertilizer demand and output supply. Our estimates of the marginal effects of the FRA on smallholder behavior control for the potentially confounding effects of GRZ fertilizer subsidies and other factors. In addition to its conceptual and econometric modeling contributions, the article also provides empirical evidence to inform policy debates on the role and effectiveness of the FRA, and of GMBs/SGRs more broadly.

The remainder of the article is organized as follows. The next section provides an overview of FRA activities with particular emphasis on the FRA's domestic maize purchases from 1996/97 to 2007/08. We then summarize smallholder maize sales to the FRA in the years captured in the household panel survey data, and compare the socioeconomic characteristics of households that did and did not sell to the FRA. Subsequent sections describe the conceptual framework, data, empirical application, and results. The final section of the article discusses the conclusions and policy implications.

Background on FRA Activities in Zambia

The FRA, a government parastatal, was established in 1996 by the Food Reserve Act of 1995. The FRA's original function was to establish and administer a national food reserve (GRZ 1995). Crop marketing and "market facilitation" were officially added as FRA functions when the Food Reserve Act was amended in 2005 (GRZ 2005). The Agency's current objectives include raising rural incomes, improving national food security, and stabilizing crop prices (FRA n.d.). Maize is the most important crop in Zambia and the FRA's emphasis has been almost exclusively on maize.

The scale and geographic scope of the FRA's domestic maize purchase activities have varied considerably over the years. Table 1 summarizes these activities during the 1996/97 through 2010/11 marketing years.[4] During its first two years in operation (1996/97 and 1997/98), the FRA purchased relatively small quantities of maize and operated in only a handful of districts. The price paid to contracted traders varied across districts to reflect different market conditions (Kabaghe 2010). The FRA did not purchase maize in Zambia from 1998/99 to 2001/02 due to lack of funding. Therefore, at planting time in 1999/2000 (captured in the first wave of the panel data used here), the FRA had not purchased maize in Zambia in two years and had no plans to do so for the foreseeable future.

In July 2002 following drought-related poor harvests in many areas of Zambia, GRZ allocated 12 billion Zambian Kwacha (ZMK) to the FRA to buy 15,000 MT of maize directly from smallholders in eight surplus districts (FEWSNET and WFP 2002).[5] FRA set up satellite depots to which smallholders delivered their maize. Sourcing maize directly from

[4] The agricultural marketing year in Zambia is from May to April. The agricultural year is from October to September.
[5] The exchange rate in July 2002 was 4,527 ZMK per US dollar (USD).

smallholders rather than through private traders marked a distinct change in FRA procurement practices. By the end of October 2002, the FRA had purchased 9,059 MT in eight districts. They continued buying maize through March 2003 and purchases for the 2002/03 marketing year totaled 23,535 MT from 10 districts. Thus, at planting time in 2002/03 (captured in the second wave of the panel data used in this article), the FRA was buying maize directly from smallholders for the first time since its establishment but in only eight of Zambia's 72 districts.

In May 2003, the FRA announced plans to purchase 205,700 MT of maize directly from smallholders in 37 districts at a pan-territorial price. This was the first time since 1992 that GRZ announced a pan-territorial price for maize (FEWSNET 2003a; FEWSNET 2003b). The Agency ultimately purchased only 54,847 MT (21% of smallholder maize sales) due to funding shortfalls but its ambitious purchase target signaled its intention to become a major player in the Zambian maize market.

The FRA increased maize purchases in 2004/05 and 2005/06, and then dramatically so in 2006/07. After purchasing 360,000 MT, FRA suspended purchases at the end of September 2006. The Agency re-entered the market in November and December, and total FRA purchases for 2006/07 were 389,510 MT (86% of smallholder maize sales). Therefore, at planting time in 2006/07 (captured in the third wave of the panel survey), the FRA was the dominant buyer of smallholder maize in Zambia and had purchased maize directly from smallholders in five consecutive years. At K38,000 per 50-kg bag, the FRA 2006/07 buy price was well above wholesale maize market prices, which ranged from K23,000 to K31,000. The Agency's buying presence had increased from 10 districts in 2002/03 to 53 districts in 2006/07. The FRA purchased nearly 400,000 MT again in 2007/08.

After purchasing maize, the FRA stores it and later sells most of it to large industrial millers and trading firms via a tender process. FRA occasionally sells maize directly to consumers at a pan-territorial price or exports it. Although the FRA typically buys maize at above-market prices, it often sells maize on the domestic market at below-market prices. In this article, we focus on the effects of the FRA's maize purchase price and quantities purchased on smallholder behavior. The FRA may also affect smallholder behavior through its maize storage and sales activities, and through general equilibrium effects on maize and other prices. However, such effects are beyond the scope of this article.

Although the FRA purchased as much as 86% of smallholders' marketed maize during the study period, smallholder sales to the FRA were highly concentrated among a small number of relatively better off households. Table 2 summarizes the rate and level of smallholder participation in selling maize to the FRA during the marketing years captured in the second and third waves of the panel survey data used in the study (2003/04 and 2007/08) and contrasts the socioeconomic characteristics of sellers and non-sellers.[6] Less than 1% of smallholder households sold maize to the Agency in 2003/04. This percentage rose to nearly 10% in 2007/08 as the FRA scaled up its activities. In 2007/08, participating households sold an average of 2.76 MT to the FRA. Households that sold maize to the Agency had considerably larger landholdings, more farm assets, and heads with higher educational attainment, and were less likely to be female-headed than households that did not (table 2).

Conceptual framework

FRA policies are hypothesized to influence the maize price that smallholders expect to receive at the next harvest, which, in turn, affects farmers' fertilizer demand and output supply. In modeling these effects, four key features of farmers' decision environment need to

[6] The FRA did not buy maize in Zambia during the marketing year captured by the first wave of the panel survey (2000/01).

be taken into account. First, at planting time they do not know the price at which the FRA will buy maize and the prices at which private traders will buy maize and other crops at the next harvest. Second, households do not know if the FRA will be buying maize in their area during the next marketing year. Third, the FRA pan-territorial buy price is *not* a floor price. Private sector buyers can legally buy maize for more or less. Fourth, the *farmgate* FRA price (i.e., the FRA pan-territorial price adjusted for transfer costs from the homestead to an FRA satellite depot) varies across households.

With these features in mind, consider a risk-neutral, expected profit-maximizing agricultural producer with implicit production function $G(q, \boldsymbol{q_o}, \boldsymbol{x}; \boldsymbol{z}) = 0$, where q is the quantity of maize produced, $\boldsymbol{q_o}$ is a vector of the quantities produced of other crops, $\boldsymbol{x}$ is a vector of variable input quantities, and $\boldsymbol{z}$ is a vector of other variables not under direct control of the producer (e.g., growing season rainfall). We assume a single (private sector) marketing channel for non-maize crops but two potential marketing channels for maize: private sector and FRA. The private sector channel is always available but the FRA channel may or may not be available. Let γ be a Bernoulli random variable equal to one if the FRA channel is available at harvest and zero otherwise. Let p_f, p_p, and $\boldsymbol{p_o}$ be, respectively, the farmgate FRA and private sector maize prices and a vector of other crop prices at the next harvest. These prices and γ are unobserved random variables at planting time. Assume that the household sells maize to only one marketing channel (the one with the higher farmgate price) and that variable input prices ($\boldsymbol{w}$) are known at planting time.[7] Then, the household's expected profit maximization problem is:

$$\text{(1a)} \quad \max_{q, \boldsymbol{q_o}, \boldsymbol{x}} E\left\{\left[\gamma \max(p_f, p_p) + (1-\gamma)p_p\right]q + \boldsymbol{q_o}\boldsymbol{p_o}\right\} - \boldsymbol{xw}$$

$$\text{(1b) s.t. } G(q, \boldsymbol{q_o}, \boldsymbol{x}; \boldsymbol{z}) = 0$$

Under the additional assumption that γ is independent of p_f and p_p (but allowing p_f and p_p to be correlated) (1a) can be simplified to:

$$\text{(1a}'\text{)} \quad \max_{q, \boldsymbol{q_o}, \boldsymbol{x}} \left\{E(\gamma)E[\max(p_f, p_p)] + [1 - E(\gamma)]E(p_p)\right\}q + \boldsymbol{q_o}E(\boldsymbol{p_o}) - \boldsymbol{xw}$$

Let $\boldsymbol{y} = [q,\ \boldsymbol{q_o},\ \boldsymbol{x}]'$ be a vector of output and variable input quantities and let

$$\text{(2)} \; p^* \equiv E(\gamma)E[\max(p_f, p_p)] + [1 - E(\gamma)]E(p_p)$$

be the expected farmgate maize price received by the household. Then solving (1a′) subject to (1b) gives factor demand and output supply functions of the form:

$$\text{(3)} \; \boldsymbol{y} = \boldsymbol{y}\left(p^*, E(\boldsymbol{p_o}), \boldsymbol{w}; \boldsymbol{z}\right).$$

To evaluate p^* we need an assumption on the joint distribution of (p_f, p_p). Two tractable joint distributions for commodity prices used in the literature are bivariate normal and

[7] This is consistent with household survey evidence from Zambia. In the 2007/08 and 2009/10 marketing years, only 5% of maize-selling smallholder households sold maize to both private sector buyers and the FRA. More than 80% of maize-selling smallholder households had only one maize sale transaction.

bivariate lognormal (see, e.g., Chavas and Holt 1990, and Myers 1989). We assume bivariate lognormality as an approximation.

Let $E(\ln p_j) = \mu_j$, $Var(\ln p_j) = \sigma_j^2$, $j = f, p$, and $Cov(\ln p_f, \ln p_p) = \sigma_{fp} = \rho\sigma_f\sigma_p$, where ρ is the correlation coefficient between $\ln p_f$ and $\ln p_p$. Following Lien (2005), under bivariate lognormality then,

$$\text{(4a) } E[\max(p_f, p_p)] = \exp[\mu_f + (\sigma_f^2/2)]\left\{1 - \Phi\left[\frac{\mu_p - \mu_f - \sigma_f^2 + \sigma_{fp}}{\sqrt{\sigma_f^2 + \sigma_p^2 - 2\sigma_{fp}}}\right]\right\}$$

$$+ \exp[\mu_p + (\sigma_p^2/2)]\left\{1 - \Phi\left[\frac{\mu_f - \mu_p - \sigma_p^2 + \sigma_{fp}}{\sqrt{\sigma_f^2 + \sigma_p^2 - 2\sigma_{fp}}}\right]\right\}$$

$$\text{(4b) } E(p_p) = \exp[\mu_p + (\sigma_p^2/2)].$$

Given data, appropriate functional forms, and producers' subjective assessments of μ_f, μ_p, σ_f^2, σ_p^2, σ_{fp}, $E(\gamma)$, and $E(\boldsymbol{p_o})$, then the supply and factor demand equation (3) can be estimated subject to the specifications in (2) and (4).

Data

Most of the data are drawn from a three-wave, nationally representative longitudinal survey of rural smallholder households in Zambia. The first wave was done in two parts: the 1999/2000 Post-Harvest Survey (PHS9900) conducted by the Zambian Central Statistical Office (CSO) and Ministry of Agriculture and Cooperatives (MACO) in August-September 2000, and the linked CSO/MACO/Food Security Research Project (FSRP) Supplemental Survey conducted in May 2001 (SS01). The second and third waves were the Supplemental Surveys (SS) conducted in May 2004 (SS04) and June-July 2008 (SS08).

PHS9900 and SS01 covered the 1999/2000 agricultural year and 2000/01 marketing year. A total of 7,699 rural households from 70 districts were interviewed for PHS9900. Households were selected using a stratified three-stage sampling design. See Megill (2005) for details. For SS01, attempts were made to revisit all PHS9900 households to collect information on household demographics, off-farm income, remittances, and other details. 6,922 of the 7,699 PHS9900 households were successfully re-interviewed in SS01 (a re-interview rate of 89.9%).

A second attempt was made to revisit PHS9900 households for SS04, which covered the 2002/03 agricultural year and 2003/04 marketing year. SS04 included questions comparable to those on PHS9900 and SS01 plus additional questions. The SS04 survey successfully re-interviewed 5,358 SS01 households (a re-interview rate of 77.4%). The third re-interview of PHS9900 households was SS08, which covered the 2006/07 agricultural year and 2007/08 marketing year. SS08 questions mirrored SS04, and 4,286 SS04 households were successfully revisited (a re-interview rate of 80.0%). Unless otherwise noted, we use the unbalanced panel of households that were interviewed in at least SS01 and SS04, if not SS08. Given non-trivial attrition rates between survey rounds, attrition bias is a potential problem.

However, tests for attrition bias as described in Wooldridge (2002, p. 585) fail to reject the null hypothesis of no attrition bias in all cases (0.27 < p < 0.94).

Other data used in the article are: (i) FRA administrative records on yearly district-level maize purchases from 1996/97 to 2006/07; (ii) dekad (10-day period) rainfall data covering the 1990/91 to 2006/07 growing seasons and collected from 36 stations throughout Zambia by the Zambia Meteorological Department; (iii) crop prices from MACO/CSO Post-Harvest Surveys for 1998/99, 2001/02, and 2005/06; (iv) constituency-level data on the percentage of votes won by the ruling party and opposition parties during the 1996, 2001, and 2006 presidential elections from the Electoral Commission of Zambia; and (v) monthly maize wholesale prices from trading centers in each of Zambia's nine provinces from MACO's Agriculture Market Information Center.

Empirical models and estimation strategy

In order to operationalize the conceptual framework, we first need to estimate households' subjective values for μ_f, μ_p, σ_f^2, σ_p^2, σ_{fp}, and $E(\gamma)$. We hypothesize that these values are influenced by past FRA policies and other factors. We then use the estimated subjective values to construct a household's expected farmgate maize price per equations (2) and (4), and include it as an explanatory variable in the empirical fertilizer demand and output supply regressions. FRA policies are hypothesized to influence smallholder fertilizer demand and output supply by affecting farmers' expected maize price. If (i) a given FRA policy has a statistically significant marginal effect on farmers' expected maize price, *and* (ii) the expected maize price has a statistically significant marginal effect on farm production decisions, then we conclude that the FRA policy affects that behavior. The marginal effect of the FRA policy is computed by applying the chain rule to marginal effects (i) and (ii).

Estimating subjective values for μ_f and μ_p

We assume a process of price expectations formation similar to quasi-rational expectations (see Nerlove and Fornari 1998). Estimates of households' subjective values for expected log maize prices in the FRA and private sector channels are obtained by first estimating

(5) $\ln p_{j,i,t} = \mathbf{\Omega}_{i,t-1}\boldsymbol{\beta}_j + c_i + \varepsilon_{j,i,t}$

where $p_{j,i,t}$ is the channel *j* farmgate maize price received by household *i* in harvest year *t*; $\mathbf{\Omega}_{i,t-1}$ is a vector of information observed by the household at planting time; $\boldsymbol{\beta}_j$ is a vector of parameters to be estimated; c_i is time invariant household-level unobserved heterogeneity; and $\varepsilon_{j,i,t} \sim N(0,\sigma_{j,i,t}^2)$ is the error term. $\mathbf{\Omega}_{i,t-1}$ includes, *inter alia*, maize prices in the private sector and FRA marketing channels at the previous harvest and the volume of maize purchased by the FRA in the household's district during the previous marketing year. See tables A.1 and A.2 in Appendix A for a full list of the variables included in $\mathbf{\Omega}_{i,t-1}$ and associated summary statistics.

Equation (5) is estimated by correlated random effects pooled ordinary least squares (CRE-POLS) using data from households that sold maize to marketing channel *j*. Estimating (5) poses two main econometric challenges. First, the unobserved heterogeneity (c_i) may be correlated with the observed covariates in equation (5) (call them $\boldsymbol{X}_{i,t}$). In order to use the CRE approach to control for c_i and consistently estimate the parameters in equation (5), we first need to assume strict exogeneity of $\boldsymbol{X_{i,t}}$ conditional on c_i, i.e., $E(u_{i,t} \mid \boldsymbol{X_i}, c_i) = 0,\ t = 1,2,...,T$. If in addition to strict exogeneity we assume that $c_i = \psi + \bar{\boldsymbol{X}}_{\boldsymbol{i}}\xi + a_i$ and $c_i \mid \boldsymbol{X_i} \sim Normal(\psi + \bar{\boldsymbol{X}}_{\boldsymbol{i}}\xi,\ \sigma_a^2)$, where $\bar{\boldsymbol{X}}_{\boldsymbol{i}}$ is the average of $\boldsymbol{X_{i,t}}$, t=1,…,T, and σ_a^2 is the variance of a_i, then we can control for c_i by including $\bar{\boldsymbol{X}}_{\boldsymbol{i}}$ as additional explanatory variables in the POLS regression (Wooldridge 2002).[8]

Although equation (5) is estimated using data from households that sold maize to marketing channel *j*, once estimated, (5) can be used to obtain predicted values for *all* households in the sample. This is possible because the variables in $\boldsymbol{\Omega}_{i,t-1}$ are observed for all households whether or not they sold maize to marketing channel *j*.[9] These predicted values are used as measures of households' subjective values for μ_f and μ_p, i.e.,

(6) $\hat{\mu}_{j,i,t} = \boldsymbol{\Omega}_{i,t-1}\hat{\boldsymbol{\beta}}_j$ for $j = f, p$

The second main econometric challenge is related to the fact that although roughly 80% of Zambian smallholder households grow maize, only approximately 30% sell the crop. An even smaller percentage of households sell maize to the FRA (table 2). Predicted log maize prices obtained for all smallholder households from parameter estimates based on data for those that sold maize to marketing channel *j* could therefore be subject to selection bias. However, tests as described in Wooldridge (2002, p. 572) fail to reject the null hypothesis of no sample selection bias in all cases (p>0.10).

Estimating subjective values for σ_f^2 and σ_p^2

From equation (5), note that

(7) $\sigma_{j,i,t}^2 = E(\varepsilon_{j,i,t}^2)$, for $j = f, p$

To obtain subjective variances we first estimate

(8) $\ln \hat{\varepsilon}_{j,i,t}^2 = \boldsymbol{\Omega}_{i,t-1}\boldsymbol{\delta}_j + c_i + v_{j,i,t}$

using CRE-POLS where $\hat{\varepsilon}_{j,i,t}^2$ are the squared residuals from equation (5), $\boldsymbol{\delta}_j$ is a vector of parameters to be estimated, and $v_{j,i,t}$ is the error term. We obtain predicted values $\widehat{\hat{\varepsilon}_{j,i,t}^2}$ for each household in the sample and use this as the household's subjective value for $\sigma_{j,i,t}^2$,

[8] We estimate equation (5) using CRE-POLS instead of fixed effects because although the right-hand side variables are observed for all households in all survey waves in which they were interviewed, households may have only sold maize to the FRA and/or the private sector in one wave. That is, the dependent variable (the farmgate maize price in channel *j*) may only be observed for one wave. Such observations would be dropped in a fixed effects regression but are retained in a CRE-POLS regression. Both fixed effects and CRE-POLS control for unobserved heterogeneity.

[9] The farmgate maize price received from marketing channel *j* is observed only for households that sold maize to that channel.

i.e., $\hat{\sigma}^2_{j,i,t} \equiv \widehat{\varepsilon^2_{j,i,t}}$.[10] The econometric challenges and estimation strategy for equation (8) are similar to those described in the previous sub-section. We find no evidence of selection bias in the estimates of equation (8).

Estimating subjective values for σ_{fp}

We assume that the correlation coefficient between $\ln p_f$ and $\ln p_p$ is a constant ($\bar{\rho}$) and estimate it as the sample correlation between $\hat{\varepsilon}_{f,i,t}$ and $\hat{\varepsilon}_{p,i,t}$ (the residuals from the log farmgate maize price equations for households that sold to both channels in year *t*). A household's subjective value for σ_{fp} is then measured as $\hat{\sigma}_{fp,i,t} \equiv \bar{\rho}\hat{\sigma}_{f,i,t}\hat{\sigma}_{p,i,t}$.

Estimating subjective values for $E(\gamma)$

SS04 and SS08 did not ask respondents if the FRA channel was available in their area during the 2003/04 and 2007/08 marketing years, respectively, but we do know if a given household sold maize to the FRA in these years. In the empirical application, $\gamma_{i,t} \equiv 1$ if the household sold maize to the FRA, and zero otherwise. A household's subjective probability that $\gamma_{i,t} = 1$ (call it $\hat{\gamma}_{i,t}$) is defined as the predicted probability from the probit model:

(9) $E(\gamma_{i,t} \mid \mathbf{\Omega}_{i,t-1}) = \Pr(\gamma_{i,t} = 1 \mid \mathbf{\Omega}_{i,t-1}) = \Phi(\mathbf{\Omega}_{i,t-1}\boldsymbol{\omega})$

where $\boldsymbol{\omega}$ is a vector of parameters to be estimated. Equation (9) is estimated by CRE-probit. CRE is used to control for the unobserved heterogeneity in the probit equation (Wooldridge 2002). There is no selection bias issue because $\gamma_{i,t}$ is observed for all households in the sample. All 1999/2000 households and 2002/03 households outside of the eight districts where the FRA had purchased maize as of planting time in 2002 are excluded from the probit and assigned zero probability of selling to the FRA at the next harvest.

Having obtained estimates of $\hat{\mu}_{f,i,t}$, $\hat{\mu}_{p,i,t}$, $\hat{\sigma}^2_{f,i,t}$, $\hat{\sigma}^2_{p,i,t}$, $\hat{\sigma}_{fp,i,t}$, and $\hat{\gamma}_{i,t}$, the expected farmgate maize price is constructed according to equations (2) and (4). We also compute the average partial effects (APEs) of FRA policies on the expected maize price by taking the partial derivative of the expected maize price (equations 2 and 4) with respect to the farmgate FRA price or FRA district-level maize purchases in the previous year. (Recall that these two variables are included in $\mathbf{\Omega}_{i,t-1}$ and are therefore explanatory variables in all of the auxiliary regressions used to construct the expected maize price.) Standard errors for these APEs are obtained via bootstrapping to account for the multiple stage estimation.

Empirical factor demand and output supply equations

The empirical factor demand and output supply equations are specified as

(10) $y_{i,t} = \alpha_0 + \alpha_1 \hat{p}^*_{i,t} + \mathbf{p}_{o,k,t-1}\boldsymbol{\alpha_2} + \alpha_3 w_{i,t} + \mathbf{z}_{i,t}\boldsymbol{\alpha_4} + \alpha_5 govtfert_{i,t} + c_i + u_{i,t}$

[10] Since $\widehat{\ln X} \neq \ln(\hat{X})$, we follow the procedure described in Wooldridge (2009, p. 212, equation 6.43) to obtain the desired values, $\widehat{\hat{\varepsilon}^2_{j,i,t}}$, after estimating equation (8).

where $\hat{p}^*_{i,t}$ is the expected farmgate maize price (ZMK/kg); $\boldsymbol{p_o}_{,k,t\text{-}1}$ is a vector of median prices for other crops in province *k* at the previous harvest in ZMK/kg; $w_{i,t}$ is the farmgate fertilizer market price in ZMK/kg paid by households that purchased fertilizer from commercial sources, or the district median farmgate fertilizer market price if no fertilizer was purchased; $\boldsymbol{z}_{i,t}$ is a vector of other production shifters such as quasi-fixed factors of production, rainfall, and household characteristics affecting production; $govtfert_{i,t}$ is the kilograms of government-subsidized fertilizer acquired by the household; c_i is time invariant household-level unobserved heterogeneity; and $u_{i,t}$ is the error term.[11] In equation (10), expected prices for non-maize crops ($E(\boldsymbol{p_o})$) in harvest year *t* are proxied by prices in *t-1*. While this naïve price expectations assumption is much simpler than the specification of households' maize price expectations, insufficient data are available to estimate households' other price expectations in a similar way to maize. The commonly marketed crops for which lagged prices are available are groundnuts and sweet potatoes. (See tables A.1 and A.2 in Appendix A for summary statistics for all explanatory variables.) The key parameter estimate of interest in equation (10) is $\hat{\alpha}_1$, the APE of the expected maize price.

A factor demand equation is estimated for the maize fertilizer application rate (kilograms of fertilizer per hectare of maize) and output supply equations are estimated for area planted and yield.[12] Since crop output is equal to area planted times yield, we apply the product rule to estimation results for area planted and yield to compute the APEs of key variables of interest on crop output, rather than estimating a separate equation for crop output. Area and yield equations are estimated for maize and "other crops", namely, the 16 non-maize crops covered by all three SSs: cassava, sweet potato, sorghum, millet, groundnut, mixed bean, cotton, rice, sunflower, soybean, Irish potato, ground bean, cowpea, velvet bean, tobacco, and coffee. An index of the yield of other crops is computed as the Fisher-Ideal Quantity Index for those 16 crops (FIQI) (Diewert 1992; Diewert 1993) divided by hectares planted to those crops. See table A.3 in Appendix A for summary statistics for the various dependent variables.

Two econometric challenges associated with estimating equation (10) are controlling for the unobserved heterogeneity (c_i) and testing and controlling for the potential endogeneity of $govtfert_{i,t}$. We control for the unobserved heterogeneity using the fixed effects (FE) estimator or the CRE approach. The FE estimator is consistent under strict exogeneity and a rank condition (Wooldridge 2002), and is used to estimate equation (10) for all dependent variables. We also use CRE-Tobit to estimate the fertilizer application rate equation as well as the area planted equations for maize and other crops because these dependent variables are equal to zero for 64%, 20%, and 20% of the sample, respectively. A Tobit model may therefore characterize the full distribution of these variables better than a linear model, and CRE is compatible with Tobit.

[11] Price data on variable inputs other than fertilizer are not available. Following Ricker-Gilbert, Jayne, and Chirwa (2011), the quantity of government-subsidized fertilizer acquired by the household is treated as a quasi-fixed factor.
[12] We focus on the fertilizer application rate for maize in particular because approximately 96% of the fertilizer used on field crops in Zambia is applied to maize.

All explanatory variables in equation (10) are assumed to be strictly exogenous except for the quantity of subsidized fertilizer acquired by the household. $govtfert_{i,t}$ may be endogenous because GRZ fertilizer program participants are not randomly selected. $govtfert_{i,t}$ is also a corner solution variable: most households acquire zero government-subsidized fertilizer in a given year, and the quantity acquired by recipients is approximately continuous. We follow Ricker-Gilbert, Jayne, and Chirwa (2011) and use the control function approach to test and control for the potential endogeneity of $govtfert_{i,t}$.

The control function approach entails using CRE-Tobit to estimate a reduced form (RF) model where $govtfert_{i,t}$ is the dependent variable and the explanatory variables are all of the regressors in equation (10) and at least one instrumental variable (IV). The RF Tobit residuals are then included as an additional regressor in equation (10). If the coefficient on the Tobit residuals is statistically significant, then we reject the null hypothesis that $govtfert_{i,t}$ is exogenous. Including the Tobit residuals in equation (10) also solves the endogeneity problem (Rivers and Vuong 1988; Vella 1993).[13]

Three candidate IVs are included in the RF for $govtfert_{i,t}$: (i) a binary variable equal to one if the household's constituency (*s*) was won by the ruling party (the Movement for Multi-Party Democracy, MMD) during the last presidential election, and zero otherwise ($MMD_{s,t}$); (ii) the absolute value of the percentage point spread between the MMD and the lead opposition party in the constituency in the last presidential election ($spread_{s,t}$); and (iii) the interaction term, $MMD_{s,t} \times spread_{s,t}$.[14] Banful (2011) uses similar variables to explain district level subsidized fertilizer allocation in Ghana in 2008. RF Tobit results indicate that $MMD_{s,t}$ and the interaction effect are strongly partially correlated with $govtfert_{i,t}$ ($p<0.001$).[15] We maintain that the IVs should be uncorrelated with $u_{i,t}$ given the explanatory variables included in equation (10) and the use of FE or CRE to control for c_i. Furthermore, results from tests for over-identifying restrictions generally support the exogeneity of the two extra IVs. (Only one IV is need for the model to be just-identified.)

The last econometric challenge in estimating equation (10) is that two of the explanatory variables in the equation are 'generated regressors', i.e., they are estimated in first-stage auxiliary models. The two generated regressors are the expected maize price and the RF Tobit residuals. Standard errors are computed using bootstrapping to account for the sampling variation inherent in these generated regressors (Wooldridge 2002).

Results

We begin by presenting the first stage results: the estimated marginal effects of the lagged farmgate FRA maize price and lagged FRA district-level maize purchases on a smallholder household's expected farmgate maize price. We then report the second stage results: the

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[13] Tests for the statistical significance ($p<0.10$) of the Tobit residuals suggest that $govfert_{i,t}$ is endogenous in all of the factor demand and output supply equations estimated in this study except for the other crops area equation estimated via FE. See tables B.1 to B.3 in Appendix B for details.

[14] There are 150 total constituencies in Zambia's 72 districts. Presidential and parliamentary elections in Zambia take place every five years and the MMD candidate won all presidential elections between 1991 and 2008.

[15] See Table B.4 in Appendix B for the full regression results for the reduced form Tobits.

estimated marginal effects of the expected maize price on smallholders' fertilizer application rate and crop output supply. Finally, we discuss the combined first and second stage results: the marginal effects of FRA policies on smallholder behavior.

The marginal effects of FRA policies on a smallholder's expected farmgate maize price
Estimation results in table 3 suggest that, of the two FRA policy variables (the lagged FRA farmgate maize price and lagged FRA purchases in a household's district), only the lagged FRA price has a statistically significant effect on a smallholder's expected maize price ($p<0.10$).[16] The average elasticity (AE) of the lagged FRA price is highly significant in the 2006/07 agricultural year ($p=0.005$) but not statistically different from zero in the 2002/03 agricultural year ($p=0.800$) (table 3). The AE is also larger in magnitude (0.088) in 2006/07 than in 2002/03 (0.004). These results are as expected because the FRA did not purchase any maize domestically from 1998/99 through 2001/02, and the 2002/03 marketing year was the first time the Agency bought maize directly from smallholders. Furthermore, as of planting time in the 2002/03 agricultural year, the FRA had only purchased maize in eight of Zambia's 72 districts and the quantities purchased were small (table 1). Therefore, at planting time in 2002/03, smallholders would have had little reason to expect the FRA to be a major buyer of maize at the next harvest, and thus little reason for the lagged FRA farmgate price to influence their maize price expectations.

In contrast, by 2006/07, the FRA had established itself as a major player in the Zambian maize market. Between 2002/03 and 2006/07, the Agency steadily increased the scale and geographic scope of its maize purchases (table 1). It is therefore consistent with *a priori* expectations that the lagged FRA farmgate maize price would have influenced smallholders' expected maize price in 2006/07.

Also evident in table 4 is the greater expected maize price responsiveness to the lagged FRA price among farmers cultivating two or more hectares (AE=0.17) compared to those cultivating smaller areas (AE=0.06). Farmer's maize price expectations are also more elastic with respect to the lagged FRA price in areas that are agro-ecologically suitable for rainfed maize production (AE=0.11) compared to less suitable areas (AE=0.06). These results are consistent with *a priori* expectations.

What are the channels through which the lagged FRA farmgate maize price affects smallholders' expected maize price? Increases in the lagged FRA price raise farmers' expected maize price by raising their expected FRA farmgate price and by increasing the probability of their selling to the FRA at the next harvest. This can be seen in table 4, which shows the results of the five auxiliary regressions used to construct the expected maize price variable: the mean and variance of farmgate private sector and FRA maize prices (columns A through D), and the probability of selling maize to the FRA at the next harvest (column E).

The lagged FRA farmgate price has a highly significant and large positive effect on the FRA farmgate price farmers expect to receive at the next harvest ($p=0.000$, AE=0.345). This result is consistent with the fact that it has proven difficult politically for the FRA to lower its pan-territorial buy price from one year to the next. In fact, the FRA price has either increased or stayed the same every year since it began setting a pan-territorial price in 2003/04. An increase in the lagged FRA farmgate maize price also has a statistically significant ($p=0.001$) positive effect on the probability that a household will sell to the FRA at the next harvest.

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[16] Table 4 shows that lagged FRA maize purchases in a household's district have marginally significant effects on the mean and variance of the farmgate private sector price, and on the probability of selling maize to the FRA. However, these effects are too weak to affect the overall expected farmgate price. After bootstrapping to take into account the multiple auxiliary regressions used to construct the expected maize price, lagged FRA maize purchases have no statistically significant effect on smallholders' expected maize price ($p=0.172$).

Marginal effects of the expected farmgate maize price on smallholder behavior
APEs and AEs of the fertilizer application rate and crop output supply with respect to the expected farmgate maize price are summarized in table 5. Results suggest that Zambian smallholders respond to increases in the expected maize price by both intensifying and extensifying their maize production. A 1% increase in the expected maize price is associated with a 0.74% increase in the rate of fertilizer applied to maize (p=0.011, row B), and a 0.67% increase in the area planted to maize (p=0.023, row D). Despite the increase in the fertilizer application rate, there is no statistically significant change in the maize yield (p=0.245).[17] The area expansion combined with no change in yield result in an increase in maize quantity harvested of 0.67% for each 1% increase in the expected maize price (p=0.023, row G). Changes in the expected maize price have no statistically significant effect on the area planted, yields, or output of other crops (p>0.10, rows I-K).

Marginal effects of the FRA farmgate maize price (t-1) on smallholder behavior
The positive marginal effect of the lagged FRA price on farmers' expected maize price coupled with the positive marginal effect of the expected maize price on their fertilizer application rate, maize area planted, and maize quantity harvested suggest that increases in the lagged FRA price result in increases in these three dimensions of smallholder behavior. Based on the CRE-Tobit results in table 6, a 1% increase in the previous year's FRA farmgate price raises smallholders' fertilizer application rate by 0.14%, and increases their maize area planted and maize quantity harvested by 0.06%. As expected, smallholders that cultivate more land are more responsive to changes in the FRA farmgate price, as are farmers in areas that are more agro-ecologically suitable for rainfed maize production (table 6). Estimation results also suggest no statistically significant marginal effect of the expected maize price on the area, yields, or output of other crops, and therefore no significant FRA price effect on these behaviors. Thus, although the conventional wisdom in Zambia attributes recent declines in the production of non-maize crops to the scale-up of FRA activities, we find no empirical evidence to support this claim.

In Zambia and in sub-Saharan Africa more broadly, landholding size is highly positively correlated with household incomes (Jayne et al. 2003). How do the effects of changes in the lagged FRA price vary across households with different landholdings sizes and, by proxy, incomes? Table 7 shows these distributional effects by landholding size category.[18] The table also shows the extent to which farmers in each category sell to the FRA and therefore directly benefit from the above-market prices the Agency pays farmers for their maize. Approximately 70% of Zambian smallholders have landholdings of less than 2 ha (column A). The supply responsiveness of these farmers to changes in the lagged FRA price is considerably lower in both elasticity and absolute terms than the nearly 30% of farmers that control 2 ha of land or more (columns B through D). For example, households in the

[17] Mather and Jayne (2011) obtain a similar result for Kenya. In Zambia, 98% of smallholders' maize fields are on highly acidic soils (3.1≤pH≤5.4). Burke (2012) estimates a production function and finds that maize yield response rates to an increase in the basal dressing fertilizer application rate are very low on these soils. (Other factors constant, a one kg/ha increase in the basal fertilizer application rate raises maize yields by only 2.14 to 3.74 kg/ha.) In this article we estimate factor demand and output supply functions, not production functions; nonetheless, the pervasive soil acidity problem in Zambia may explain our finding that an increase in the expected maize price raises smallholders' fertilizer application rates but does not significantly raise their maize yields.
[18] Columns C and D of Table 7 show the estimated changes in maize ha planted and kg harvested given a 100 ZMK/kg increase in the lagged FRA price. To put this price change in perspective, the FRA pan-territorial price during the 2006/07 and 2007/08 marketing years was 760 ZMK/kg. This price rose to an average of 1,000 ZMK/kg during the 2008/09 marketing year, an increase of 240 ZMK/kg. The average exchange rate in 2007 was 4,006 ZMK/USD.

smallest landholding category (0-0.99 ha) have an average elasticity of supply that is only 57% that of farmers in the largest landholding category (5+ ha category, table 7, column B). In absolute terms, the smallest farms' increase in maize area planted and quantity harvested in response to an increase in the lagged FRA price is only roughly 10% that of the largest farmers' supply response (table 7, columns C and D).

Farmers' with smaller landholdings are also much less likely to sell to the FRA than are households with larger landholdings. For example, only 2.2% of farmers with landholdings of less than 1 ha sold maize to the FRA during the 2007/08 marketing year, whereas 28.1% of smallholders with landholdings of 5 ha or more sold to the FRA that year (table 7, column E). Moreover, smallholder sales to the FRA are highly concentrated in the hands of households with larger landholdings. Although farmers cultivating 5 ha or more make up only 5.4% of the smallholder population, they account for 53.2% of smallholder maize sales to the FRA (table 7, column F). The direct benefits of the high price the FRA pays for maize therefore accrue disproportionately to households with more land (and presumably higher incomes). These relatively better-off households also benefit more from increases in the FRA price through a larger supply response, i.e., a larger *ceteris paribus* increase in maize kg harvested.

Conclusions & policy implications

Over the last decade there has been a resurgence in direct government participation in agricultural input and output marketing in eastern and southern Africa (ESA). After being scaled back or eliminated during the market reforms of the 1980s and 1990s, parastatal marketing boards and strategic reserves are once again active players in the region's grain markets. Private grain trade remains legal in most cases, thus an increasingly important feature of grain markets in ESA is dual marketing channels: government and private sector. However, little is known about how the revival of GMBs/SGRs is affecting input use and crop production by smallholder farmers in the region.

In this article, we first develop a conceptual framework to model factor demand and crop output supply in the context of dual grain marketing channels when there is uncertainty about the prices to be paid by the two channels and about whether one of the channels will be available at harvest time. Farmers in ESA and elsewhere often find themselves in such situations. We then operationalize the conceptual model and apply it to the case of Zambia, where the FRA has become a major player in the domestic maize market in recent years. Using nationally-representative panel survey data covering more than 5,000 Zambian smallholder households in the 1999/2000, 2002/2003, and 2006/2007 agricultural years, we estimate the marginal effects of the FRA's past farmgate maize purchase price and maize quantities purchased on seven dimensions of smallholder behavior: the fertilizer application rate on maize; maize area planted, yields, and quantity harvested; and area planted, yields, and output of other crops.

The article provides the following key findings. First stage estimation results suggest that an increase in the previous year's farmgate FRA maize price raises the maize price that smallholders expect to receive at the next harvest. More specifically, a 1% increase in the lagged FRA price increases households' expected maize price in 2006/07 by 0.09%. The magnitude of this elasticity is larger for households that cultivate two or more hectares of land or are located in areas that are well suited for low input rainfed maize production. Changes in the FRA's maize purchase volumes have no statistically significant effect on farmers' expected maize price; rather, the FRA farmgate price captures most of the FRA effects.

Second stage estimation results suggest that an increase in the expected maize price has a positive effect on smallholders' fertilizer application rate on maize as well as their maize area planted and maize quantity harvested. Changes in the expected maize price have no statistically significant effect on maize yields or on the area, yields, or output of other crops.

Together, the first and second stage results suggest that for 2006/07, smallholders responded to an increase in the lagged FRA farmgate maize price by both *intensifying* and *extensifying* their maize production. We find no evidence to support the claim that the increase in maize production stimulated by FRA policies comes at the expense of other crops. A 1% increase in the lagged FRA price is associated with a 0.14% increase in the fertilizer application rate and 0.06% increases in maize area planted and maize quantity harvested. The maize supply response is larger among the roughly 30% of smallholders with landholdings of 2 ha or more (average elasticities are 0.069% to 0.082%) than among the 70% of households that control less than 2 ha of land (average elasticities are 0.047% to 0.056%). Households with larger landholdings also account for a disproportionate share of maize sales to the FRA: the 5.4% of smallholder households with landholdings of 5 ha or more account for 53.2% of all smallholder maize sales to the FRA. The FRA continued to ramp up its maize purchases after 2006/07. Smallholders may have become even more responsive to FRA activities as the Agency became a more permanent fixture of the maize marketing landscape in Zambia.

The results of this study are largely consistent with those of Mather and Jayne (2011), which estimates the effects of the National Cereals and Produce Board on smallholder behavior in Kenya. Although the NCPB buys almost exclusively from large-scale farmers, not smallholders, increases in the NCPB maize purchase price do raise smallholders' expected maize price. Kenyan smallholders respond to an increase in the expected maize price by intensifying maize production (i.e., increasing their fertilizer application rate) rather than expanding the area planted to maize (Mather and Jayne 2011). Kenyan farmers are generally more land-constrained than their Zambian counterparts. This may explain why NCPB activities raise maize output in Kenya mainly through intensification whereas FRA activities raise maize output in Zambia through both intensification and extensification. As in the Zambia case, Mather and Jayne (2011) find no evidence that the increases in maize production brought about by NCPB policies have come at the expense of other crops.

Although the results of this study indicate that FRA policies have indeed increased maize production in Zambia, additional research is needed to assess the cost-effectiveness of these policies, especially given the high level of public resources devoted to the FRA. For example, in the 2010/11 marketing season, spending on the FRA amounted to approximately 2% of the nation's GDP (IMF 2011). Between 2004 and 2011, GRZ allocated an average of 25% of its annual agricultural sector Poverty Reduction Programmes budget to the FRA. Despite these large expenditures on FRA activities, rural poverty rates have remained stubbornly high at roughly 80% since the early 2000s, and there has been no substantive reduction in rural poverty since the FRA was established in 1996 (CSO 2010). This calls into question whether the FRA has accomplished its "strategic mission" of ensuring national food security and income (FRA n.d.). Results presented here also cast doubt on the effectiveness of FRA policies as poverty reduction strategies. In particular, we show that although poorer households with relatively small landholdings make up the vast majority of the smallholder population, these households sell very little maize to the FRA. They also have a much smaller maize supply response to changes in the FRA price than larger, relatively better-off smallholders.

GRZ and donor funds devoted to the FRA come at a high opportunity cost. Limiting FRA involvement in the maize market to securing the national strategic food reserve, its original mandate, would free up resources that could be invested in the known drivers of pro-poor agricultural growth such as agricultural research, development and extension, rural infrastructure, and education (Fan, Gulati, and Thorat 2008; World Bank 2008).

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TABLES

Table 1. FRA maize purchases and estimated smallholder maize production and sales, 1996/97-2010/11

Marketing year	# of districts in which FRA purchased maize	FRA domestic maize purchases (MT)	Estimated smallholder maize: Production (MT)	Estimated smallholder maize: Sales (MT)	FRA purchases as % of small-holder maize sales
		(A)	(B)	(C)	(D)=(A)/(C)
1996/1997	5	10,500	1,117,955	280,955	3.7
1997/1998	4	4,989	804,626	206,557	2.4
1998/1999	0	0	724,024	175,515	0
1999/2000	0	0	929,304	242,753	0
2000/2001	0	0	1,253,722	303,738	0
2001/2002	0	0	957,437	209,326	0
2002/2003	10	23,535	673,673	143,453	16.4
2003/2004	36	54,847	970,317	260,885	21.0
2004/2005	46	105,279	1,364,841	331,006	31.8
2005/2006	50	78,667	652,414	151,514	51.9
2006/2007	53	389,510	1,339,479	454,676	85.7
2007/2008	58	396,450	1,419,545	533,632	74.3
2008/2009	58	73,876	1,392,180	522,033	14.2
2009/2010	59	198,630	1,657,117	613,356	32.4
2010/2011	62	878,570	2,463,523	1,062,010	82.7

Sources: FRA; CSO/MACO Crop Forecast & Post-Harvest Surveys.

Table 2. Smallholder socioeconomic characteristics by participation in FRA

		Sold maize to FRA?	
Descriptive result	Marketing year	Yes	No
Percentage of smallholder households	2003/2004	0.8%	99.2%
	2007/2008	9.7%	90.3%
Mean (median) kg of maize sold to FRA	2003/2004	2,315 (600)	0
	2007/2008	2,764 (1,250)	0
Mean landholding size (ha)	2003/2004	3.65	2.11
	2007/2008	3.65	1.84
Mean value of farm assets	2003/2004	59.4	23.1
(100,000 ZMK, 2007/08=100)	2007/2008	65.7	18.8
Percentage of female-headed households	2003/2004	8.6%	21.9%
	2007/2008	14.0%	25.0%
Median education of HH head	2003/2004	8	5
(highest grade completed)	2007/2008	7	5

Note: Farm assets are plows, harrows, and ox carts.
Sources: CSO/MACO/FSRP 2004 and 2008 Supplemental Surveys.

Table 3. Average elasticities (AE) of the expected maize price with respect to FRA policies

AE of the expected maize price with respect to:	FRA farmgate maize price (t-1)		FRA district-level maize purchases (t-1)	
	AE	p-val.	AE	p-val.
Overall	**0.0415**	**0.053**	0.0241	0.172
By agricultural year:				
2002/03	0.00433	0.800	-9.15E-5	0.926
2006/07	**0.0882**	**0.005**	0.0546	0.167
2006/07 by farm size category:				
< 2 ha cultivated	**0.0602**	**0.021**	0.0439	0.188
>= 2 ha cultivated	**0.168**	**0.001**	0.0850	0.145
2006/07 by suitability of the SEA for low input management rainfed maize production:				
Highly/moderately suitable	**0.107**	**0.001**	0.0676	0.193
Marginally suitable/unsuitable	**0.0637**	**0.047**	0.0377	0.170

Notes: p-values are based on 500 bootstrap replications. Results in **bold** are statistically significant at the 10% level or lower. Overall refers to all households in both the 2002/03 and 2006/07 agricultural years. SEA is standard enumeration area. An SEA contains approximately 150-200 households and 2-4 villages.
Source: Authors' calculations

Table 4. Results from auxiliary regressions used to construct the expected maize price

Dependent variable:	(A) Log farmgate private sector maize price			(B) Log sqd. residuals from (A)			(C) Log farmgate FRA maize price			(D) Log sqd. residuals from (C)			(E) HH sold maize to FRA =1; =0 otherwise		
Estimator:	CRE-POLS			CRE-POLS			CRE-POLS			CRE-POLS			CRE-Probit		
Explanatory variables:	Coef.	Sig.	p-val.	Coef.	Sig.	p-val.	Coef.	Sig.	p-val.	Coef.	Sig.	p-val.	APE	Sig.	p-val.
Log farmgate FRA maize price (ZMK/kg, t-1)	0.106		0.277	0.612		0.371	0.345	***	0.000	-3.203		0.299	0.286	***	0.001
Log farmgate FRA maize price × 1999/2000 agricultural year	0.329	**	0.021	-0.335		0.915									
FRA district- level maize purchases ('000 MT, t-1)	0.00437	*	0.089	-0.0819	*	0.087	-0.00213		0.357	0.0172		0.790	0.0101	*	0.082
FRA district-level maize purchases, squared				0.00331		0.135									
Log maize producer price (ZMK/kg, t-1)	0.0528		0.424	-3.167		0.887	0.00921		0.828	-2.070		0.200	-0.144	**	0.027
Log maize producer price, squared				0.155		0.929									
Log regional wholesale maize price, Oct. current agric. year (ZMK/kg)	0.0374		0.287	0.551		0.101							0.0410		0.567
Log farmgate market price of fertilizer (ZMK/kg)	0.0219		0.663	-0.353		0.285	0.0302		0.360	-2.024		0.111	-0.118	**	0.016
Log wage to weed 0.25 ha field ('000 ZMK)	-0.0332		0.355	-0.147		0.590	-0.0137		0.362	0.342		0.642	-0.0353		0.184
Landholding size (ha, cultivated+fallow land)	-6.74E-4		0.786	-0.0109		0.151	8.98E-4		0.332	-0.0361		0.337	0.0101	***	0.000
Landholding size, squared	-9.90E-6		0.352												
Adult equivalents	0.00280		0.448	0.0208		0.515	-0.00155		0.433	0.0221		0.757	3.55E-4		0.878
Age of household head	6.09E-4		0.702	-0.157	***	0.001	7.96E-4		0.237	0.00983		0.764	4.26E-4		0.611
Age of household head, squared				0.00140	***	0.001									
Highest level of education completed by HH head (base is none):															
Lower primary (grades 1-4) (=1)	0.0330		0.263	0.447	**	0.038	0.0504	**	0.011	0.0163		0.985	-0.0187		0.274
Upper primary (grades 5-7) (=1)	0.0443		0.124	0.450	**	0.049	0.0364	*	0.082	0.0860		0.928	-0.0117		0.520
Secondary (grades 8-12) (=1)	0.0267		0.482	0.259		0.320	0.0633	***	0.003	0.688		0.477	0.00101		0.965
Post-secondary education (=1)	0.0977	*	0.085	0.456		0.301	0.0249		0.329	-0.0957		0.937	-0.0163		0.616
Female-headed household (=1)													-0.0138		0.443
Gender & residence status of HH head (non-resident if <6 months; base is resident male):															
Female-headed with non-resident husband (=1)	-0.0849		0.262	-0.0371		0.930	-0.0603	**	0.023	0.465		0.634			
Female-headed with no husband (=1)	0.00235		0.938	0.235		0.386	0.0437	***	0.003	0.419		0.503			
HH owns radio (=1)	0.0260		0.123	-0.00644		0.957	0.0103		0.194	0.402		0.391	0.0132		0.198

Table 4 (cont'd)

Dependent variable:	(A) Log farmgate private sector maize price			(B) Log sqd. residuals from (A)			(C) Log farmgate FRA maize price			(D) Log sqd. residuals from (C)			(E) HH sold maize to FRA =1; =0 otherwise		
Estimator:	CRE-POLS			CRE-POLS			CRE-POLS			CRE-POLS			CRE-Probit		
Explanatory variables:	Coef.	Sig.	p-val.	Coef.	Sig.	p-val.	Coef.	Sig.	p-val.	Coef.	Sig.	p-val.	APE	Sig.	p-val.
HH owns cell phone (=1)	-0.0202		0.461	0.305		0.256	0.00472		0.585	0.451		0.267	0.0265	*	0.052
HH does not own but has access to cell phone (=1)	-0.00944		0.675	0.0779		0.754	0.00167		0.838	-0.279		0.417	0.0202	**	0.043
HH owns bicycle (=1)	0.0184		0.251	-0.00859		0.944	-0.00991		0.271	0.365		0.379	0.0240	**	0.039
HH owns motorcycle (=1)	0.00696		0.906	0.742	**	0.036	0.0488		0.295	0.468		0.749			
HH owns car, pick-up, van, truck/lorry, or tractor-trailer (=1)	0.0136		0.837	0.509		0.211	0.00352		0.826	-0.794		0.248	0.0268		0.568
HH owns ox-cart (=1)	5.93E-5		0.998	0.223		0.291	-7.71E-4		0.932	-0.0736		0.903	0.0316		0.155
Km from center of SEA to nearest district town (as of 2000)	8.16E-4		0.859	0.00918	***	0.000	2.53E-4		0.246	0.0128		0.192	2.43E-4		0.423
Km from center of SEA to nearest tarred/main road (as of 2000)	-4.76E-4		0.260	-0.00617	**	0.017	3.21E-5		0.719	-0.00443		0.358	-3.58E-5		0.835
Km from center of SEA to nearest feeder road (as of 2000)	-0.00535	*	0.054	-0.0157		0.200	6.48E-4		0.601	-0.0696		0.347	-0.00690		0.000
Expected growing season rainfall ('00 mm)	0.268	**	0.013	-0.186		0.368	-0.00780		0.529	0.127		0.818	0.0252		0.171
Expected growing season rainfall, squared	-0.0163	***	0.003												
Expected moisture stress	0.0537		0.116	0.417		0.119	-0.0344		0.190	-0.161		0.871	0.0933	**	0.015
SEA suitable for low input management rainfed maize production (=1)	0.0116		0.531	-0.174	*	0.081	0.00817		0.103	0.465		0.128	0.00267		0.799
Agricultural year (2006/2007 is base):															
Agricultural year 1999/2000 (=1)	-2.561	***	0.003	1.375		0.942									
Agricultural year 2002/2003 (=1)	-0.277	***	0.000	0.172		0.616	-0.219	***	0.000	1.848	*	0.087	-0.0827	***	0.000
Constant	7.478	*	0.059	-124.628		0.364	3.989	***	0.000	-14.622		0.616			
District dummies	Yes			Yes			No			No			No		
Provincial & agro-ecological region dummies	No			No			Yes			Yes			Yes		
Time averages (CRE)	Yes			Yes			Yes			Yes			Yes		
Observations	3,969			3,969			492			492			5,441		
R-squared (Pseudo R-squared for probit)	0.678			0.076			0.605			0.112			0.277		
Overall model F-test	73.04	***	0.000	3.57	***	0.000	20.17	***	0.000	4.29	***	0.000	17.74	***	0.000
Theil's U	0.809						0.543								
Unbiasedness of forecast	0.000		1.000	0.00		1.000	0.00		1.000	0.00		1.000			

Notes: See Tables A.1 and A.2 in Appendix A for more complete explanatory variable descriptions. ***, **, * significant at the 1%, 5%, and 10% levels. Complex survey weights & Huber-White robust variance matrix estimator used in computation of standard errors. SEA is standard enumeration area. An SEA contains approximately 150-200 households and 2-4 villages.
Source: Authors' calculations

Table 5. Average partial effects (APE) and average elasticities (AE) of the fertilizer application rate and output supply with respect to the expected maize price

Row	Dependent variable	Estimator	APE	AE	Bootstrap p-value
A	Fertilizer application rate (kg/ha)	FE	0.0543	0.199	0.194
B		CRE-Tobit	**0.152**	**0.737**	**0.011**
C	Maize area planted (ha)	FE	**0.000813**	**0.896**	**0.026**
D		CRE-Tobit	**0.000667**	**0.674**	**0.023**
E	Maize yield (kg/ha)	FE	-0.574	-0.354	0.245
F	Maize output (kg)	Derived from C & E	**1.271**	**0.888**	**0.026**
G		Derived from C & D	**1.186**	**0.670**	**0.023**
H	Area planted to other crops (ha)	FE	5.10E-6	0.005	0.978
I		CRE-Tobit	2.01E-5	0.019	0.932
J	Yield of other crops (FIQI/ha)	FE	-0.0150	-0.671	0.295
K	Output of other crops (FIQI)	*No stat. sig. effect on area or yield, so no stat. sig. effect on output*			

Note: Results in **bold** are statistically significant at the 10% level or lower.
Source: Authors' calculations. See Tables B.1 to B.3 in Appendix B for the full regression results.

Table 6. Average elasticities of the fertilizer application rate, maize area planted, and maize output with respect to the FRA farmgate maize price (t-1), 2006/07 agricultural year

Dependent variable:	Fertilizer application rate (kg/ha)	Maize area planted (ha)		Maize output (kg)	
Estimator:	CRE-Tobit	FE	CRE-Tobit	FE	CRE-Tobit
Overall	0.142	0.0688	0.0598	0.0689	0.0599
By farm size category:					
< 2 ha cultivated	0.0702	0.0715	0.0570	0.0716	0.0571
>= 2 ha cultivated	0.243	0.0623	0.0662	0.0625	0.0665
By suitability of the SEA for low input management rainfed maize production:					
Highly/moderately suitable	0.150	0.0797	0.0704	0.0792	0.0701
Marginally suitable/unsuitable	0.125	0.0539	0.0453	0.0546	0.0458

Note: SEA is standard enumeration area. An SEA contains approximately 150-200 households and 2-4 villages.
Source: Authors' calculations

Table 7. Smallholder maize supply responsiveness to the lagged FRA farmgate price by landholding size, 2006/07 agricultural year

Landholding size	% of smallholder households	Maize supply responsiveness to an increase in the FRA farmgate price (t-1): Average elasticity[a]	Estimated changes per 100 ZMK/kg FRA price increase: Ha planted	Estimated changes per 100 ZMK/kg FRA price increase: Kg harvested	% of smallholder households selling maize to FRA (2007/08 marketing year)	% of total smallholder sales to FRA (2007/08 marketing year)
	(A)	(B)	(C)	(D)	(E)	(F)
0-0.99 ha	37.6%	0.047%	0.00203	4.29	2.2%	1.4%
1-1.99 ha	32.7%	0.056%	0.00441	8.47	7.9%	10.3%
2-4.99 ha	24.3%	0.069%	0.01037	19.28	15.8%	35.2%
5+ ha	5.4%	0.082%	0.02117	41.24	28.1%	53.2%
Overall	100.0%	0.060%	0.00647	13.21	9.7%	100.0%

Notes: [a]The average elasticity is the percentage change in maize area planted and quantity harvested given a 1% increase in the lagged FRA farmgate price. Results are based on CRE-Tobit estimates of the maize ha planted equation and associated derived effects on maize kg harvested. For column (F), the sum of the percentages in the landholding size categories slightly exceeds 100% due to rounding.
Source: 2008 CSO/MACO/FSRP Supplemental Survey and authors' calculations.

APPENDIX A: SUMMARY STATISTICS

Table A.1. Summary statistics for continuous explanatory variables

					Percentile				
Explanatory variables	(A)	(B)	Mean	Std. dev.	10th	25th	50th	75th	90th
FRA district-level maize purchases ('000 MT, t-1)	X		1.911	4.88	0	0	0	0.33	9.89
Farmgate FRA maize price (ZMK/kg, t-1)	X		495	219	219	249	611	700	733
Maize producer price (ZMK/kg, t-1)	X		447	186	219	249	498	609	661
Regional wholesale maize price, October of current agricultural year (ZMK/kg)	X		447	277	130	146	465	657	856
Farmgate market price of fertilizer (ZMK/kg)	X	X	1,442	660	720	780	1,476	1,960	2,400
Wage to weed 0.25 ha (‘000 ZMK, SEA median)	X	X	24.334	12.911	10.870	13.587	20.000	30.000	45.000
Kilometers from center of SEA to nearest (as of 2000):									
District town	X	X	34.5	22.6	9.8	16.0	28.9	47.0	70.2
Tarred/main road	X	X	25.5	35.7	0.9	4.0	12.0	29.2	69.8
Feeder road	X	X	3.3	3.3	0.6	1.1	2.4	4.3	7.7
Age of household head		X	48.3	15.3	30.0	36.0	46.0	60.0	70.0
Landholding size (ha, cultivated+fallow land)	X	X	2.1	2.6	0.5	0.8	1.5	2.5	4.0
Adult equivalents	X	X	4.811	2.437	2.035	3.097	4.48	6.153	7.880
Growing season rainfall (November-March, mm)		X[a]	969	254	639	788	943	1,140	1,258
Moisture stress (# of 20-day periods, Nov.-Mar., with <40 mm rain)		X[a]	1.4	1.4	0	0	1.0	2.0	4.0
Expected growing season rainfall (mm, moving average of past 9 years)	X	X	896	184	660	757	877	1,059	1,167
Expected moisture stress (# of 20-day periods with <40mm rain, moving average of past 9 years)	X	X	1.8	1.0	0.6	0.9	1.9	2.4	3.1
Groundnut producer price (ZMK/kg, t-1, provincial median)		X	1,139	355	769	900	1,053	1,400	1,667
Sweet potato producer price (ZMK/kg, t-1, provincial median)		X	214	102	100	145	193	232	386
Percentage point spread between MMD & leading opposition party in last presidential election[b]			41.8	23.6	11.6	21.2	41.1	61.4	74.4

Note: Variables with X in column (A) included in auxiliary regressions for expected maize price. Variables with X in column (B) included in fertilizer application rate and output supply equations. N=16,566. SEA is standard enumeration area. An SEA contains approximately 150-200 households and 2-4 villages. [a]Included in yield equations but not area planted or fertilizer application rate equations. [b]Candidate instrumental variable in government-subsidized fertilizer reduced form Tobit.
Sources: CSO/MACO/FSRP 2001, 2004, & 2008 Supplemental Surveys.

Table A.2. Summary statistics for binary explanatory variables

Explanatory variables	(A)	(B)	Percentage of households 1999/2000	2002/2003	2006/2007
HH owns radio (=1)	X		34.2	47.0	57.6
HH owns cell phone (=1)	X		0	0	21.1
HH does not own but has access to cell phone (=1)	X		0	0	45.7
HH owns bicycle (=1)	X		41.7	46.0	55.6
HH owns motorcycle (=1)	X		0.5	1.1	0.9
HH owns car, pick-up, van, truck/lorry, or tractor-trailer (=1)	X		1.1	0.8	1.1
HH owns ox-cart (=1)	X		5.1	7.1	8.3
Highest level of education completed by HH head:					
Lower primary (grades 1-4) (=1)	X	X	23.0	25.6	27.0
Upper primary (grades 5-7) (=1)	X	X	36.2	34.0	34.5
Secondary (grades 8-12) (=1)	X	X	19.3	18.3	19.4
Post-secondary education (=1)	X	X	2.5	2.7	1.8
Female-headed with non-resident husband (=1)	X	X	0.6	0.9	0.4
Female-headed with no husband (=1)	X	X	20.8	21.8	23.6
SEA is suitable for low input management rainfed maize production (=1)	X		55.3	56.0	56.4
Agro-ecological region I (low rainfall, less than 800 mm) (=1)	X	X	5.6	5.1	5.4
Agro-ecological region IIa (moderate rainfall, 800-1000 mm, clay soils) (=1)	X	X	40.4	42.1	44.1
Agro-ecological region IIb (moderate rainfall, 800-1000 mm, sandy soils) (=1)	X	X	9.6	9.5	8.6
Agro-ecological region III (high rainfall, over 1000 mm) (=1)	X	X	44.4	43.3	41.9
MMD won the constituency in the last presidential election (=1)[a]			92.8	44.0	59.1
Total number of households in sample			6,922	5,358	4,286

Note: Variables with X in column (A) included in auxiliary regressions for expected maize price. Variables with X in column (B) included in fertilizer demand and output supply equations. [a]Candidate instrumental variable in government-subsidized fertilizer reduced form Tobit.
Sources: CSO/MACO/FSRP 2001, 2004, & 2008 Supplemental Surveys.

Table A.3. Summary statistics for dependent variables

Dependent variable	Ag. year	Obs.	Mean	Std. dev.	Percentile 10th	25th	50th	75th	90th
Auxiliary regressions used to construct the expected maize price									
Farmgate private sector maize price	All	4,475	427.899	237.007	179.105	243.478	375.000	560.462	695.652
Farmgate FRA maize price	2002/03	48	530.021	63.958	420.000	488.000	537.500	596.000	600.000
	2006/07	482	687.684	55.852	640.000	660.000	690.000	720.000	745.000
HH sold maize to FRA (=1)	2002/03	5,358	0.00761						
	2006/07	4,286	0.0971						
Reduced form Tobit for kg of government-subsidized fertilizer acquired by the HH									
Kg of gov't fertilizer acquired	All	16,566	29.294	143.258	0	0	0	0	0
Fertilizer application rate and output supply equations									
Fertilizer application rate (kg fertilizer/ha maize)	All	13,095	85.113	176.275	0	0	0	114.286	327.869
Maize area planted (ha)	All	16,566	0.746	1.085	0	0.155	0.500	1.000	1.620
Area planted to other crops (ha)	All	16,566	0.774	0.949	0	0.180	0.500	1.013	1.820
Maize yield (kg/ha)	All	13,092	1568.644	1208.216	402.000	744.444	1240.741	2010.000	3130.328
Yield of other crops (FIQI/ha)	All	13,087	24.316	26.741	4.763	9.511	17.329	30.025	48.091
Maize output (kg)	All	13,092	1504.640	2934.940	172.500	345.000	804.000	1608.000	3162.500
Output of other crops (FIQI)	All	13,087	21.328	31.929	2.001	5.176	12.794	27.232	48.023

Note: "All" refers to all three agricultural years (1999/2000, 2002/03, and 2006/07) covered by the panel survey data used in the study. Obs. is the number of unweighted observations. 16,566 is the total number of observations in the panel dataset (6,922 for SS01; 5,358 for SS04; 4,286 for SS08).
Sources: CSO/MACO/FSRP 2001, 2004, & 2008 Supplemental Surveys.

APPENDIX B: FULL REGRESSION RESULTS

Table B.1. Fertilizer application rate regression results (kg fertilizer/ha maize)

Estimator:	Fixed Effects			CRE-Tobit		
Explanatory variables:	Coef.	Sig.	Bootstrap p-val.	APE	Sig.	Bootstrap p-val.
Expected farmgate maize price (ZMK/kg)	0.0543		0.194	0.152	**	0.011
Kg of government-subsidized fertilizer acquired by the HH	0.176	***	0.000	0.0995	***	0.000
Tobit residuals from government-subsidized fertilizer reduced form	-0.0987	***	0.000	-0.103	***	0.000
Groundnut price (ZMK/kg, t-1, provincial median)	-0.0108		0.466	0.00842		0.429
Sweet potato price (ZMK/kg, t-1, provincial median)	-0.0273		0.301	0.0392		0.115
Farmgate market price of fertilizer at the farmgate (ZMK/kg)	0.00784		0.367	0.0118		0.187
Wage to weed 0.25 ha field ('000 ZMK)	0.0172		0.945	0.165		0.449
Expected growing season rainfall ('00 mm)	37.180		0.331	2.756		0.641
Expected growing season rainfall, squared	-1.933		0.320			
Expected moisture stress	-12.102		0.191	-0.737		0.936
Adult equivalents	2.174		0.177	2.114	**	0.040
Landholding size (ha, cultivated+fallow land)	-8.725	***	0.000	-4.076	***	0.000
Landholding size, squared	0.0742		0.310			
Age of household head	-0.353		0.259	-0.275		0.387
Highest level of education completed by HH head (base is none):						
Lower primary (grades 1-4) (=1)	4.918		0.416	6.949		0.307
Upper primary (grades 5-7) (=1)	-0.542		0.944	0.470		0.949
Secondary (grades 8-12) (=1)	-2.322		0.812	1.675		0.862
Post-secondary education (=1)	30.120		0.182	20.865		0.285
Gender & residence status of HH head (non-resident if <6 months; base is resident male):						
Female-headed with non-resident husband (=1)	21.736		0.417	13.213		0.520
Female-headed with no husband (=1)	2.453		0.799	-0.300		0.973

Table B.1 (cont'd)

Explanatory variables:	Estimator: Fixed Effects Coef.	Sig.	Bootstrap p-val.	CRE-Tobit APE	Sig.	Bootstrap p-val.
Agricultural year (2006/2007 is base):						
Agricultural year 1999/2000 (=1)	22.962		0.319	110.247	***	0.005
Agricultural year 2002/2003 (=1)	1.984		0.853	38.540	***	0.010
Constant	8.968		0.962			
Provincial & agro-ecological region dummies	N/A			Yes		
Time averages (CRE)	N/A			Yes		
Observations	11,960			11,960		
Within R-squared (Pseudo R-squared for Tobit)	0.0632			0.0515		
Overall model F-stat.	9.75	***	0.000	30.43	***	0.000
Hansen J statistic (over-identification test of all instruments)	1.556		0.459			

Notes: ***, **, * significant at the 1%, 5%, and 10% levels. See Tables A.1 and A.2 in Appendix A for more complete explanatory variable descriptions.

Table B.2. Regression results for maize area planted (ha) and maize yield (kg/ha)

Dependent variable (estimator):	Maize ha (FE)			Maize ha (CRE-Tobit)			Maize yield (kg/ha)		
Explanatory variables:	Coef.	Sig.	Bootstrap p-val.	APE	Sig.	Bootstrap p-val.	Coef.	Sig.	Bootstrap p-val.
Expected effective maize price (ZMK/kg)	8.13E-4	**	0.026	6.67E-4	**	0.023	-0.574		0.245
Quantity of government-subsidized fertilizer acquired by the HH (kg)	9.54E-4	***	0.000	6.62E-4	***	0.000	0.743	***	0.000
Tobit residuals from government-subsidized fertilizer reduced form	-3.28E-4	**	0.020	-2.81E-4	***	0.009	-0.369	*	0.096
Groundnut price (ZMK/kg, t-1, provincial median)	-3.22E-4	***	0.000	-2.11E-4	***	0.000	0.522	***	0.000
Sweet potato price (ZMK/kg, t-1, provincial median)	-4.90E-4	***	0.000	-4.25E-4	***	0.000	-1.100	***	0.000
Farmgate market price of fertilizer (ZMK/kg)	5.71E-5		0.208	4.46E-5		0.197	-0.0826		0.249
Wage to weed 0.25 ha field ('000 ZMK)	-0.00201		0.160	-0.00182		0.104	-1.368		0.659
Growing season rainfall ('00 mm)							99.283		0.103
Growing season rainfall, squared							-5.790	**	0.024
Moisture stress							-21.268		0.334
Expected growing season rainfall ('00 mm)	0.332	*	0.070	-0.0267		0.315	-1.21E-3	***	0.000
Expected growing season rainfall, squared	-0.0203	**	0.025				69.463	***	0.000
Expected moisture stress	-0.0344		0.476	-0.0411		0.273	-344.387	***	0.000
Adult equivalents	0.0130		0.380	0.0130	***	0.003	-1.305		0.956
Adult equivalents, squared	-5.79E-5		0.961				1.8171		0.289
Landholding size (ha, cultivated+fallow land)	0.257	***	0.000	0.182	***	0.000	-88.056	***	0.000
Landholding size, squared	-0.00171		0.116				1.287		0.197
Age of household head	0.00176		0.274	0.00277	**	0.033	-0.691		0.811
Highest level of education completed by HH head (base is none):									
Lower primary (grades 1-4) (=1)	-0.0250		0.320	-0.0189		0.37	74.224		0.168
Upper primary (grades 5-7) (=1)	-0.0307		0.307	-0.0129		0.604	43.023		0.525
Secondary (grades 8-12) (=1)	-0.0212		0.563	-0.0102		0.731	39.122		0.643
Post-secondary education (=1)	-9.82E-4		0.993	0.00775		0.929	109.402		0.479

Table B.2 (cont'd)

Dependent variable (estimator):	Maize ha (FE)			Maize ha (CRE-Tobit)			Maize yield (kg/ha)		
Explanatory variables:	Coef.	Sig.	Bootstrap p-val.	APE	Sig.	Bootstrap p-val.	Coef.	Sig.	Bootstrap p-val.
Gender & residence status of HH head (non-resident if <6 months; base is resident male):									
Female-headed with non-resident husband (=1)	0.0841		0.375	0.116		0.175	-148.759		0.299
Female-headed with no husband (=1)	-0.0355		0.317	-0.0345		0.252	-17.299		0.822
Agricultural year (2006/2007 is base):									
Agricultural year 1999/2000 (=1)	-0.0526		0.767	-0.0123		0.931	164.717		0.527
Agricultural year 2002/2003 (=1)	-0.295	***	0.000	-0.199	***	0.001	77.350		0.477
Constant	-0.639		0.507				7351.893	***	0.000
District dummies	N/A			Yes			N/A		
Time averages (CRE)	N/A			Yes			NA		
Observations	14,999			14,999			11,957		
Within R-squared (Pseudo R-squared for Tobit)	0.322			0.278			0.045		
Overall model F-stat.	25.37			43.950			9.2		
Hansen J statistic (over-identification test of all instruments)	3.545		0.170				5.764	*	0.056

Notes: ***, **, * significant at the 1%, 5%, and 10% levels. See Tables A.1 and A.2 in Appendix A for more complete explanatory variable descriptions.

Table B.3. Regression results for area planted (ha) and yield (FIQI/ha) of other crops

Dependent variable (estimator):	Hectares of other crops (FE)			Hectares of other crops (CRE-Tobit)			Yield of other crops in FIQI/ha (FE)		
Explanatory variables:	Coef.	Sig.	Bootstrap p-val.	APE	Sig.	Bootstrap p-val.	Coef.	Sig.	Bootstrap p-val.
Expected effective maize price (ZMK/kg)	5.10E-6		0.978	2.01E-5		0.932	-0.0150		0.295
Quantity of government-subsidized fertilizer acquired by the HH (kg)	-9.20E-6		0.937	3.30E-5		0.723	0.00762	**	0.025
Tobit residuals from government-subsidized fertilizer reduced form	*Not stat. sig. (p=0.186)*			2.54E-4	**	0.025	-0.0220	***	0.000
Groundnut price (ZMK/kg, t-1, provincial median)	-6.70E-5		0.181	-3.56E-5		0.507	6.25E-4		0.891
Sweet potato price (ZMK/kg, t-1, provincial median)	5.53E-4	***	0.000	4.77E-4	***	0.000	-0.00161		0.830
Farmgate market price of fertilizer (ZMK/kg)	9.91E-5	***	0.003	1.17E-4	***	0.004	8.16E-4		0.703
Wage to weed 0.25 ha field ('000 ZMK)	0.00190		0.104	0.00114		0.393	0.193	**	0.025
Growing season rainfall ('00 mm)							10.291	***	0.000
Growing season rainfall, squared							-0.380	***	0.000
Moisture stress							2.297	***	0.001
Expected growing season rainfall ('00 mm)	0.751	***	0.000	0.0916	***	0.001	51.246	***	0.000
Expected growing season rainfall, squared	-0.0334	***	0.000				-2.674	***	0.000
Expected moisture stress	0.198	***	0.000	0.151	***	0.000	-0.583		0.811
Adult equivalents	0.0226	***	0.008	0.0191	***	0.000	-0.342		0.619
Adult equivalents, squared	-5.97E-4		0.323				0.0611		0.241
Landholding size (ha, cultivated+fallow land)	0.289	***	0.000	0.226	***	0.000	-2.579	***	0.000
Landholding size, squared	-0.00336	***	0.000				0.0310		0.106
Age of household head	0.00137		0.332	0.00287	*	0.075	-0.124		0.192
Highest level of education completed by HH head (base is none):									
Lower primary (grades 1-4) (=1)	0.0331		0.160	0.0476	**	0.049	-0.657		0.710
Upper primary (grades 5-7) (=1)	0.0485	*	0.084	0.0739	**	0.012	-2.185		0.265
Secondary (grades 8-12) (=1)	0.0912	**	0.026	0.131	***	0.001	-2.317		0.336
Post-secondary education (=1)	0.238	**	0.012	0.256	***	0.010	0.372		0.933

Table B.3 (cont'd)

Dependent variable (estimator):	Hectares of other crops (FE)			Hectares of other crops (CRE-Tobit)			Yield of other crops in FIQI/ha (FE)		
Explanatory variables:	Coef.	Sig.	Bootstrap p-val.	APE	Sig.	Bootstrap p-val.	Coef.	Sig.	Bootstrap p-val.
Gender & residence status of HH head (non-resident if <6 months; base is resident male):									
Female-headed with non-resident husband (=1)	-0.0653		0.451	-0.0250		0.741	-0.653		0.894
Female-headed with no husband (=1)	-0.0103		0.738	-0.00637		0.835	1.110		0.610
Agricultural year (2006/2007 is base):									
Agricultural year 1999/2000 (=1)	0.305	***	0.008	0.226		0.140	7.945		0.350
Agricultural year 2002/2003 (=1)	0.304	***	0.000	0.303	***	0.000	-2.330		0.555
Constant	-4.746	***	0.000				-247.045	***	0.000
District dummies	N/A			Yes			N/A		
Time averages (CRE)	N/A			Yes			N/A		
Observations	14,999			14,999			11,984		
Within R-squared (Pseudo R-squared for Tobit)	0.318			0.2315			0.061		
Overall model F-stat.	41.06	***	0.000	38.12	***	0.000	12.14	***	0.000
Hansen J statistic (over-identification test of all instruments)	0.979		0.613				17.492	***	0.000

Notes: ***, **, * significant at the 1%, 5%, and 10% levels. See Tables A.1 and A.2 in Appendix A for more complete explanatory variable descriptions.

Table B.4. Reduced form CRE-Tobit regression results: factors affecting the kg of subsidized fertilizer acquired by the household

Reduced form CRE-Tobit with covariates from the:	Fertilizer app. rate & area planted equations			Yield equations		
Explanatory variables:	APE	Sig.	Bootstrap p-val.	APE	Sig.	Bootstrap p-val.
IV: MMD won the constituency in the last presidential election (=1)	21.452	***	0.000	22.842	***	0.000
IV: Percentage point spread between MMD & lead opposition (%)	-0.0890		0.238	-0.106		0.167
IV: Interaction effect: MMD won (=1) × percentage point spread	0.519	***	0.000	0.542	***	0.000
Expected effective maize price (ZMK/kg)	0.0889	**	0.014	0.0928	**	0.015
Groundnut price (ZMK/kg, t-1, provincial median)	-6.78E-4		0.931	-0.0113		0.234
Sweet potato price (ZMK/kg, t-1, provincial median)	-0.00310		0.848	-0.0397	**	0.028
Farmgate market price of fertilizer (ZMK/kg)	0.0165	***	0.005	0.0133	**	0.027
Wage to weed 0.25 ha field ('000 ZMK)	0.118		0.472	0.122		0.467
Growing season rainfall ('00 mm)				-3.238	***	0.001
Moisture stress				-1.607		0.382
Expected growing season rainfall ('00 mm)	-10.268	**	0.013	-13.856	***	0.002
Expected moisture stress	-10.340		0.144	-8.651		0.213
Adult equivalents	0.0702		0.920	0.145		0.833
Landholding size (ha, cultivated+fallow land)	2.501	***	0.000	2.6313	***	0.000
Age of household head	0.220		0.314	0.218		0.312
Highest level of education completed by HH head (base is none):						
Lower primary (grades 1-4) (=1)	-0.652		0.892	-0.9600		0.839
Upper primary (grades 5-7) (=1)	4.242		0.410	3.860		0.439
Secondary (grades 8-12) (=1)	12.169	*	0.078	12.064	*	0.084
Post-secondary education (=1)	-5.451		0.545	-4.931		0.577

Table B.4 (cont'd)

Reduced form CRE-Tobit with covariates from the:	Fertilizer app. rate & area planted equations			Yield equations		
Explanatory variables:	APE	Sig.	Bootstrap p-val.	APE	Sig.	Bootstrap p-val.
Gender & residence status of HH head (non-resident if <6 months; base is resident male):						
Female-headed with non-resident husband (=1)	15.057		0.418	14.960		0.423
Female-headed with no husband (=1)	-0.992		0.843	-1.074		0.830
Agricultural year (2006/2007 is base):						
Agricultural year 1999/2000 (=1)	28.361		0.173	-6.290		0.704
Agricultural year 2002/2003 (=1)	31.318	***	0.001	12.949		0.151
Provincial & agro-ecological region dummies	Yes			Yes		
Time averages (CRE)	Yes			Yes		
Observations	14,999			14,999		
Within R-squared (Pseudo R-squared for Tobit)	0.0472			0.0492		
Overall model F-stat.	8.98	***	0.000	8.62	***	0.000

Notes: ***, **, * significant at the 1%, 5%, and 10% levels. See Tables A.1 and A.2 in Appendix A for more complete explanatory variable descriptions.