Fertilizer Subsidies and Smallholder Commercial Fertilizer Purchases: Crowding Out, Leakage, and Policy Implications for Zambia

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Nicole M. Mason and T. S. Jayne

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EXECUTIVE SUMMARY

Targeted fertilizer subsidies are growing in popularity in Sub-Saharan Africa and are a pillar of the Government of the Republic of Zambia's (GRZ's) agricultural sector strategy. For example, over the 2004 to 2011 fiscal years, the budget allocation to the Fertilizer Support Programme (FSP) and its successor, the Farmer Input Support Programme (FISP), averaged 40% of the total allocation to the ministries responsible for agriculture, livestock, and fisheries, and 64% of the total budget for agricultural sector poverty reduction programs. However, if subsidized fertilizer is allocated to households that would have otherwise purchased it at commercial prices, then the increase in total fertilizer use as a result of the subsidy program will be negligible. In other words, the change in total fertilizer use depends in part on the extent to which subsidized fertilizer *crowds out* or *displaces* commercial fertilizer purchases.

In this study, we empirically estimate the rate of crowding out in Zambia. The analysis is based on nationally representative household-level panel survey data covering the 1999/2000, 2002/03, and 2006/07 agricultural years and collected by the government Central Statistical Office and Ministry of Agriculture and Cooperatives. Two previous studies have examined this issue: Xu et al. (2009) for Zambia and Ricker-Gilbert, Jayne, and Chirwa (2011) for Malawi. Our paper adds value to these previous studies in three important ways. First, the previous study for Zambia (Xu et al. 2009) is based on the 1999/2000 and 2002/03 waves of the panel survey. Since that study was completed, the 2006/07 wave of data has become available. FSP was significantly scaled up from 48,000 metric tonnes (MT) in 2002/03 to 84,000 MT in 2006/07. In this study, we use all three waves of the panel survey data and compare the rate of crowding out in 2002/03 to the rate in 2006/07, when the subsidy program was 75% larger.

Second, we adopt Ricker-Gilbert, Jayne, and Chirwa's methodology to control for the possibility that unobserved factors that affect how much commercial fertilizer a household purchases might also affect how much subsidized fertilizer the household receives. Failure to control for this correlation creates statistical problems (endogeneity) and can lead to biased estimates of crowding out.

Third and perhaps most importantly, we adjust our estimate of the change in total fertilizer use given an additional kg of subsidized fertilizer injected into the system by GRZ for the fact that some of the GRZ fertilizer leaks into private sector channels. In the years covered by the panel survey, only 67% of the fertilizer intended for distribution through the Fertilizer Credit Programme (in place in 1999/2000) and FSP (in place in 2002/03 and 2006/07) reached smallholders as government-subsidized fertilizer. The remaining 33% leaked out of the government channel and was likely resold through commercial channels. Previous studies have failed to account for such leakage, and their estimates of the change in total fertilizer use due to government subsidy programs may be biased upward as a result.

The current study highlights five key findings. First, we find that each additional kg of subsidized fertilizer received by a household decreases its fertilizer purchases from commercial retailers by an average of 0.13 kg. This is nearly double the rate of crowding out estimated for Zambia by Xu et al. (2009) but less than the 0.22 kg rate of crowding out estimated for Malawi by Ricker-Gilbert, Jayne, and Chirwa (2011). Crowding out may be higher in Malawi due to the broader coverage of the subsidy program there. For example, only 13% of Zambian smallholders received FSP fertilizer in 2006/07 but 57% of Malawian households received government-subsidized fertilizer that year. The broader coverage of the

Malawi program may make it more difficult to successfully target the subsidized fertilizer to households that would not otherwise buy fertilizer at commercial prices.

Second, based on the results of the current study, the displacement rate in Zambia was somewhat higher in 2006/07 (0.15 kg) than in 2002/03 (0.13 kg). This may be due to greater targeting challenges in 2006/07 compared to 2002/03 resulting from the 75% increase in the scale of FSP and a reduction in the share of government-subsidized fertilizer distributed through the typically better-targeted Food Security Pack Programme.

Third, the rate of crowding out in Zambia is higher in areas where the private sector was initially more active in fertilizer retailing compared to areas where it was less active. In high private sector activity areas, each additional kilogram (kg) of government-subsidized fertilizer reduces smallholders' commercial fertilizer purchases by 0.23 kg. In contrast, in low private sector activity areas, commercial fertilizer purchases only decline by 0.07 kg.

Fourth, displacement rates are higher among households that cultivate two or more hectares of land (0.21 kg) than among those that cultivate less than two hectares (0.11 kg). Landholding size and area planted are highly positively correlated with household income and assets, thus households planting larger areas are more likely to have the means to purchase fertilizer at commercial prices. The extent of crowding out is also higher among male-headed households (0.15 kg) than among female-headed households (0.09 kg).

Fifth, as mentioned above, in the years covered by the panel survey, 33% of the fertilizer intended for GRZ subsidy programs did not reach its intended beneficiaries as subsidized fertilizer and was likely resold as commercial fertilizer. This result coupled with the estimate that each kg of subsidized fertilizer acquired by a household reduces its commercial fertilizer purchases by 0.13 kg implies that each kg of subsidized fertilizer injected into the system by GRZ raises total fertilizer use by 0.53 kg. If the leakage of subsidized fertilizer into commercial channels had not been taken into account, we would have concluded that total fertilizer use increases by 0.87 kg, an over-estimate of 63%.

Based on these findings, the Zambian government may be able to add more to total fertilizer use through its fertilizer subsidy programs by reducing leakage and by targeting households in low private sector activity areas, those with relatively small landholdings or cultivated area, and female-headed households. Under FISP, GRZ has taken steps to improve targeting by involving traditional leaders in the selection of beneficiaries. The government could also consider channeling more subsidized fertilizer through the Food Security Pack Programme, which has a better targeting track record. The use of an electronic voucher (e-voucher) system for FISP, where the vouchers are redeemable at commercial retailers, may be a way of crowding in private investment in fertilizer marketing. An e-voucher system also has the potential to improve monitoring of subsidized fertilizer and to reduce leakage.

CONTENTS

ACKNOWLEDGMENTS iii

INDABA AGRICULTURAL POLICY RESEARCH INSTITUTE TEAM MEMBERS iv

EXECUTIVE SUMMARY v

LIST OF TABLES viii

LIST OF FIGURES viii

ACRONYMS ix

1. INTRODUCTION 1

2. DATA 5

3. FERTILIZER SUBSIDY PROGRAMS IN ZAMBIA 6
- 3.1. The Food Reserve Agency Fertilizer Credit Programme 6
- 3.2. The Fertilizer Support Programme 7
- 3.3. The Food Security Pack Programme 7
- 3.4. Household Socioeconomic Characteristics by Fertilizer Source 7

4. METHODOLOGY 10
- 4.1. Conceptual Framework: Fertilizer Subsidies, Leakage, and Effects on Fertilizer Demand 10
- 4.2. Conceptual Framework and Empirical Model: Factor Demand Equation 11
- 4.3. Estimation Strategy 12

5. RESULTS 15

6. CONCLUSIONS AND POLICY IMPLICATIONS 19

APPENDICES 21

REFERENCES 26

LIST OF TABLES

TABLE **PAGE**

1. Fertilizer Subsidy Program Beneficiaries and Quantities Distributed According to Official Ministry of Agriculture and Cooperatives' Records vs. Nationally-Representative Household Surveys, 1997/98-2010/11 3

2. Socioeconomic Characteristics of Households by Source of Fertilizer 8

3. Average Partial Effects (Apes) of A 1-Kg Increase in Government-Subsidized Fertilizer Received by the Household on Kg of Commercial Fertilizer Purchased 15

4. Estimated Kg Change in Total Smallholder Fertilizer Acquisition Given A 1-Kg Increase in Government-Subsidized Fertilizer Distributed 18

A1. Summary Statistics (Averages across All Three Survey Years).....................................22

A2. Reduced Form CRE Tobit Estimates of Factors Affecting the Kilograms of Government-Subsidized Fertilizer Acquired by the Household – High versus Low Private Sector Activity (PSA) Areas 23

A3. Factors Affecting the Quantity (kg) of Commercial Fertilizer Purchased by the Household – High PSA Areas 24

A4. Factors Affecting the Quantity (kg) of Commercial Fertilizer Purchased by the Household – Low Fertilizer PSA Areas 25

LIST OF FIGURES

FIGURE **PAGE**

1. Histograms of Kg of Fertilizer acquired by Participating Households through the Fertilizer Credit Programme, FISP, and the Food Security Pack Programme 6

ACRONYMS

CRE	correlated random effects
CSO	Central Statistical Office
CSPR	Civil Society for Poverty Reduction (Zambia)
ESA	The Agricultural Development Economics Division of FAO
e-voucher	electronic voucher
EA	East Africa
FAO	Food and Agriculture Organization of the United Nations
FE	fixed effects
FISP	Farmer Input Support Programme
FRA	Food Reserve Agency
FSP	Fertilizer Support Programme
FSRP	Food Security Research Project
GRZ	Government of the Republic of Zambia
ha	hectare
HH	household
IAPRI	Indaba Agricultural Policy Research Institute Lusaka, Zambia
kg	kilogram
MA	moving average
MACO	Ministry of Agriculture & Cooperatives
MMD	Movement for Multi-Party Democracy
MT	metric tonnes
NSSP	Nigeria Strategy Support Program
PHS	Post-Harvest Survey
PSA	private sector activity
SEA	standard enumeration area
SOAS	School of Oriental and African Studies
SS	Supplemental Survey
SSA	Sub-Saharan Africa
TNH	truncated normal hurdle model
ZMK	Zambian Kwacha

1. INTRODUCTION

Governments throughout Sub-Saharan Africa (SSA) use fertilizer subsidies to pursue a number of objectives, among them improving access to agricultural inputs, increasing agricultural productivity, raising farm incomes, improving household and national food security, and increasing private sector participation in agricultural input marketing. Many of these countries devote a large share of their public budgets to input subsidy programs. For example, Malawi allocated 5% to 15% of its national budget between 2005 and 2008 to fertilizer and seed subsidy programs (Ricker-Gilbert, Jayne, and Chirwa 2011). In Zambia over the 2004 to 2011 budget years, the government allocated an average of 40% of its agricultural sector budget to its fertilizer subsidy program, the Farmer Input Support Programme (FISP).[1] Government resources devoted to input subsidies cannot be used for other poverty reduction, food security, or agricultural development initiatives. The potentially high opportunity costs involved motivate for a more detailed and accurate understanding of the costs and benefits of input subsidy programs.

Unlike the universal fertilizer subsidies that were common prior to the agricultural market reforms of the 1980s and 1990s, today fertilizer subsidies are typically targeted at certain intended beneficiaries. Malawi's subsidy program is officially targeted at full time smallholder farmers who cannot afford to purchase one to two bags of fertilizer at commercial prices (SOAS et al. 2008). In Zambia, FISP officially targets smallholder farmers who are members of farm cooperatives, have the capacity to grow one to five hectares of maize, can pay the farmer share of the input costs (which has ranged from 25% to 50%), and are not beneficiaries of another government subsidy program (MACO various years); Tembo 2007).[2]

A key measure of the impact of a targeted fertilizer subsidy program is the extent to which it raises total fertilizer use. If subsidized fertilizer is allocated to households that would have otherwise purchased fertilizer at commercial prices, then the program's impact on total fertilizer use will be minimal. On the other hand, if subsidy beneficiaries would not have purchased commercial fertilizer, then each ton of government-subsidized fertilizer injected into the system would, in theory, increase total fertilizer use by one ton. Measuring the extent to which a fertilizer subsidy program *displaces* or *crowds out* commercial fertilizer purchases is therefore necessary to determine the impact of the program on total fertilizer use (Ricker-Gilbert, Jayne, and Chirwa 2011).

Two previous studies have empirically estimated the degree to which fertilizer subsidy programs displace commercial fertilizer purchases. Xu et al. (2009) examine crowding out in Zambia using data from 1999/2000 and 2002/2003. Ricker-Gilbert, Jayne, and Chirwa (2011) estimate the rate of crowding out in Malawi and improve upon the Xu et al. (2009) methodology by explicitly taking into account the potential endogeneity of subsidized fertilizer in a commercial fertilizer demand equation.

Both Xu et al. (2009) and Ricker-Gilbert, Jayne, and Chirwa (2011) estimate displacement as the change in the quantity of commercial fertilizer purchased (*comm*) given a one-unit increase in the quantity of government-subsidized fertilizer acquired by the household (*govt*).

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[1] The program was called the Fertilizer Support Programme from 2002 until 2009, when it was renamed the Farmer Input Support Programme. For simplicity, we hereafter refer to the program as FISP.
[2] Smallholder households are defined by the Government of Zambia as those cultivating less than 20 ha. The other government subsidy program is the Food Security Pack Programme, which is discussed in Section 3.3.

The change in total fertilizer use (*total*) can therefore be calculated as one plus the displacement estimate. This is based on the following identity and associated derivative:

$$total = govt + comm \tag{1}$$

$$\frac{\partial total}{\partial govt} = \frac{\partial govt}{\partial govt} + \frac{\partial comm}{\partial govt} = 1 + \frac{\partial comm}{\partial govt} \tag{2}$$

However, if there is leakage of government-subsidized fertilizer and it is being resold through private retailers at market or near-market prices, making it indistinguishable from commercial fertilizer for the researcher, then estimates of $\frac{\partial comm}{\partial govt}$ and hence $\frac{\partial total}{\partial govt}$ may be biased upward. Neither of the aforementioned studies addresses the leakage issue.[3]

Unfortunately, allegations of government fertilizer having been diverted and resold through commercial channels are a common feature of input subsidy programs in Africa.[4] In Zambia, initial evidence suggests that a fairly large proportion of government-subsidized fertilizer cannot easily be accounted for. The estimated quantity of FISP fertilizer received by smallholder farmers based on nationally-representative survey data collected by the Zambia Central Statistical Office (CSO) and Ministry of Agriculture and Cooperatives (MACO) is only 34% to 87% of the quantity of fertilizer distributed under FISP according to MACO records (Table 1, column D).

The purpose of this study is to develop improved estimates of the extent to which fertilizer subsidy programs contribute to total fertilizer use, using nationally-representative survey data from Zambia as a case study. The study builds on the work of Xu et al. (2009) and Ricker-Gilbert, Jayne, and Chirwa (2011) in several ways. First, it explicitly takes into account the leakage issue described above, which may in some contexts be quite substantial. Second, since the publication of Xu et al. (2009), which uses panel data covering the 1999/2000 and 2002/03 agricultural years, a third wave of panel data covering 2006/07 has become available. FISP began in 2002/03 and 48,000 MT of fertilizer were distributed through the program that year. During the next three years, the program operated at approximately the same scale (Table 1). Then in 2006/07, FISP was expanded to 84,000 MT and the subsidy level was raised from 50% to 60%. Officials responsible for implementing FISP at the Ministry of Agriculture and Cooperatives stated that the efficiency of the program improved over time as they were able to identify problems and address them. Thus FISP has changed significantly since the Xu et al. (2009) study, and the newly available data provide the means to compare the rate of crowding out in 2002/03 to the rate in 2006/07 when the program was 75% larger.

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[3] Other recent studies on the crowding in/out effects of input subsidies include Mason and Ricker-Gilbert (2012), who examine the extent to which subsidized maize seed crowds out commercial purchases of maize seed in Malawi and Zambia, and Holden and Lunduka (2012), who study the effects of Malawi's fertilizer subsidy program on the use of organic manures. These studies also fail to account for the leakage issue.

[4] See, for example, Mulenga (2009), Nkanga and Sinyangwe (2009), Chulu (2010), and http://www.aec.msu.edu/fs2/zambia/tour/FSP_Difficulties_Press_Clipping_Nov_Dec_2008.pdf for Zambia; Banful and Olayide (2010) and Banful, Nkonya, and Oboh (2010) for Nigeria; Druilhe and Barreiro-Hurlé (2012) for Mali; Dorward and Chirwa (2011) for Malawi; and Kapchanga (2008) for Kenya.

Table 1. Fertilizer Subsidy Program Beneficiaries and Quantities Distributed According to Official Ministry of Agriculture and Cooperatives' Records vs. Nationally-
Representative Household Surveys, 1997/98-2010/11

		From Ministry of Agriculture and Cooperatives' records		Estimated from household survey data	
Agricultural year	% of the total fertilizer cost to be paid by the government	MT of Fertilizer Credit Programme/ FISP fertilizer delivered to districts	Intended number of beneficiary households	MT of Fertilizer Credit Programme/ FISP fertilizer received by smallholder households (as % of col. B in paren.)	Number of beneficiary smallholder households (as % of col. C in paren.)
	(A)	(B)	(C)	(D)	(E)
1997/1998	0 (loan)	15,495	--	--	--
1998/1999	0 (loan)	50,001	--	--	--
1999/2000	0 (loan)	34,999	--	21,038 (60%)	64,493 (--)
2000/2001	0 (loan)	23,227	--	11,266 (49%)	30,103 (--)
2001/2002	0 (loan)	28,985	--	8,365 (29%)	26,763 (--)
2002/2003	50	48,000	120,000	31,722 (66%)	102,113 (85%)
2003/2004	50	60,000	150,000	33,372 (56%)	101,139 (67%)
2004/2005	50	50,000	125,000	16,792 (34%)	64,854 (52%)
2005/2006	50	50,000	125,000	23,595 (47%)	74,040 (59%)
2006/2007	60	84,000	210,000	58,404 (70%)	164,229 (78%)
2007/2008	60	50,000	125,000	43,596 (87%)	140,612 (112%)
2008/2009	75	80,000	200,000	55,114 (69%)	192,860 (96%)
2009/2010	75	106,000	534,000[a]	69,103 (65%)	292,685 (55%)
2010/2011	75	178,000	890,000[a]	116,116 (65%)	430,141 (48%)

Sources: FRA Agro Support Department 1999; MACO (various years), MACO (2008); CSO/MACO Post-Harvest Surveys; CSO/MACO/FSRP Supplemental Surveys; and CSO/MACO Crop Forecast Surveys.
Notes: GRZ = Government of the Republic of Zambia. -- Information not available. [a]Pack size reduced from eight 50 kg bags to four 50 kg bags. Values in the table are for the Fertilizer Credit Programme for 1997/1998-2001/2002, and for FISP for 2002/2003-2010/2011.

Third, we follow Ricker-Gilbert, Jayne, and Chirwa (2011) and use the control function/ instrumental variables approach to test and control for the potential endogeneity of subsidized fertilizer when estimating the effect of subsidized fertilizer on a household's demand for commercial fertilizer. This issue is not addressed in Xu et al. (2009), which may lead to biased and inconsistent estimates of crowding out. Finally, our study goes beyond the other two studies by controlling for the potentially confounding effects of other major government programs affecting commercial fertilizer demand. In the particular case of Zambia, the Food Reserve Agency (FRA), the government parastatal strategic food reserve/maize marketing board, greatly expanded its network of rural depots and increased its maize purchases 16-fold between 2002/03 and 2006/07.[5] These developments are likely to have greatly altered

[5] The FRA bought a total of 23,535 MT of maize from 10 districts in 2002/03. By 2006/07, it had established buying depots in 53 of Zambia's 72 districts and purchased 389,510 MT of maize that year.

farmers' perceptions of a guaranteed maize market for their produce and thereby affected farmer input demand. Failure to control for the effects of other government operations could result in biased and inconsistent estimates of input demand parameters, including those involved in the calculation of crowding out.

The remainder of this paper is organized as follows. Section 2 describes the data used in the study. Section 3 provides an overview of fertilizer subsidy programs in Zambia and examines the socioeconomic characteristics of farmers according to whether they received fertilizer from government programs, purchased fertilizer from the market, did both or neither. Section 4 describes the methodology. The main findings of the study are presented in Section 5. Conclusions and policy implications are discussed in Section 6.

2. DATA

The analysis draws upon a three-wave, nationally representative panel survey of smallholder households in Zambia. The first wave of the survey covers the 1999/2000 agricultural season and involves two linked surveys: the 1999/2000 Post-Harvest Survey (PHS 9900), conducted by the Central Statistical Office (CSO) and the Ministry of Agriculture and Cooperatives (MACO) in August/September 2000, and the 2001 Supplemental Survey (SS01) conducted by CSO, MACO, and the Food Security Research Project (FSRP) in May 2001. The second and third waves of the CSO/MACO/FSRP Supplemental Survey (SS) were conducted in May 2004 to cover the 2002/03 agricultural season (SS04) and in June/July 2008 to cover the 2006/07 agricultural season (SS08).

The PHS9900 sample of 7,699 households from 70 districts was selected using a stratified three-stage sample design as described in Megill (2005). Of the 7,699 PHS9900 households, 6,922 were interviewed in SS01. A total of 5,358 (77.4%) of the SS01 households were successfully re-interviewed in SS04, and of these, 4,286 (80.0%) were re-interviewed in SS08. In the analysis, we use the unbalanced panel of households that were interviewed in at least SS01 and SS04. Given attrition between survey waves, attrition bias is a potential concern. We therefore follow the approach recommended in Wooldridge (2010, p. 837) to test for attrition bias but fail to reject the null of no attrition bias in all models ($p>0.10$).

Other data used in the analysis are: (i) MACO administrative records on the district-level volumes of fertilizer distributed through its subsidy programs; (ii) household-level fertilizer purchases from private retailers in 1997/98 from the MACO/CSO 1997/98 PHS; (iii) 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; (iv) maize, groundnut, and sweet potato prices from the MACO/CSO PHSs for 1998/99, 2001/02, and 2005/06; and (v) constituency-level data on the percentage of votes won by the Movement for Multiparty Democracy (MMD) and opposition parties during the 1996, 2001, and 2006 presidential elections from the Electoral Commission of Zambia.

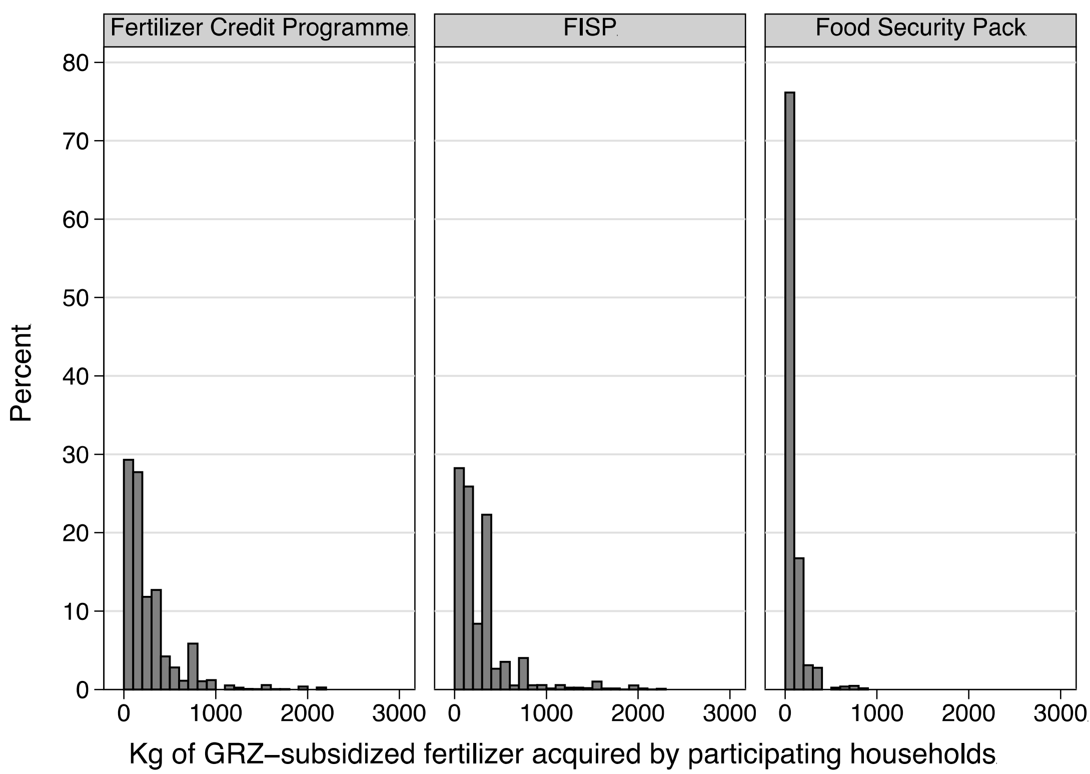
3. FERTILIZER SUBSIDY PROGRAMS IN ZAMBIA

Fertilizer subsidy programs have been implemented almost every year in Zambia since independence. The Government of the Republic of Zambia (GRZ) implemented three main fertilizer programs during the period of analysis (1999/2000 to 2006/2007): (i) the Food Reserve Agency Fertilizer Credit Programme; (ii) the Fertilizer Support Programme; and (iii) the Food Security Pack Programme. We discuss each of these in turn.

3.1. The Food Reserve Agency Fertilizer Credit Programme

The Fertilizer Credit Programme replaced earlier fertilizer subsidy programs starting in 1997/98. Under the program, fertilizer was distributed to small-scale farmers on credit at a pan-territorial price (MACO 2002). In 1999/2000 (the first wave of the panel survey), approximately 35,000 MT of fertilizer were distributed through the Fertilizer Credit Programme. Farmers applied to participate in November 1999 and made an 11% down payment on the full cost of the fertilizer package. They were to pay the remaining 89% in cash or in maize at harvest (MACO 2002). Therefore, Fertilizer Credit Programme fertilizer was not subsidized *per se*. However, the loan recovery rate was only 34.5% in 1999/2000 (MACO 2002). Thus farmers that defaulted on the loan that year received the fertilizer at an 89% effective subsidy, having paid only the 11% down payment.

Figure 1. Histograms of Kg of Fertilizer acquired by Participating Households through the Fertilizer Credit Programme, FISP, and the Food Security Pack Programme



Sources: CSO/MACO/FSRP 2001, 2004, and 2008 Supplemental Surveys. Notes: Quantities are for 1999/2000 for the Fertilizer Credit Programme (N=480) and for 2002/03 and 2006/07 for FISP (N=1,032) and the Food Security Pack Programme (N=309).

The Fertilizer Credit Programme was discontinued after 2001/02, when recognition of low recovery rates and associated high financial costs led to efforts to reform the system. See Figure 1 for a histogram of the quantities of Fertilizer Credit Programme fertilizer acquired by participating households in 1999/2000 based on the panel survey data.

3.2. The Fertilizer Support Programme

GRZ moved to an up-front 50% cash payment (no credit) system when it replaced the Fertilizer Credit Programme with the Fertilizer Support Programme (FISP) in 2002/03 (the second wave of panel survey). Two main goals of FISP were "improving household and national food security, incomes, [and] accessibility to agricultural inputs by small-scale farmers through a subsidy" and "building the capacity of the private sector to participate in the supply of agricultural inputs" (MACO 2008, p. 3).

From 2002/03 through 2008/09, the official FISP pack consisted of four 50-kg bags of basal fertilizer, four 50-kg bags of top dressing fertilizer, and 20 kg of hybrid maize seed. Each participating farmer was to receive only one pack. However, as shown in Figure 1, the quantity of FISP fertilizer received varied widely across participants.

Fertilizer for FISP was supplied and delivered to the district level by traders that were selected through a national tender process. Local distributors in the districts then transported the fertilizer to satellite depots where it was distributed to selected farmers through cooperatives and other farmer groups (MACO various years).

3.3. The Food Security Pack Programme

Unlike the Fertilizer Credit Programme and FISP, the Food Security Pack Programme is a 100% grant-based program. Started in 2001, the Food Security Pack Programme targets farming households that cultivate less than one hectare of land and are 'vulnerable but viable', e.g., households headed by women or children, households with disabled members or that are supporting orphans, and unemployed youth (Tembo 2007). The contents of a Food Security Pack vary based on agro-ecological conditions. In areas suitable for maize, a pack included 5 kg of improved maize seed and one 50-kg bag each of basal and top dressing fertilizer (ibid). According to program records, 140,399 and 21,700 households participated in the program in the 2002/03 and 2006/07 agricultural years, respectively (ibid). Figure 1 shows the quantities of Food Security Pack fertilizer acquired by participating households in 2002/03 and 2006/07 based on the panel survey data.

3.4. Household Socioeconomic Characteristics by Fertilizer Source

Table 2 summarizes fertilizer acquisition patterns and socioeconomic characteristics of smallholder households by source of fertilizer for each year of the panel survey. More than 70% of smallholder households in Zambia do not acquire fertilizer from any channel, although this percentage declined from 79% in 1999/2000 to 71% in 2002/03 and 2006/07. Approximately 15-18% of smallholders purchased fertilizer from commercial retailers while 7-13% acquired it through government programs. Fewer than 2% of households obtain fertilizer from both government and commercial channels. There was a larger increase between 1999/2000 and 2006/07 in the share of households acquiring fertilizer from

Table 2. Socioeconomic Characteristics of Households by Source of Fertilizer

Descriptive result	Agricul-tural year	Source of fertilizer: Fertilizer Credit Programme (A)	FISP (B)	Food Security Pack Programme (C)	Government programs (A, B or C)	Commercial retailers	Both government and commercial sources		Did not acquire fertilizer
Share of households	1999/2000	6.5%	--	--	6.5%	15.4%	0.7%		78.8%
	2002/2003	--	8.8%	4.5%	13.2%	16.4%	0.7%		71.1%
	2006/2007	--	11.2%	1.1%	12.4%	18.2%	1.6%		71.1%
							Gov't	Comm.	
Mean kg fertilizer from source	1999/2000	338	--	--	338	243	144	139	0
	2002/2003	--	300	131	244	245	325	229	0
	2006/2007	--	356	131	336	336	471	645	0
Median kg fertilizer from source	1999/2000	200	--	--	200	150	100	100	0
	2002/2003	--	200	100	100	150	180	200	0
	2006/2007	--	300	100	200	200	400	300	0
Mean landholding size (ha*)	1999/2000	3.12	--	--	3.12	2.84	2.76		2.02
	2002/2003	--	3.13	2.14	2.79	2.84	4.21		1.86
	2006/2007	--	3.13	1.80	3.01	2.84	5.39		1.71
Mean value of farm assets	1999/2000	6.32	--	--	6.32	4.06	2.69		1.12
(Real 100,000 ZMK**,	2002/2003	--	5.63	2.52	4.54	4.74	9.54		1.53
2007/08=100)	2006/2007	--	4.85	0.74	4.48	4.56	10.81		1.22
% female-headed	1999/2000	8.7%	--	--	8.7%	14.2%	4.8%		21.8%
	2002/2003	--	15.7%	24.6%	18.9%	14.3%	9.4%		23.9%
	2006/2007	--	14.3%	28.9%	15.6%	17.9%	11.1%		26.7%
Median education of HH head	1999/2000	7	--	--	7	7	7		5
(highest grade completed)	2002/2003	--	7	6	7	7	6		4
	2006/2007	--	7	5	7	7	7		5
Km to nearest district town	As of 2000	27.8	29.5	31.3	29.5	27.1	24.6		36.4
Km to nearest tarred/main road	As of 2000	21.2	20.9	20.9	21.0	22.8	16.3		27.6
Km to nearest feeder road	As of 2000	2.3	2.6	2.8	2.6	2.6	2.2		3.5

Sources: CSO/MACO/FSRP 2001, 2004, and 2008 Supplemental Surveys. Notes: Weighted results based on the balanced panel of 4,286 households. Among households acquiring fertilizer from both government and commercial sources, 77% and 96% of these households obtained the government fertilizer through FISP in 2002/03 and 2006/07. The other households obtained it through the Food Security Pack Programme. * ha – hectare; ** ZMK–Zambian Kwacha.

government programs than in the share acquiring it from commercial sources. The mean and median quantities of fertilizer acquired among households sourcing it through FISP and commercial channels increased between 2002/03 and 2006/07.

In terms of socioeconomic characteristics, Fertilizer Credit Programme and FISP beneficiary households have larger average land and farm asset holdings than households that source fertilizer from commercial retailers (Table 2). Assuming that landholding size and value of farm assets are positively correlated with a household's ability to afford fertilizer at commercial prices, these results are indicative of potential targeting problems and crowding out. In the later years of FISP implementation, Ministry of Agriculture officials responded that targeting subsidized FISP fertilizer to relatively better off farmers was a deliberate plan, even though the impact of this *de facto* targeting strategy on the achievement of the program's goals was unclear. Participants in the Food Security Pack Programme, by contrast, had smaller average land and asset holdings, lower median educational attainment, and a higher percentage of female-headed households than households that acquired fertilizer from the Fertilizer Credit Programme, FISP, or commercial retailers. Households that did not acquire fertilizer from any source lived farther away, on average, from the nearest district town, tarred/main road, and feeder road than did households acquiring fertilizer from government programs or commercial retailers.

4. METHODOLOGY

4.1. Conceptual Framework: Fertilizer Subsidies, Leakage, and Effects on Fertilizer Demand

The study's primary objective is to measure the extent to which an increase in the quantity of government-subsidized fertilizer distributed affects smallholders' commercial fertilizer purchases and, ultimately, total fertilizer use. As noted in the introduction, subsidized fertilizer may leak from the government channel and be resold through private retailers. Equations (1) and (2) still hold but it is helpful to decompose total government fertilizer distributed (*govt*) into that which is acquired by end users through the government channel (*nonleaked*) and that which leaks out of the government channel and is acquired by end users from commercial retailers (*leaked*):

$$govt = nonleaked + leaked \tag{3}$$

Similarly, we can separate all fertilizer acquired by end users through commercial channels (*allcomm*) into the portion that is imported and distributed by private companies under commercial terms (*comm*) and that which is fertilizer imported under a government subsidy program and subsequently diverted for sale by local traders to farmers (*leaked*):

$$comm = allcomm - leaked \tag{4}$$

We note that farmers may not distinguish between strictly commercially imported and leaked fertilizer because they acquire both from private entrepreneurs at prices approximating market prices. Hence *comm* and *leaked* are unobserved in survey data; only *allcomm* is observed. Plugging (4) into (1) and taking the derivative with respect to *govt* gives:

$$\frac{\partial total}{\partial govt} = \frac{\partial (govt + allcomm - leaked)}{\partial govt} = 1 + \frac{\partial allcomm}{\partial govt} - \frac{\partial leaked}{\partial govt} \tag{5}$$

Equation (5) shows that if $\frac{\partial leaked}{\partial govt}$ is positive, then estimates of $\frac{\partial total}{\partial govt}$ will be biased upward if leakage is ignored.

In the empirical work, the challenge is to estimate $\frac{\partial allcomm}{\partial govt}$ and $\frac{\partial leaked}{\partial govt}$ in order to obtain an unbiased estimate of the contribution of a fertilizer subsidy program to total fertilizer use. For the former, a household-level factor demand equation is estimated for *allcomm* with *govt* as an explanatory variable. The coefficient on *govt* is then the estimate of $\frac{\partial allcomm}{\partial govt}$. The conceptual framework motivating the factor demand model specification is outlined in the next section. For the latter, $\frac{\partial leaked}{\partial govt}$ is assumed not to vary with the size of the program (i.e., $\frac{\partial leaked}{\partial govt} = \frac{leaked}{govt}$) and it is estimated as the share of Fertilizer Credit Programme/FISP fertilizer delivered to the district level (based on FRA and MACO records) that did not reach farmers through the government channel (e.g., 40% in 1999/2000 per Table 1, column D).

The quantity of government program fertilizer received by farmers through the government channel is estimated from the household panel survey data described in Section 2.

4.2. Conceptual Framework and Empirical Model: Factor Demand Equation

Our starting point is a factor demand function for commercial fertilizer for a risk-neutral, expected profit-maximizing agricultural producer:

$$allcomm = allcomm\left(E(\boldsymbol{p}), \boldsymbol{w}; govt, \boldsymbol{z}\right) \quad (6)$$

where *allcomm* is the quantity of fertilizer purchased from commercial retailers. $\boldsymbol{p}$ is a vector of crop prices at the next harvest; these prices are random variables and unobserved by the household at the time that commercial fertilizer purchases and other crop production decisions are made. Variable input prices ($\boldsymbol{w}$) are assumed known at this time. *govt* is the quantity of government-subsidized fertilizer acquired by the household. Following Ricker-Gilbert, Jayne, and Chirwa (2011), it is treated as a quasi-fixed factor because households cannot freely choose how much subsidized fertilizer they acquire. $\boldsymbol{z}$ is a vector of other production shifters including quasi-fixed factors of production, agro-ecological conditions, and household characteristics affecting production.

In the empirical application, equation (6) is specified as:

$$allcomm_{i,t} = \alpha_0 + \alpha_1 \hat{p}^*_{i,t} + \boldsymbol{p}_{\boldsymbol{o},k,t-1}\boldsymbol{\alpha_2} + \boldsymbol{w}_{i,t}\boldsymbol{\alpha_3} + \alpha_4 govt_{i,t} + \boldsymbol{z}_{i,t}\boldsymbol{\alpha_5} + c_i + u_{i,t} \quad (7)$$

where i indexes the household, t indexes the harvest year (t=2000, 2003, and 2007), and k indexes the province; *allcomm* is the kilograms of commercial fertilizer purchased; $\hat{p}^*_{i,t}$ is the household-level expected farmgate maize price in ZMK/kg (discussed further below); $\boldsymbol{p}_{\boldsymbol{o},k,t-1}$ is a vector of provincial median groundnut and sweet potato prices at the previous harvest in ZMK/kg;[6] $\boldsymbol{w}$ includes the farmgate fertilizer market price in ZMK/kg paid by households that purchased commercial fertilizer and the district median farmgate fertilizer market price otherwise, as well as the agricultural wage rate (wage to weed a 0.25 ha field); *govt* is the kilograms of government-subsidized fertilizer acquired by the household (through the Fertilizer Credit Programme, FISP, or the Food Security Pack Programme); $\boldsymbol{z}$ is a vector of other shifters; c_i is time-invariant household-level unobserved heterogeneity; $u_{i,t}$ is the time-varying error term; and the $\boldsymbol{\alpha}$'s are parameters to be estimated.

$\boldsymbol{z}$ includes the household's landholding size (measured as hectares of cultivated plus fallow land); the value of plows, harrows, and oxcarts owned by the household (henceforth, "farm assets"); the number of adult equivalents in the household; the age and highest level of education completed by the household head; the gender and residence status of the household

[6] We include the prices of maize, sweet potato, and groundnut in the model because theory suggests that input demand is affected by the prices of various crops. While most fertilizer used in Zambia is applied to maize, the prices of other crops may affect how much maize a household decides to plant, which, in turn, may affect their fertilizer demand. We include sweet potato and groundnut prices in particular because after maize, these are two of the most commonly grown and marketed crops in Zambia.

head; the kilometers from the center of the household's standard enumeration area (SEA)[7] to the nearest district town, tarred/main road, and feeder road as of the first panel survey year; expected growing season rainfall (a moving average of November-March rainfall over the past nine years); expected moisture stress (a nine-year moving average of the number of 20-day periods, November-March, with less than 40 mm of rainfall); and provincial, agro-ecological zone, and year dummies. See Table A1 in the Appendix for summary statistics for the variables in equation (7).

The expected farmgate maize price in equation (7), $\hat{p}^*_{i,t}$, is estimated as in Mason, Jayne, and Myers (2012). There are two main maize marketing channels in Zambia: the FRA channel and the private sector channel. Although the FRA buys maize at the same price at all of its depots, the *farmgate* FRA price varies across households based on their proximity to an FRA depot and the cost of transporting maize to the depot. In the Mason, Jayne, and Myers (2012) approach, a farmer's expected maize price is estimated as a function of past FRA maize purchases in the household's district, the farmgate FRA maize price in the previous year, the maize price offered by private traders in the previous year, and other factors that might affect a household's expected maize price. Because past FRA behavior can affect $\hat{p}^*_{i,t}$, which can in turn affect demand for commercial fertilizer ($allcomm_{i,t}$), the resultant estimates of crowding out/displacement in the current study have a "holding FRA behavior fixed" interpretation.[8]

The key parameter of interest in equation (7) is $\hat{\alpha}_4$, which is the empirical estimate of $\frac{\partial allcomm}{\partial govt}$. If $\hat{\alpha}_4$ is statistically significant at the 10% level or lower and negative (positive), then we conclude that government subsidized fertilizer crowds out (crowds in) commercial fertilizer purchases by the households.

4.3. Estimation Strategy

Equation (7) is estimated using fixed effects (FE), correlated random effects (CRE) Tobit, and a CRE truncated normal hurdle model (CRE TNH), also known as a double-hurdle model. Each of these estimators controls for time invariant household-level unobserved heterogeneity (c_i), which may be correlated with the observed covariates in equation (7) (call them $\boldsymbol{X}_{i,t}$). To produce consistent estimates, all three estimators require, *inter alia*, strict exogeneity of $\boldsymbol{X}_{i,t}$ conditional on c_i (i.e., $E(u_{i,t} \mid \boldsymbol{X}_i, c_i) = 0,\ t = 1,2,...,T$). FE is consistent under the assumptions of strict exogeneity and a rank condition (Wooldridge 2010).

CRE Tobit and CRE TNH are used in addition to FE because of the corner solution nature of the dependent variable. *allcomm* is greater than zero for only 16% of the observations hence the partial effect of *govt* on *allcomm* may not be constant over the range of $\boldsymbol{X}_{i,t}$. A Tobit or TNH model may therefore better characterize the full distribution of *allcomm*,

[7] SEAs are the most disaggregated geographic units in the dataset. An SEA contains approximately 150-200 households (two to four villages).
[8] Expected maize price estimation results available from the authors upon request.

$D(allcomm_{i,t} \mid \boldsymbol{X}_{i,t}, c_i)$, than a linear model estimated via FE.

For the CRE approach, if in addition to strict exogeneity we assume that $c_i = \psi + \bar{\boldsymbol{X}}_i \xi + a_i$ and $c_i \mid \boldsymbol{X}_i \sim Normal(\psi + \bar{\boldsymbol{X}}_i \xi,\ \sigma_a^2)$, where $\bar{\boldsymbol{X}}_i$ 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 in a Tobit or TNH model by including $\bar{\boldsymbol{X}}_i$ as additional explanatory variables (Wooldridge 2010). See Wooldridge (2010) for the likelihood functions for and additional details on the Tobit and TNH models.

Equation (7) is estimated separately for districts with high versus low initial levels of fertilizer private sector activity (PSA). *A priori*, one would expect the degree of crowding out to be greater in initially high PSA areas than in initially low ones. Chow test results suggest that the two areas should not be pooled (p<0.001). High PSA districts are defined as those in the top tercile when ranked by mean kilograms of commercial fertilizer purchased per household in 1997/98. The cutoff between the top and bottom terciles is 20 kg per household on average. Across the three years of the panel, 1999/2000, 2002/03, and 2006/07, 39%, 40%, and 42% of smallholder households, respectively, are located in initially high PSA districts. The 1997/98 pattern of PSA is used because this precedes the scaling-up of fertilizer subsidies in Zambia (see Table 1) and therefore represents commercial fertilizer demand in a baseline period that was affected only in a minor way by fertilizer subsidy programs.

All explanatory variables in equation (7) are assumed to be strictly exogenous except for $govt_{i,t}$. GRZ fertilizer program participants are not randomly selected, so $govt_{i,t}$ may be correlated with $u_{i,t}$. $govt_{i,t}$ is also a corner solution variable: most households acquire zero government-subsidized fertilizer in a given year, and the quantity acquired by recipients is an approximately continuous variable (see Figure 1 and Table 2). We therefore use the control function approach to test and control for the potential endogeneity of $govt_{i,t}$ (Rivers and Vuong 1988; Vella 1993; Ricker-Gilbert, Jayne, and Chirwa 2011).

The control function approach entails first estimating via CRE Tobit a reduced form model in which $govt_{i,t}$ is the dependent variable and the explanatory variables are all of the right-hand side variables in equation (7), the structural equation, and at least one instrumental variable (IV). The Tobit residuals from the reduced form are then included as an additional regressor in equation (7). A simple test of endogeneity is a t-test of the coefficient on the Tobit residuals. If this coefficient is statistically significant (p<0.10), then we reject the null hypothesis that $govt_{i,t}$ is exogenous. Including the Tobit residuals in the structural equation also solves the endogeneity problem (Rivers and Vuong 1988; Vella 1993). Both the Tobit residuals and expected maize price are generated regressors so bootstrapping is used to obtain standard errors for equation (7) parameter estimates that account for the first-stage estimation (Wooldridge 2010).

We use the three candidate IVs for $govt_{i,t}$ employed by Mason and Ricker-Gilbert (2012). The first is a binary variable equal to one if the household's constituency was won by the ruling party (the MMD) during the last presidential election, and zero otherwise. Call this variable $MMD_{c,t}$, where *c* indexes the constituency.[9] In Zambia, presidential elections take place every five years and the MMD candidate won all presidential elections from 1991 to 2008 (i.e., 1991, 1996, 2001, 2006, and the 2008 emergency election following the death of President Levy Mwanawasa). The second IV is the percentage point spread between the MMD and the lead opposition party in the constituency in the last presidential election ($spread_{c,t}$). The third IV is the interaction, $MMD_{c,t} \times spread_{c,t}$. Banful (2011) uses similar variables to explain subsidized fertilizer allocation at the district level in Ghana in 2008.

To be valid, these IVs should be (i) partially correlated with $govt_{i,t}$, and (ii) partially uncorrelated with $u_{i,t}$. Reduced form CRE Tobit results for $govt_{i,t}$ (reported in Table A2 in the Appendix) support condition (i). For high PSA areas, $MMD_{c,t}$ is statistically significant at the 1% level in the reduced form Tobit model. The other two candidate IVs are not statistically significant and so are excluded from the high PSA reduced form. For low PSA areas, $MMD_{c,t}$ and the interaction effect are highly statistically significant (p≤0.002), while $spread_{c,t}$ is weakly significant (p=0.079).[10] Condition (ii) is a maintained hypothesis. However, in the low PSA models, we have only one suspected endogenous variable (*govt*) but three IVs, so it is possible to test the null hypothesis that the two 'extra' IVs are uncorrelated with $u_{i,t}$. A Hansen J test fails to reject this null hypothesis in low PSA (p=0.834) model, supporting the validity of the IVs.

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[9] During the study period, there were 150 total constituencies and 72 districts in Zambia. The numbers of constituencies per district were: 1 (26 districts), 2 (22 districts), 3 (20 districts), 4 (2 districts), 5 (1 district), and 7 (1 district). A constituency contains multiple villages.

[10] See Mason and Ricker-Gilbert (2012) for a discussion of the political economy implications of these results.

5. RESULTS

What do the econometric results suggest about the degree to which government-subsidized fertilizer crowds out commercial fertilizer purchases by Zambian smallholders? Displacement estimates for high versus low PSA areas based on the three different estimators (FE, CRE Tobit, and CRE TNH) are summarized in Table 3. Tables A3 and A4 in the Appendix contain the full regression results. The CRE TNH estimates are the most conservative and the CRE Tobit model is rejected in favor of the CRE TNH model in both high and low PSA areas based on likelihood ratio tests ($p<0.001$).

Table 3. Average Partial Effects (Apes) of A 1-Kg Increase in Government-Subsidized Fertilizer Received by the Household on Kg of Commercial Fertilizer Purchased

Population	Fixed effects	CRE Tobit	CRE TNH
PANEL A. High PSA areas	***-0.356***	***-0.319***	***-0.228***
Farm size			
< 2 ha cultivated		-0.284	-0.207
≥ 2 ha cultivated		-0.396	-0.274
Gender of HH head			
Female		-0.231	-0.168
Male		-0.341	-0.243
Agricultural year			
1999/2000		-0.305	-0.229
2002/2003		-0.307	-0.219
2006/2007		-0.349	-0.237
PANEL B. Low PSA areas	***-0.199***	***-0.075***	***-0.070***
Farm size			
< 2 ha cultivated		-0.059	-0.052
≥ 2 ha cultivated		-0.133	-0.138
Gender of HH head			
Female		-0.050	-0.043
Male		-0.083	-0.079
Agricultural year			
1999/2000		-0.065	-0.056
2002/2003		-0.077	-0.068
2006/2007		-0.087	-0.093
PANEL C. National estimate	***-0.263***	***-0.174***	***-0.134***
Farm size			
< 2 ha cultivated		-0.144	-0.110
≥ 2 ha cultivated		-0.263	-0.206
Gender of HH head			
Female		-0.117	-0.089
Male		-0.190	-0.147
Agricultural year			
1999/2000		-0.161	-0.125
2002/2003		-0.169	-0.128
2006/2007		-0.197	-0.153

Note: All APEs are statistically significant at the 1% level. See Tables A3 and A4 in the Appendix for the full regression results.

Both CRE TNH and CRE Tobit are preferred over FE because these estimators account for the fact that most smallholder households do not purchase any fertilizer from commercial retailers.

The APE of a 1-kg increase in government-subsidized fertilizer received by a household (*govt*) on the kg of fertilizer purchased from commercial retailers (*allcomm*) is negative and highly statistically significant ($p<0.001$) in all six models estimated (three each for high and low PSA areas, Tables A3 and A4 in the Appendix). The displacement estimates are also economically significant, particularly in high PSA areas where crowding out is expected to be greater *a priori*. In high PSA areas, each additional kg of government-subsidized fertilizer received reduces commercial fertilizer purchases by 0.23 to 0.36 kg (Table 3). The estimated displacement rate is much lower in low PSA areas (0.07 based on CRE TNH). Taken together, the high and low PSA CRE TNH results suggest a national displacement rate of 0.13.

How do these results compare to those in Xu et al. (2009)? The current paper suggests a somewhat higher rate of displacement at the national level than the 0.07 to 0.08 rate reported in Xu et al. (2009). However, results in the current paper do not support the Xu et al. finding of crowding in in low PSA areas, nor do the results support their finding of such a high degree of crowding out in high PSA areas that total fertilizer acquisition actually decreases with each additional kg of government-subsidized fertilizer injected into the system.

The differences in results between the current study and Xu et al. (2009) are likely due to differences in methodology. The main econometric improvement in the current paper is the careful treatment of potential endogeneity using the control function approach (following Ricker-Gilbert, Jayne, and Chirwa 2011). The residuals from the reduced form CRE Tobit models for government-subsidized fertilizer are statistically significant at the 10% level or lower in four of the six commercial fertilizer demand equations estimated here (Tables A3 and A4 in the Appendix). This suggests that government-subsidized fertilizer is indeed endogenous. Xu et al. (2009) do not directly address the endogeneity issue. They use the community/SEA-level average quantity of government-subsidized fertilizer received per household rather than the observed household-level quantity received in their household-level commercial fertilizer demand equations. Although the correlation between this community-level average and the error term may be weaker than the correlation between the household-level quantity of subsidized fertilizer received and the error term, using the community-level average does not solve the endogeneity problem.

Although the current paper's overall Zambia crowding out estimate of 0.13 is larger than Xu et al.'s estimate thereof, it is smaller than the estimated Malawi displacement rate of 0.22 (Ricker-Gilbert, Jayne, and Chirwa 2011). Since this paper follows the econometric methods in Ricker-Gilbert, Jayne, and Chirwa (2011), the gap in displacement rates is not due to methodological differences. The higher displacement rate in Malawi may be due to the fact that a far greater percentage of smallholder households receives subsidized fertilizer in Malawi than in Zambia. Ricker-Gilbert, Jayne, and Chirwa (2011) report that 31% and 57% of Malawian smallholders received government fertilizer in 2002-2004 and 2006/07, respectively. In Zambia, only 13% and 12% of smallholders received subsidized fertilizer in 2002/03 and 2006/07 (Table 2). The broader coverage of the Malawi input subsidy program may exacerbate targeting challenges and lead to the higher rate of displacement of commercial fertilizer purchases observed there.

In addition to overall displacement estimates, Table 3 reports crowding out estimates by farm size, gender of the household head, and agricultural year. The crowding out effect of subsidized fertilizer on commercial fertilizer purchases is larger among households cultivating more than two hectares than among those cultivating smaller areas. This finding is consistent with *a priori* expectations. Landholding size and area planted are highly positively correlated with household income and assets, thus households planting larger areas are more likely to have the means to purchase fertilizer at commercial prices.

Results suggest a slightly higher displacement rate in 2006/07 than in earlier years (Table 3). A likely driver of the higher level of crowding out in 2006/07 compared to 2002/03 in particular is the scaling up of FISP and the scaling down of the Food Security Pack Programme. Smallholder households acquired approximately 29% more total government-subsidized fertilizer in 2006/07 than in 2002/03 based on the balanced panel of households. However, the increase was due entirely to an increase in fertilizer acquired through FISP (+53%); the quantity of fertilizer acquired through the Food Security Pack shrank by 75%. Recall that the Food Security Pack Programme targets vulnerable but viable households such as female- and child-headed households and households with disabled members or that are supporting orphans. Displacement rates are expected to be lower among such households and estimation results suggest that they are indeed lower among female-headed households (Table 3). Holding fixed the total quantity of government-subsidized fertilizer distributed but reducing the share distributed through the Food Security Pack compared to FISP, we would expect an increase in crowding out as happened between 2002/03 and 2006/07. As shown earlier, fertilizer distributed through FISP was targeted more toward households with higher assets and larger farms than the Food Security Pack was, and therefore the scaling up of FISP and the downsizing of the Food Security Pack in 2006/07 may have contributed to the somewhat higher rates of crowding out in 2006/07 compared to 2002/03.

In the two previous studies on the topic (Xu et al. 2009; Ricker-Gilbert, Jayne, and Chirwa 2011), the change in total fertilizer purchases given a one-unit increase in government-subsidized fertilizer ($\frac{\partial total}{\partial govt}$) was calculated as one minus the displacement rate (e.g., 1 - 0.22 = 0.78 for Malawi). However, as discussed in Section 4.1 and shown in equation (5), if there is leakage of government-subsidized fertilizer into the commercial channel and if, as in our case, it is impossible for the researcher to determine if fertilizer that households report as being purchased from commercial sources is ‘real’ commercial fertilizer or leaked government-subsidized fertilizer, then the increase in total fertilizer use calculated in this way will be overestimated. An adjustment must be made to account for the leakage.

Table 4 reports unadjusted and adjusted estimates of $\frac{\partial total}{\partial govt}$ based on the CRE TNH displacement estimates in Table 3 and assuming that $\frac{\partial leaked}{\partial govt} = \frac{leaked}{govt}$. Estimates of $\frac{leaked}{govt}$ in Table 4, column B, are the share of subsidized fertilizer delivered to the district level according to MACO records that was not ultimately acquired by farmers as government-subsidized fertilizer based on the household panel survey data. A non-trivial share of the fertilizer intended for government subsidy programs leaks out of the government channel: 21% in high PSA areas, 53% in low PSA areas, and 33% nationally. Assuming the leaked fertilizer is resold through commercial channels, then each additional kg of government-subsidized fertilizer injected into the system increases total fertilizer acquisition nationally by just 0.53 kg (0.56 kg in high PSA areas and 0.40 kg in low PSA areas) (Table 4, column D). Failure to account for leakage would have resulted in a 63% overestimate of the change in total fertilizer used by farmers in Zambia given a 1-kg increase in the quantity of government-subsidized fertilizer distributed (a 37% overestimate in high PSA areas and a 131% overestimate in low PSA areas where leakage was much greater).

Table 4. Estimated Kg Change in Total Smallholder Fertilizer Acquisition Given A 1-Kg Increase in Government-Subsidized Fertilizer Distributed

Area	$\frac{\partial allcomm}{\partial govt}$[a]	$\frac{leaked}{govt}$[b]	$\frac{\partial total}{\partial govt}$ Unadjusted	$\frac{\partial total}{\partial govt}$ Adjusted	% difference
	A	B	C=1+A	D=1+A-B	E=(C-D)/D
High PSA	-0.228	0.208	0.772	0.564	36.9%
Low PSA	-0.070	0.527	0.930	0.403	130.8%
National	-0.134	0.334	0.866	0.532	62.8%

Notes***:*** [a]From CRE TNH estimates in Table 3. [b]Derived by comparing MACO records of Fertilizer Credit Programme/FISP quantities delivered to the district-level to the actual quantities of Fertilizer Credit Programme/FISP fertilizer received by farmers based on nationally representative household survey data.

6. CONCLUSIONS AND POLICY IMPLICATIONS

Targeted fertilizer subsidies are growing in popularity in Sub-Saharan Africa. However, if subsidized fertilizer is allocated to households that would have otherwise purchased it at commercial prices, then the impact of the fertilizer subsidy program on total fertilizer use will be overestimated. In other words, the change in total fertilizer use will depend on, *inter alia*, the extent to which subsidized fertilizer crowds out or displaces commercial fertilizer purchases. Taking account of potential displacement is important for understanding the benefits and costs of input subsidy programs, their contribution to food production, and their impacts on the development of a vibrant commercial input distribution system. These are all important stated goals of many input subsidy programs in Sub-Saharan Africa.

In this paper, we revisit this issue and build on the previous studies in several ways. We extend the conceptual framework used by Xu et al. (2009) and Ricker-Gilbert, Jayne, and Chirwa (2011) to incorporate leakage of government-subsidized fertilizer into commercial channels, a problem that is anecdotally widespread in input subsidy programs in Africa. In Zambia's case, evidence indicates that roughly 33% of the fertilizer allocated under the government's fertilizer subsidy program was not received through the program by farmers. We show that if such leakage exists, then an adjustment needs to be made when going from the econometric estimate of crowding out to an estimate of the change in total fertilizer acquisition given an increase in the quantity of government-subsidized fertilizer injected into the system. We then apply the framework to the case of Zambia and use nationally representative panel household survey data covering 1999/2000, 2002/03, and 2006/07 to produce updated estimates of the effects of government fertilizer subsidies on total and commercial fertilizer use by Zambian farmers. The econometric models estimated deal with endogeneity issues following the approach used by Ricker-Gilbert, Jayne, and Chirwa (2011) and also control for the potentially confounding effects of past Food Reserve Agency activities on fertilizer demand.

The study highlights six main findings. First, each additional kg of subsidized fertilizer received by a household decreases its fertilizer purchases from commercial retailers by 0.13 kg. This estimate is larger than Xu et al.'s (2009) overall displacement estimates for Zambia (0.07 to 0.08) but smaller than Ricker-Gilbert, Jayne, and Chirwa's (2011) estimate for Malawi (0.22). A far greater percentage of smallholders receive government-subsidized fertilizer in Malawi (31-57%) than in Zambia (12-13%), which may explain the higher level of crowding out in Malawi.

Second, at 0.23, the displacement rate in areas where the private sector was initially more active in fertilizer retailing ("high PSA areas") is substantially higher than in low PSA areas (0.07). This is consistent with *a priori* expectations and the general insight from Xu et al. (2009) that displacement rates differ in important ways between areas with high versus low initial private sector activity in fertilizer retailing. Third, the displacement rate is higher among households that cultivate two or more hectares of land (0.21) than among households cultivating smaller areas (0.11). Displacement rates are also higher among male-headed households (0.15) than among female-headed ones (0.09). Fourth, the displacement rate was somewhat higher in 2006/07 (0.15) than in 2002/03 (0.13), perhaps due to greater targeting challenges in 2006/07 resulting from a 75% increase in the scale of the Fertilizer Support Programme and a reduction in the share of government-subsidized fertilizer distributed through the typically better-targeted Food Security Pack Programme.

Fifth, comparisons of the quantity of fertilizer delivered to the district level to be distributed as government-subsidized fertilizer with the total quantity of government-subsidized fertilizer actually received by farmers in Zambia suggest significant leakage. In the years covered in the panel survey data used in this study, 67% of the fertilizer intended for distribution through the Fertilizer Credit Programme or Fertilizer Support Programme reached farmers as subsidized fertilizer. That is, 33% leaked out of the government channel and was likely resold through commercial channels. Sixth, coupling this leakage figure with the crowding out estimate of 0.13 suggests that each additional kg of fertilizer intended for government subsidies that is injected into the system increases total fertilizer acquisition by 0.53 kg. Without adjusting for leakage, we would have concluded that total fertilizer acquisition increases by 0.87 kg, an overestimate of approximately 63%. This implies that the contribution of the subsidy program to national maize production is considerably lower per dollar spent on the program than previous estimates would suggest. However, because of the sheer size of the program, it clearly did contribute to the rise in national maize production that Zambia experienced during this period.

Based on these findings, the Zambian government may be able to add more to total fertilizer use through its fertilizer subsidy programs by reducing leakage and by targeting households in areas where private sector activity in fertilizer distribution is relatively underdeveloped, as well as to farmers with relatively small landholdings or cultivated area, and female-headed households. In recent years, the Zambian government has taken steps to improve targeting by involving traditional leaders in the selection of beneficiaries for the Farmer Input Support Programme (the successor program to Fertilizer Support Programme). The government could also consider channeling more subsidized fertilizer through the Food Security Pack Programme, which has a better targeting track record. The use of an electronic voucher (e-voucher) system for the fertilizer subsidies, where the vouchers are redeemable at commercial retailers, may be a way of crowding in private investment in fertilizer marketing. Under the current Farmer Input Support Programme modalities, there is limited engagement of the private sector. An e-voucher system also has the potential to improve monitoring of subsidized fertilizer and to reduce leakage (Sitko et al. 2012).

APPENDIX

TABLE A1. Summary Statistics (Averages across All Three Survey Years)

Variables	Mean	Median	Std. dev.
Dependent variable: kg of commercial fertilizer purchased by the HH	42.625	0	200.814
Explanatory variables:			
Kg of government-subsidized fertilizer acquired by the HH	29.294	0	143.258
Expected farmgate maize price (ZMK/kg)	452.833	458.900	177.074
Groundnut price (ZMK/kg, t-1)	1138.862	1052.632	355.036
Sweet potato price (ZMK/kg, t-1)	214.314	193.237	102.471
Farmgate market fertilizer price (ZMK/kg)	1442.297	1476	659.593
Wage to weed 0.25 ha field (‘000 ZMK)	24.334	20	12.911
Expected growing season rainfall (‘00 mm, Nov.-Mar., 9-year MA)	8.956	8.767	1.841
Expected moisture stress (# of 20-day periods, Nov.-Mar., with <40 mm rainfall, 9-year MA)	1.826	1.889	1.031
Adult equivalents	4.811	4.48	2.437
Landholding size (cultivated+fallow, ha)	2.056	1.5	2.621
Value of farm assets (’00,000 ZMK) – plows, harrows, and ox-carts	1.205	0	4.656
Age of household head	48.280	46	15.350
Highest level of education completed by HH head:			
No formal education (=1)	0.187		
Lower primary (grades 1-4) (=1)	0.249		
Upper primary (grades 5-7) (=1)	0.351		
Secondary (grades 8-12) (=1)	0.190		
Post-secondary education (=1)	0.024		
Gender & residence status of HH head (non-resident if <6 months):			
Male-headed (=1)	0.775		
Female-headed with non-resident husband (=1)	0.007		
Female-headed with no husband (=1)	0.218		
Km from center of SEA to nearest (as of 2000):			
District town	34.530	28.9	22.644
Tarred/main road	25.466	12	35.708
Feeder road	3.323	2.4	3.276
High private sector fertilizer retailing activity in HH’s district in 1997/98 (=1)	0.402		
Candidate instrumental variables:			
MMD won constituency in last presidential election (=1)	0.684		
Percentage point spread between MMD & lead opposition party (absolute value)	41.842	41.142	23.581

Sources: CSO/MACO/FSRP 2001, 2004, and 2008 Supplemental Surveys. Notes***:*** N=16,566. MA = moving average.

Table A2. Reduced Form CRE Tobit Estimates of Factors Affecting the Kilograms of Government-Subsidized Fertilizer Acquired by the Household – High versus Low Private Sector Activity (PSA) Areas

Explanatory variables	-----High PSA Areas----- APE	Sig.	Bootstrap p-value	-------Low PSA Areas ------- APE	Sig.	Bootstrap p-value
IV: MMD won constituency in last presidential election (=1)	24.722	***	0.000	9.464	***	0.001
IV: Percentage point spread between MMD & lead opposition party	--			-0.101	*	0.079
IV: Interaction effect (MMD won constituency × % point spread)	--			0.409	***	0.002
Expected farmgate maize price (ZMK/kg)	0.196	*	0.059	0.00454		0.798
Groundnut price (ZMK/kg, t-1)	-0.0171		0.307	0.0139	**	0.043
Sweet potato price (ZMK/kg, t-1)	-0.0680		0.110	-0.00791		0.554
Farmgate market fertilizer price (ZMK/kg)	0.00190		0.891	0.0143	***	0.010
Wage to weed 0.25 ha field (‘000 ZMK)	0.544	*	0.063	-0.0667		0.706
Expected growing season rainfall (‘00 mm)	2.439		0.753	-5.546		0.121
Expected moisture stress	9.891		0.551	-5.747		0.248
Adult equivalents	0.219		0.866	0.0823		0.863
Landholding size (cultivated+fallow, ha)	2.316		0.114	2.345	***	0.001
Value of farm assets (’00,000 ZMK)	0.491		0.313	0.160		0.624
Age of household head	-0.352		0.369	0.465	***	0.004
Highest level of education completed by HH head (base is no formal education):						
Lower primary (grades 1-4) (=1)	0.644		0.941	1.223		0.766
Upper primary (grades 5-7) (=1)	5.848		0.531	4.485		0.335
Secondary (grades 8-12) (=1)	0.820		0.943	15.713	**	0.020
Post-secondary education (=1)	-22.925	*	0.052	3.699		0.751
Gender & residence status of HH head (non-resident if <6 months; base is resident male):						
Female-headed with non-resident husband (=1)	-5.134		0.818	20.128		0.386
Female-headed with no husband (=1)	-4.718		0.534	0.594		0.918
Km from center of SEA to nearest (as of 2000):						
District town	-0.463	**	0.028	-0.0471		0.408
Tarred/main road	-0.178		0.260	-0.0745		0.129
Feeder road	-2.484	*	0.086	-1.071	***	0.005
Agricultural year (base is 2006/2007):						
1999/2000 (=1)	40.464		0.566	4.645		0.778
2002/2003 (=1)	24.053		0.331	22.708	***	0.007
Provincial & agro-ecological dummies	Yes			Yes		
Time averages (CRE)	Yes			Yes		
Observations	5,919			9,036		
Pseudo R-squared	0.041			0.065		
Overall model F-statistic	6.13	***	0.000	5.72	***	0.000

Notes: ***, **, * significant at the 1%, 5%, and 10% levels. MMD wins constituency and percentage point spread APEs for low PSA areas include effects of interaction term. Bootstrap p-values based on 325 replications.

Table A3. Factors Affecting the Quantity (kg) of Commercial Fertilizer Purchased by the Household – High PSA Areas

Explanatory variables	Fixed Effects APE	Sig.	Bootstrap p-value	CRE Tobit APE	Sig.	Bootstrap p-value	CRE TNH APE	Sig.	Bootstrap p-value
Kg of government-subsidized fertilizer acquired by HH	-0.356	***	0.000	-0.319	***	0.000	-0.228	***	0.000
Tobit residuals from gov't fertilizer reduced form	*Excluded (p=0.325)*			-0.0688 [a]		0.172	-0.0736	***	0.004
Expected farmgate maize price (ZMK/kg)	0.751	***	0.001	0.320	**	0.025	0.381	**	0.015
Groundnut price (ZMK/kg, t-1)	-0.0276		0.214	0.0103		0.581	0.00684		0.739
Sweet potato price (ZMK/kg, t-1)	-0.168	***	0.000	-0.0809		0.158	-0.0873		0.160
Farmgate market fertilizer price (ZMK/kg)	-0.0151		0.559	0.0254		0.176	0.0109		0.586
Wage to weed 0.25 ha field ('000 ZMK)	0.0145		0.973	-0.198		0.663	-0.574		0.150
Expected growing season rainfall ('00 mm)	156.008	***	0.007	0.416		0.967	-15.793		0.122
Expected growing season rainfall, squared	-8.185	***	0.006	--		--	--		--
Expected moisture stress	18.893		0.433	2.152		0.930	-2.475		0.931
Adult equivalents	2.710		0.144	2.528		0.113	3.694	***	0.005
Landholding size (cultivated+fallow, ha)	18.648	***	0.000	7.915	***	0.001	3.153	**	0.034
Landholding size, squared	-0.235		0.109	--		--	--		--
Value of farm assets ('00,000 ZMK)	5.253	***	0.000	2.945	***	0.000	1.574	***	0.000
Value of farm assets, squared	-0.0298	*	0.060	--		--	--		--
Age of household head	-0.0248		0.968	0.233		0.684	0.536		0.364
Highest level of education completed by HH head (base is no formal education):									
Lower primary (grades 1-4) (=1)	-23.772	**	0.018	-10.480		0.340	-22.287	**	0.028
Upper primary (grades 5-7) (=1)	-30.822	**	0.019	-18.378		0.105	-30.302	***	0.005
Secondary (grades 8-12) (=1)	-27.375	*	0.096	-19.882		0.129	-19.052		0.118
Post-secondary education (=1)	2.194		0.956	9.526		0.776	12.549		0.619
Gender & residence status of HH head (non-resident if <6 months; base is resident male):									
Female-headed with non-resident husband (=1)	64.660		0.241	46.255		0.524	4.048 [b]		0.770
Female-headed with no husband (=1)	3.651		0.783	-8.248		0.485			
Km from center of SEA to nearest (as of 2000):									
District town	--		--	-1.077	***	0.006	-0.813	***	0.007
Tarred/main road	--		--	0.308	*	0.066	0.339	**	0.026
Feeder road	--		--	1.534		0.652	2.062		0.552
Agricultural year (base is 2006/2007):									
1999/2000 (=1)	173.814		0.111	172.636	*	0.074	188.545		0.452
2002/2003 (=1)	11.248		0.797	20.546		0.516	13.381		0.694
Constant	-995.382	***	0.009	--		--	--		--
Provincial & agro-ecological dummies	N/A			Yes			Yes		
Time averages (CRE)	N/A			Yes			Yes		
Pseudo R-squared (Within R-squared for Fixed Effects)	0.145			0.050			--		
Overall model F-statistic (Chi-squared for CRE TNH)	7.85	***	0.000	11.37	***	0.000	642.38	***	0.000

Notes: [a]Residuals stat. sig. without bootstrapping. [b]Female-headed household (with or without resident husband). ***, **, * significant at the 1%, 5%, and 10% levels. CRE Tobit APEs include effects of associated squared terms. No squared terms included in CRE TNH model. N=5,919 (4,068 at corner).

TABLE A4. Factors Affecting the Quantity (kg) of Commercial Fertilizer Purchased by the Household – Low Fertilizer PSA Areas

	-----Fixed Effects-----			-------CRE Tobit-------			-------CRE TNH-------		
Explanatory variables	APE	Sig.	Bootstrap p-value	APE	Sig.	Bootstrap p-value	APE	Sig.	Bootstrap p-value
Kg of government-subsidized fertilizer acquired by HH	-0.199	***	0.000	-0.0753	***	0.000	-0.0704	***	0.000
Tobit residuals from gov't fertilizer reduced form	-0.0754	***	0.001	-0.0416	***	0.002	-0.0473	***	0.000
Expected farmgate maize price (ZMK/kg)	0.0869	**	0.034	0.0657	**	0.012	0.0975	***	0.000
Groundnut price (ZMK/kg, t-1)	-0.000362		0.979	-0.00143		0.868	-0.00348		0.689
Sweet potato price (ZMK/kg, t-1)	0.0248		0.240	0.0109		0.440	0.0202		0.151
Farmgate market fertilizer price (ZMK/kg)	-0.00110		0.880	-5.94E-05		0.992	-0.00338		0.572
Wage to weed 0.25 ha field ('000 ZMK)	0.328		0.277	0.346	*	0.062	0.211		0.302
Expected growing season rainfall ('00 mm)	8.052		0.126	5.630	*	0.076	8.770	***	0.010
Expected moisture stress	2.466		0.716	3.563		0.473	6.007		0.265
Adult equivalents	0.892		0.271	1.297	**	0.024	1.135	**	0.048
Landholding size (cultivated+fallow, ha)	1.036		0.688	1.114		0.142	0.278		0.645
Landholding size, squared	0.221		0.396	--		--	--		--
Value of farm assets ('00,000 ZMK)	1.259		0.128	0.300		0.280	0.135		0.602
Age of household head	-0.572	*	0.093	-0.371	*	0.065	-0.422		0.127
Highest level of education completed by HH head (base is no formal education):									
Lower primary (grades 1-4) (=1)	-6.542		0.158	-2.330		0.562	-5.563		0.124
Upper primary (grades 5-7) (=1)	-5.595		0.290	0.710		0.867	-3.232		0.425
Secondary (grades 8-12) (=1)	-11.796		0.143	-3.510		0.533	-8.834	*	0.059
Post-secondary education (=1)	16.643		0.398	12.386		0.504	3.438		0.766
Gender & residence status of HH head (non-resident if <6 months; base is resident male):									
Female-headed with non-resident husband (=1)	-23.516		0.323	-1.035		0.934	-5.776[a]		0.279
Female-headed with no husband (=1)	-2.209		0.782	-0.748		0.883			
Km from center of SEA to nearest (as of 2000):									
District town	--		--	-0.0505		0.281	-0.0410		0.424
Tarred/main road	--		--	-0.0881	*	0.054	-0.0268		0.669
Feeder road	--		--	-0.193		0.588	0.291		0.507
Agricultural year (base is 2006/2007):									
1999/2000 (=1)	56.013	**	0.015	86.354	*	0.055	130.964		0.220
2002/2003 (=1)	6.736		0.561	12.395		0.217	9.697		0.399
Constant	-49.978		0.570	--		--	--		--
Provincial & agro-ecological dummies	N/A			Yes			Yes		
Time averages (CRE)	N/A			Yes			Yes		
Pseudo R-squared (Within R-squared for Fixed Effects)	0.073			0.079			--		
Overall model F-statistic (Chi-squared for CRE TNH)	4.64	***	0.000	7.97	***	0.000	682.29	***	0.000

Notes: [a]Female-headed household (with or without resident husband). ***, **, * significant at the 1%, 5%, and 10% levels. CRE Tobit APEs include effects of associated squared terms. No squared terms included in CRE TNH model. N=9,036 (8,278 at corner).

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