The Impact of State Marketing Board Operations on Smallholder Behavior and Incomes: The Case of Kenya

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1. INTRODUCTION

The appropriate role of the state in food markets remains an issue that is both highly contentious and of fundamental importance for food security and poverty reduction. Soon after gaining independence, many governments in eastern and southern Africa (ESA) continued or created state-led marketing boards, grain reserves, and/or input distribution programs, ostensibly to resolve failures in domestic fertilizer and grain markets. However, the high fiscal burden of such state-led operations was a major factor underlying the macroeconomic and budgetary crises faced by many ESA governments in 1970s, which forced them to accept macroeconomic stabilization and structural adjustment policies from the IMF/IMDB beginning in the 1980s. As part of these policy and structural reforms, many of these parastatal entities were either dismantled or dramatically scaled down during the 1980s and 1990s, leaving grain marketing largely in the hands of the private sector.[1] Yet, a variety of factors have led to a resurgence of the "development state" in the past decade, featuring a return of government fertilizer subsidy programs, parastatal grain marketing boards, and strategic food reserves in the ESA region. The governments of Ethiopia, Kenya, Malawi, Tanzania, Zambia, and Zimbabwe have all recently re-instated grain marketing boards and/or strategic grain reserves as significant (though no longer monopolistic) actors in domestic grain markets (Jayne et al., 2007).

Despite the importance of the topic, there remains little empirical research on how the re-emergence of grain marketing boards is affecting the input use and cropping decisions of smallholder farmers in the region. The vast majority of the existing literature on marketing boards in the ESA region comes from the period when agricultural market reforms swept through the region in the late 1980s and 1990s, and is primarily based on national-level market or price data (Pinckney, T.C, 1988; Schiff and Valdés, 1991; Masters and Nuppenau, 1993; Krueger, 1996). With only a few exceptions (e.g., Kutengule et al, 2006; Mason 2011), there remains little use of household-level data to provide the micro-economic foundation for understanding how smallholder farmers respond to and are affected by the operations of state marketing boards. Such a microeconomic foundation is necessary to meaningfully guide food policy decisions in the region.

This paper aims to fill these lacunae by using household-level panel data from Kenya to investigate smallholder responses to the marketing board operations of the National Cereal and Produce Board (NCPB). Since 1988, private sector grain traders in Kenya have legally operated alongside the NCPB, which dramatically reduced its presence in the Kenyan maize market in the early 1990s, yet was never dismantled (Jayne et al, 2002). Although the level of maize purchases by NCPB in recent years is generally lower than in the years prior to structural adjustment, the NCPB still purchased an average of 8% of total maize production in Kenya between 1996 and 2008. Previous research by Jayne et al (2008) has found that NCPB activities have led to relatively higher and more stable wholesale maize prices from 1995 to 2004, though there is no research which has investigated the extent to which NCPB activities have affected smallholders' price expectations, behavior, and incomes.

[1] A small but growing number of observers have noted that many program aspects of structural adjustment were often only partially implemented (Killick, 1998; van de Walle, 2001). For example, marketing boards in some ESA countries remained active in grain markets during the 'reform' period of the 1980s and 1990s, albeit in a much smaller role (Jayne et al, 2002).

Our household-level panel survey data covers 24 districts in Kenya, for which households were interviewed in 1997, 2000, 2004 and 2007. This household-level data, along with data on NCPB pan-territorial purchase prices and district-level volumes of purchases, provide a natural experiment for measuring the effects of NCPB's activities in the Kenyan maize market on smallholder maize price expectations, and input and output decisions, and total incomes. In this paper, we: (i) measure the extent to which NCPB activities in the maize market influences farmers' expectations of maize prices at the farmgate level; (ii) measure the sensitivity of farmers' output and input decisions to changes in expected maize prices; and (iii) to determine how these effects vary across households given their heterogeneous capacities to respond to changing incentives.

This paper is organized as follows. We first provide a brief review of food marketing policies and the role of the NCPB in Kenya in Section 2, and then describe the data used in this study in Section 3. Section 4 presents the conceptual framework with which we investigate the effects of NCPB activities on smallholder behavior and then discuss the empirical models and estimation strategy. Results are presented in Section 5, and the conclusions and policy implications are discussed in Section 6.

2. FOOD MARKETING POLICY AND THE NCPB IN KENYA

Maize marketing and trade policy in Kenya has been dominated by two major challenges. The first challenge concerns the classic food price dilemma: how to keep farm prices high enough to provide production incentives for farmers while at the same time keeping them low enough to ensure poor consumers' access to food. The second major challenge has been how to effectively deal with food price instability, which is frequently identified as a major impediment to smallholder productivity growth and food security. The need to manage price instability has been elevated further in recent years since the global food price spikes of 2007-08.

In Kenya, food security has generally been viewed as synonymous with maize security, as maize is not only the main staple food, but also the most common food crop grown by the rural poor (Nyoro et al 1999). The importance attached to maize by policy-makers in Kenya can be inferred from the emphasis given to maize in current and past national food policies.

Since the early 1930s, Kenya's maize marketing system had been highly controlled. The Government set producer and into-mill prices for maize and set maize meal prices to be sold by millers and retailers to consumers. These prices were pan-territorial and pan-seasonal, adjusted once per year at the beginning of the marketing season. The government marketing board, known as the National Cereals and Produce Board (NCPB) since 1980, had a monopoly on internal and external trade and informal private trade across district boundaries was illegal, as was cross-border trade. However, private maize trade has always existed in Kenya, despite government attempts to suppress it until the liberalization process began in the late 1980s. Traders were required to apply for movement permits to allow them to transport grain across district boundaries.

Attempts to reform Kenya's maize marketing and pricing system began incrementally in the late 1980s, and intensified in late 1993, when, under pressure from international lenders, the government eliminated movement and price controls on maize trading, deregulated maize and maize meal prices, and eliminated direct subsidies on maize sold to registered millers (Nyoro et al. 1999). By 1995, private traders were allowed to transport maize across districts without any hindrance.

Prior to market liberalization in the late 1980s, the NCPB purchased between 400,000 to 750,000 metric tons of maize per year (Table 1). Even during the early years of liberalization, the NCPB received enough public funds to purchase between 250,000 to 500,000 tons per year, which was more than half of the nation's marketed maize output. Thus, the NCPB remained the dominant player in the maize market even 6-7 years into the liberalization process. This is not surprising considering that the NCPB set its maize purchase prices considerably higher than prevailing market prices (Jayne et al. 2008).

Table 1. NCPB Maize Trading Volumes and Price Setting, 1988/89 to 2009/10

Year	Total National Maize Output (000 mt)	NCPB Maize Purchase and Sale Price (Kenyan Shilling (kSH) PER 90KG BAG)				NCPB Maize Purchases (000 mt)	NCPB Maize Sales (000 mt)
		----- Nominal ----		-- Inflation Adjusted[a] –			
		Purchase price	Sale price	Purchase price	Sale price		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
1988/89	2761	201	326	1725	2703	643.8	
1989/90	2631	221	337	1680	2561	551.3	
1990/91	2290	250	337	1645	2215	235.3	669.6
1991/92	2340	300	358	1649	1961	318.9	735.2
1992/93	2430	420	646	1679	2582	493.4	257.4
1993/94	2089	950	1280	2549	3434	467.6	512.8
1994/95	3060	920	1280	1960	2728	540.0	67.7
1995/96	2699	600	887	1235	1825	100.8	111.3
1996/97	2160	1127	1100	2232	2176	62.8	54.3
1997/98	2214	1162	1318	2172	2463	151.5	14.6
1998/99	2400	1009	1209	1764	2113	34.9	123.3
1999/00	2322	1200	1436	1923	2301	177.2	145.1
2000/01	2160	1250	1300	1812	1884	311.5	74.1
2001/02	2776	1000	1250	1414	1768	257.7	23.7
2002/03	2441	1052	1265	1408	1693	89.1	196.4
2003/04	2714	1358	1680	1670	2066	162.0	136.7
2004/05	2459	1400	1950*	1566	2181	314.1	144.0
2005/06	2918	1250	1770*	1250	1770	135.3	375.6
2006/07	3248	1300	1500*	1161	1339	407.2	97.6
2007/08	2931	1300	1335	1111	1148	32.0	219.6
2008/09	2367	1950	1435-1835#	1615	1189-1520	78.3	308.6
2009/10	2443	2300	1750-1910				0.0

Notes: Shaded rows signify the years covered by the four panel Tegemeo surveys. a) Base year 2005=100; * NCPB maize selling price changed from pan-territorial to province-specific in 2004 -- selling prices shown are for Nairobi and Central Provinces. # revised four times during 2008/09 starting at the 1435 Ksh/bag and ending at 1835 Ksh/bag. Source: NCPB data files, except for maize production statistics, which come from the Ministry of Agriculture.

Starting in the 1995/96 marketing year, and under pressure from external donors, the government dramatically reduced the NCPB's operating budget. This forced the NCPB to scale back its purchases substantially to about 1 million bags per year between 1995 and 2000 (Table 4). The first year of the panel survey data covers the 1996/97 year, the second year of a dramatic cutback in NCPB maize purchases. This reduction in NCPB maize purchases led to intensive lobbying by commercial maize farmers for increased purchases. A year before the national elections, the government increased the NCPB's budget for the 2000/01 year. Since 2000, the NCPB's maize purchases have been trending upward until 2006/07, the last year of our survey data, where the NCPB purchased over 400,000 tons. This is believed to be roughly 25-35% of the total maize sold by the small and large farm sector in Kenya, and is approaching the scale of operations played by the NCPB during the pre-reform era. However, in inflated-adjusted terms, the purchase price offered by the NCPB has declined steadily over time to be more in line with market prices, though generally still exceeding them. Therefore, the four survey years shaded in Table 4 cover a period of major variations in the NCPB's presence in the market as well as the real prices offered to farmers.

Most of the maize purchased by the NCPB now appears to be directly from large-scale farmers in the maize surplus parts of the country, where unit procurement costs are low due to scale economies. Since the major withdrawal of the NCPB in 1995, the Tegemeo survey data (of 1997, 2000, 2004 and 2007) show that smallholder farmers in the aggregate sell 96% of their maize to one of two types of buyers, private traders/brokers or consuming households. While the NCPB thus accounts for 4% or less of smallholder household maize sales, the NCPB indirectly influences millions of small farmers and urban consumers through the upward pressure that its operations exert on farm-gate and wholesale maize market prices, as will be shown later.

3. DATA SOURCES

3.1 Household data

The Tegemeo Institute of Egerton University and Michigan State University designed and implemented smallholder farm surveys in 8 agro-ecological zones where crop cultivation predominates. The sampling frame for the survey was prepared in consultation with the Central Bureau of Statistics. Households and divisions were selected randomly within purposively chosen districts in the 8 agro-ecological zones; further sampling details are provided in Argwings-Kodhek (1998). A total of 1,578 small-scale farming households were surveyed in 1997. Of these, we drop 48 households either because they were found to be mainly pastoral farmers or their landholding size exceeded 20 hectares and hence are not categorized as smallholder farms according to the Kenya Bureau of Statistics. The 1997 survey therefore constituted 1,530 sedentary households farming under 20 hectares. Subsequent panel waves were conducted in 2000, 2004, and 2007. The 2007 sample contains 1,342 households of the original 1,578 sampled, a re-interview rate of 85%. The nationwide survey includes 106 villages in 24 districts in the nation's 8 agriculturally-oriented provinces. For this study, we also drop 342 households in two regions with marginal potential for maize production and where the NCPB has little or no involvement in the market, the Marginal Rain Shadow and Coastal Lowlands, leaving a sample of n=1,115 households observed in each panel year.

3.2 Price and weather data

In addition to data from the Tegemeo rural household survey, we also use monthly wholesale price data for maize and for each of the main food and cash crops, which is collected from regional wholesale markets across Kenya. Data on rainfall estimates comes from the Famine Early Warning System (FEWS), which was produced at the level of every 0.1 degree latitude and 0.1 degree longitude. This data interpolates rainfall estimates based on data from rainstations as well as satellite data (such as on cloud cover and cloud top temperatures). The FEWS rainfall estimates were then matched to Tegemeo survey households using GPS coordinates collected by the enumerators for each village. Data on agroecological zones and village-level soil characteristics are based on a map developed by Braun and the Kenya Soil Survey (1980).

4. METHODS

4.1 Econometric analysis

4.1.1 Conceptual framework

Because the post-harvest prices for maize and other crops paid by private traders to smallholders in Kenya are not known to farmers at the time that they make their cropping and input decisions, farmers must make these decisions based on the output prices they expect to receive at harvest. We therefore explicitly model the farm-gate maize price expectations of smallholders as a function of factors which they can observe at planting. Following Mason's (2011) work in Zambia, there are four key aspects of rural maize markets in Kenya which we consider in modelling the post-harvest maize price expectations of smallholders in rural Kenya. First, since 1988, private sector grain traders in Kenya have legally operated alongside the NCPB and are able to buy maize at a price above or below the NCPB purchase price. Second, fewer than 2% of smallholder farmers in the Tegemeo household surveys sold maize directly to the NCPB in any of the four survey years. This corroborates the general impression in Kenya that the NCPB purchases maize almost exclusively from large-scale farmers.[2] We therefore assume that there is effectively only one marketing channel for maize and non-maize crops: the private sector.[3] Third, given that research by Jayne et al (2008) found that NCPB activities led to an average increase in wholesale prices of roughly 20% from 1995 to 2004, NCPB purchase prices and volumes likely have an indirect effect on the farm-gate prices offered to smallholders by private traders and companies. Thus, even though very few smallholders sell directly to the NCPB, smallholders' expectations regarding the NCPB maize purchase price and purchase volumes may nevertheless affect their expectations of post-harvest farm-gate maize prices paid by traders. Fourth, neither the pan-territorial price at which the NCPB will purchase maize in a given season nor the volume of NCPB purchases at the national and district level are known to farmers at planting, so each farmer must form an expectation for both.

We further assume that a representative rural Kenyan household is risk-neutral and maximizes utility within an environment characterized by a number of market failures for some of its products (primarily food) and for some of its factors (notably credit). This implies that household consumption decisions are not separable from decisions concerning optimal household input and output levels. Under these assumptions, the agricultural household maximizes expected utility subject to production function, cash, credit, and time constraints. Following Sadoulet and de Janvry (1995), the solution to this optimization problem yields a set of output supply and factor demand equations, each of which are a function of expected output prices, variable input prices, and quasi-fixed factors. The implication of non-separability is that these output supply and input demand functions also depend upon characteristics of household

[2] Neither NCPB nor the Government of Kenya report NCPB maize purchases disaggregated by farm size.
[3] See Mason (2011) for a conceptual and modelling framework which accounts for dual marketing channels.

consumption decisions, such as household wealth/income or demographic characteristics (ibid, 1995).

4.1.2 Modelling farmgate maize price expectations

The first stage of our analysis concerns how NCPB maize purchase volumes and prices affect smallholders' expectations of post-harvest farm-gate maize prices. We model expected farm-gate maize prices as a function of variables observed by the farmer at planting time such as lagged wholesale market prices of maize from the nearest regional market, effective NCPB pan-territorial prices, and household and village characteristics which might affect the maize sale price received by a given household. [4] Due to the limited annual number of observations of smallholder maize sale prices in our survey data, we compute the household-specific smallholder maize price expectation for each survey year using coefficients derived from a pooled model of farmgate sales prices observed in all our panel survey years (1997-2007), as in Mason (2011).

The dependent variable in this maize price expectation model is the *sale price of maize received by smallholders* during the post-harvest period, as recorded in the Tegemeo panel surveys. We hypothesize that NCPB activities may potentially influence smallholders' expectations of post-harvest farmgate maize prices through either the *expected district-level NCPB maize purchase volume* and/or the *effective expected NCPB purchase price.* Given that Jayne et al (2008) found that NCPB activities led to an average increase in wholesale prices of roughly 20% from 1995 to 2004, we also suspect that NCPB activities may affect smallholders' maize price expectations indirectly through the *regional wholesale maize price* observed at planting as well as those each of the 11 months prior. Thus, if changes in wholesale maize prices are at least partially transmitted to the farmgate level, we anticipate that the 12 wholesale maize prices will have a jointly significant partial effect on expected farmgate maize sale prices. The regional wholesale market prices of maize include the price in the planting month of each year at the nearest regional wholesale market, as well as 11 months of lagged wholesale maize prices from that market. To control for variation across villages in transport costs between the village and the regional market, we include the variable *distance from the village to regional market*.

We include the variable *district-level NCPB maize purchase volume, lagged one year* as a naïve expectation of the potential influence of NCPB purchase volumes on expected farmgate maize prices. Because the NCPB does not announce the pan-territorial purchase price of maize for a given season until harvest time, we assume that farmers make a naïve expectation of the post-harvest NCPB maize purchase price, which is the NCPB maize purchase price which prevailed in the planting month each year. Although the NCPB pays the same price for maize at each of its satellite depots, the *effective expected NCPB purchase price* varies across smallholder households. We define this variable as the NCPB pan-territorial price per kilogram (at planting) minus transportation costs per kilogram from a household's village to the nearest NCPB satellite depot. Because the Tegemeo surveys did not record measures of the transport costs of maize, we instead use the provincial median transport cost/kg per kilometer of fertilizer, as reported in 2004 and 2007 by the smallholders who purchased fertilizer those years. Due to data limitations, we have to assume that the distance to the nearest depot for 2007 holds for earlier years, and that

[4] Our price expectations model was initially developed through work and discussions with Milu Muyanga, then later refined through interactions with Nicole Mason, who wrote a companion paper to this which measures the effects of Zambia's grain parastatal on expected farmgate prices, factor demand, and output supply (Mason, 2011).

transport costs per kilogram per kilometer in 2004 are the same as for earlier years (1997 and 2000).

Household characteristics which might influence the price received by a farmer include: *age of the household head* (a proxy for marketing experience), and *education level of the head* (a proxy for negotiation skill). We include a binary variable which =1 if the *household is headed by a single female* to investigate whether or not such households are at a disadvantage with respect to negotiating maize sale prices. To control for potentially adverse effects of adult mortality on household maize sales and prices received (which may otherwise be picked up by the single-female head dummy variable), we also include a binary variable which =1 if the *household suffered the death of an adult age 15-59 within the past 3 years*.

We also use measures of the *household value of storage assets, total value of farm assets,* and binary variables indicating household ownership of a *truck* or *bicycle* as proxies for negotiation leverage enjoyed by a given farmer. *Distance to the nearest motorable road* serves as a proxy for transport costs to the relevant market and market access.

Other household-level factors which may influence the household maize price received include characteristics of the buyer, for which we include dummy variables for each of four potential buyers: the *NCPB*, a *miller/processor*, *other households* and *other institutions* such as schools. The base category represents small and large private traders, by far the most frequent buyer category. Other factors include dummies for three of the four calendar quarters of the year to control for seasonality in household maize sale prices, year dummies, and *expected rainfall during the main season* and the *expected drought shocks during the main season.* Expected rainfall is computed as a six-year moving average of rainfall prior to the season in question, while expected rainfall shock is a six-year moving average of the percentage of 20-day periods during the main growing season with less than 40 mm of rainfall.[5]

Because our maize sale price data is only observed for a subsample of the population which actually sells maize (n=495 out of n=1,139 panel households sold maize in 2007), we and test for the presence of sample selection bias using a Tobit selection equation (Appendix Table A-1) and a method outlined by Wooldridge (2002, p. 572), as in Mason (2011). We find that the residual term from the Tobit selection equation is significant in the OLS regression of maize price (p=0.043) (Table 2), indicating we need to leave the Tobit residual in the price prediction model to correct for sample selection bias in maize sale prices.

4.1.3 Modelling output supply: production

The second stage of our analysis of the effects of NCPB activities on smallholder behavior concerns how smallholders' factor demand and output supply respond to changes in the expected farmgate maize price. The theoretical results of utility maximization behavior in either producer or household models predict that smallholder households will respond to higher expected farmgate maize prices by increasing maize production, as measured either by total production of

[5] The rainfall variables are based on rainfall estimates from satellites (such as on cloud cover and cloud top temperatures) and rain stations, which are combined to interpolate estimates of decadal (10-day period) rainfall, which can be matched to sample households/villages using GPS coordinates. Rainfall estimates were matched to 1360 households using GPS coordinates, and to the village for the remaining households.

maize (kg) or area planted to maize (ha). We first test the extent to which household maize production responds to changes in the expected maize price, and then measure whether this price affects the production levels of other crops and total crop production. Our group of production models includes: total production of maize (kg), total production of competing crops (index), total production of all non-maize crops (index), total production of all crops (index), and the value of total net crop income (value).

The competing crop groups include: high-value food crops (beans and cowpeas); roots and tubers (sweet potato, Irish potato, and cassava); vegetables (kale, onions, and tomatoes); perennial crops (coffee, avocado, and mango); and short perennials (banana and sugarcane). We chose the crops for each group based on those which are most widely grown by smallholders in the survey data. We use the Fisher-Ideal index to aggregate crop production across different crops (Alston et al, 1998). We estimate the output regressions for maize production, total crop production (index), and total net crop income using OLS with household fixed effects. Because specific non-maize crop groups are not grown by all households, we use Tobit to estimate the output supply models of competing crop groups and include correlated random effect terms (CRE) as described below.

Each output supply model is a function of the expected farmgate maize price, expected prices of competing crops, prices of inputs (fertilizer and rural wages), private and public quasi-fixed factors, and other exogenous variables such as year dummies. To account for differences in agroecological potential across the country, we include binary variables for 5 of the country's 6 *agroecological zones* covered by the Tegemeo survey (these variables drop out of the FE models), as well as *cumulative rainfall during the main season*, frequency of *drought shocks* during the main season (defined as the percentage of 20-day periods during the main season with less than 40 mm of rainfall).

We use the coefficients from the maize price expectation model in the first stage to compute a household-specific *expected post-harvest farmgate maize price* for both maize sellers and non-sellers.[6] We then use the expected maize price to indirectly measure the effect of NCPB activities on output supply and factor demand, as mediated through NCPB's effects on expected farmgate sales prices of maize.

We also include the *expected post-harvest wholesale price* for each competing non-maize crop. Due to data limitations, we use a naïve price expectation for each crop which is the wholesale price of that crop during the marketing period in the year prior to planting. Input prices include the *log price of fertilizer*, which is the district median price of DAP fertilizer reported by households, and also the *log rural wage*, which is the village median wage as reported by households.[7] Additional variables in each of the output regressions include quasi-fixed factors related to productive capacity such as: *the number of adults age 15-59* and its square, a dummy for *household ownership of animal traction*, *the log of total landholding* and its square. The *log*

[6] While the price equation includes dummies for buyer types, we do not observe characteristics of sales for non-sellers. Thus, we have to assume that the modal buyer type in each district is the buyer type which would hypothetically be used by all non-sellers in each district (the mode is small private trader in most cases).
[7] The Tegemeo survey instrument inquired of every household regarding the DAP fertilizer price in their village as well as the farm wage.

of the total value of household farm assets (farm equipment and livestock) serves as a proxy for both productive capacity and financial capital.

To control for potential lifecycle and human capital effects on productivity, we include the *age of the household head (years,* and *education of the household head (years)*, respectively, as well as a binary variable which =1 if the *household is headed by a single female* a binary variable which =1 if the *household suffered the death of an adult age 15-59 within the past 3 years*. Due to our assumption of non-separability of consumption and production decisions for Kenyan households, the output supply functions (and input demand) also include measures of household consumption characteristics including the *number of children age 0-4*, *number of children 5-14* and *number of adults age 60 and over.* Another consumption characteristic already in our model is the *log of the value of farm assets*, which along with *total landholding* is a proxy for household wealth.

We begin our regression analysis of the effects of expected maize prices on output supply at the national level. Anticipating that average maize price responsiveness may differ by agroecological zone, we aggregate agroecological zones into three zones which represent maize-production potential: East & West Lowlands (Low potential); West Transitional, West and Central Highlands (Medium); the High Potential Maize zone (High). We then interact zonal dummy variables with the expected maize price variable to test for differences in price responsiveness across agroecological zones. Next, we interact expected maize price with dummies for terciles of landholding, and then separately with the dummy for households headed by a single female, to see if maize price responsiveness varies by relative wealth levels or by gender of the household head.

4.1.4 Modelling output supply: area planted

Assuming that we find a significant response of household maize production to changes in expected farmgate maize prices, this begs the question of whether the production increases are due to expanded maize area, increased intensification (fertilizer use), or both. In addition, area response models are often used to estimate output supply given that they more clearly represent farmer intentions than harvested production (which is more obviously influenced by weather-related factors in that season). We therefore also estimate models of output supply which measure household area planted to maize.

Most maize area planted by smallholders in Kenya is intercropped, and the nature and extent of intercropping is highly variable across households. While the Tegemeo surveys recorded information on the area of each of a household's fields in a given season, the information recorded concerning intercrops is the name and number of crops planted within a given field as well as the quantity of seed planted to each crop (by field); that is, there was no attempt to have the farmer describe the nature of the intercrop or the effective area planted to each crop within an intercropped field. Given these data limitations, we use two different classification systems to categorize and measure maize area. First, we categorize maize area as intensive or non-intensive, where intensive maize is defined as area planted to maize with a maize seeding rate of 10+ kg of maize seed per acre, while non-intensive has <10 kg of maize seed per acre. Second, we create three categories of maize area intensity based on how many crops are in the same field with maize. The first category includes fields which are monocropped maize or maize with one tree crop. The second category includes fields with maize plus beans or maize plus beans and a third crop. The third category includes any field with maize and a non-bean/non-tree crop or maize with 3+ additional crops.

The area output supply models include all the regressors used in the maize output supply model, except that instead of using cumulative rainfall and drought shock variables, the area output models use *expected rainfall* and *expected drought shock*. Expected rainfall is a six-year moving average of rainfall prior to the season in question, while expected rainfall shock is a six-year moving average of the percentage of 20-day periods during the main growing season with less than 40 mm of rainfall.

4.1.5 Modelling factor demand

As noted above, we would expect farmers to respond to higher expected farmgate maize prices by increasing the amount of fertilizer applied to maize, *ceteris paribus*. To investigate this hypothesis, we estimate a Cragg double-hurdle model of the quantity of fertilizer applied per hectare of maize (Cragg, 1971). Unlike Tobit, the double-hurdle model allows the decisions about whether to use fertilizer and what quantity to use to be determined by different processes, which is consistent with previous research on fertilizer demand in Malawi (Ricker-Gilbert et al, 2011) and Zambia (Xu et al, 2009). The first stage of the double-hurdle for the first model is a Probit regression on a binary variable which =1 if the household used fertilizer on maize, and zero otherwise. The second stage is a lognormal regression on non-zero observations of the log of fertilizer applied to maize. We use the same explanatory variables in each stage of the fertilizer double-hurdle model.

Each of the fertilizer demand models include all the regressors used in the area response models, except that prices of competing crops are not included in the models of fertilizer applied to maize. In addition, these models include a measure of market access, the *distance between the village and the nearest motorable road*, while access to fertilizer is proxied by the *distance between the village and the nearest fertilizer seller.* The models also include four binary variables defined at the village-level for four of the six general *soil-types* found in the villages covered by the Tegemeo surveys, as categorized by Sheahan (forthcoming).

4.2 Estimation issues

4.2.1 Panel attrition

For our econometric work, we only use households which were re-interviewed in each of the Tegemeo panel surveys from 1997 to 2007. To test for panel attrition bias, we follow the regression-based approach described in Wooldridge (2002, p. 585). Only the farmgate maize sale price, maize production, and monocropped maize area models show evidence of attrition bias (Table 2). For these models, we apply sampling weights which correct for panel attrition bias using the Inverse Probability Weighting (IPW) method (Wooldridge, 2002). The attrition-correction factors for the Kenya panel household dataset were computed by Burke et al (2007). Where appropriate, we present econometric results in the following sections which were estimated with and without panel attrition correction factors. In each case, we find that use of these attrition correction factors does not change the significance or general magnitude of the partial effects of interest.

Table 2. Attrition bias test results

Dependent variable	Estimator	p-value for test of H_0: $\beta_{reinterview i,t+1} = 0$ vs H_1: $\beta_{reinterview i,t+1} = 1$
Auxilary regressions		
Quantity of maize sold	Pooled Tobit-CRE	0.130
Farmgate maize sale price	Pooled OLS-CRE	0.018
Output supply regressions (production)		
ln(maize production)	FE	0.030
ln(bean production) (FIQI)	Pooled Tobit-CRE	0.898
ln(root production) (FIQI)	Pooled Tobit-CRE	0.885
ln(vegetable production) (FIQI)	Pooled Tobit-CRE	0.192
ln(perennial production) (FIQI)	Pooled Tobit-CRE	0.445
ln(short-perennial production) (FIQI)	Pooled Tobit-CRE	0.160
ln(total non-maize crop production) (FIQI)	FE	0.720
ln(total crop production) (FIQI)	FE	0.900
ln(total net crop income)	FE	0.744
Output supply regressions (area)		
Maize area planted (ha)	FE	0.360
Intercropped maize area planted (ha)	Pooled Tobit-CRE	0.301
Monocropped maize area planted (ha)	Pooled Tobit-CRE	0.071
Bean area planted (ha)	Pooled Tobit-CRE	0.240
Root crop area planted (ha)	Pooled Tobit-CRE	0.928
Vegetable area planted (ha)	Pooled Tobit-CRE	0.670
Perennial crop area planted (ha)	Pooled Tobit-CRE	0.700
Short perennial crop area planted (ha)	Pooled Tobit-CRE	0.070
Total cultivated area planted (ha)	FE	0.760
Factor demand regressions		
Fertilizer use on maize (probability of use on maize)	Pooled Probit-CRE	0.133
Fertilizer use on maize (quantity/ha of maize)	Pooled TN-CRE	0.286
Fertilizer use on maize (quantity)	Pooled TN-CRE	0.465
Total fertilizer use (probability of use on any crop)	Pooled Probit-CRE	0.973
Total fertilizer use (quantity/ha)	Pooled TN-CRE	0.019
Total fertilizer use (quantity)	Pooled TN-CRE	0.007

Notes: OLS = Ordinary Least Squares; CRE = Correlated random effects; TN = Truncated normal; FIQI = Fisher-Ideal Quantity Index; FE = Household fixed effects

4.2.3 Unobserved household time-constant heterogeneity

The household data set used in this paper is longitudinal, which offers the analytical advantage of enabling us to control for time-constant unobservable household characteristics. We therefore use OLS with household fixed effects (FE) for the regressions of maize production, total crop production, total net crop income and total maize area planted. For output supply of competing crop groups, we use a Tobit, and for factor demand (fertilizer) we use a Cragg double-hurdle model. However, using an FE estimator for a Tobit or double-hurdle model is problematic as the FE Tobit and Probit estimators have been shown to be inconsistent (Wooldridge, 2002), while the FE truncated normal estimator has been shown to be biased when T<5 (Greene, 2004).

We estimate the sale price equation as well as each of the Tobit and double-hurdle models with Correlated Random Effects (Mundlak, 1978; Chamberlain, 1984), which explicitly accounts for unobserved heterogeneity and its correlation with observables, while yielding a fixed-effects-like interpretation. In contrast to traditional random effects, the correlated random effects (CRE) estimator allows for correlation between unobserved heterogeneity (*ci*) and the vector of explanatory variables across all time periods (*Xit)* by assuming that the correlation takes the form of: $c_i = \tau + Xi\text{-}bar\xi + a_i$, where *Xi-bar* is the time-average of *Xit*, with $t = 1, \ldots, T$; τ and ξ are constants, and a_i is the error term with a normal distribution, $a_i | Xi \sim \text{Normal}(0, \sigma^2_a)$. We estimate a reduced form of the model in which τ is absorbed into the intercept term and *Xi-bar* are added to the set of explanatory variables. To facilitate interpretation of the results from the non-linear models such as Tobit and the double-hurdle, we compute average partial effects[8] (APE) for each regressor and use a bootstrap routine to compute the standard errors.[9]

4.2.4 Generated regressors

As noted by Mason (2011), the variable *expected maize price*– which is computed from an auxiliary regression – is considered to be a generated regressor in our output supply and factor demand models. If the partial effect of this variable is statistically significant in a given model, it becomes necessary to bootstrap standard errors for the partial effect of each variable in that model (Wooldridge, 2002). Therefore, in the instances in which we find that the generated regressor (expected maize price) is initially significant in a given model, the standard errors reported for that model have been bootstrapped for use of a generated regressor.

5. ECONOMETRIC ANALYSIS

5.1 Household expectations of the farmgate maize price

The first stage of our analysis concerns how the NCPB maize purchasing activities affect smallholders' expectations of post-harvest farmgate maize prices. The model of household farmgate maize price expectations serves two purposes: the first is to estimate the effect of expected NCPB purchase prices, NCPB purchase volumes, and regional wholesale maize prices on the expected farmgate maize price; the second is to compute household-specific expected farmgate maize prices for use in our output supply and factor demand models. Our OLS regression of the log of household maize sale prices shows that a one-shilling increase in the *effective NCPB purchase price* (approximately an 8% increase) increases the expected farmgate maize price by 1.1% (Table 3). The partial effect of *expected district-level NCPB purchase volume* on the expected maize price is positive, though is insignificant. We also find that the 12 lagged regional wholesale maize prices have a jointly significant effect on the expected maize price [F(12, 760)=4.02; p-value (0.000)]. The sum of the partial effects on the 12 time-varying

[8] Because the effect of an explanatory variable in a nonlinear equation depends on the level of all explanatory variables, not just its own coefficient, analysts typically compute the marginal effects for a given variable using the mean of all regressors. By contrast, we compute the partial effect for each household, and then take the average partial effect across the entire sample (or subsample), and compute bootstrapped standard errors for inference (Wooldridge, 2002).

[9] We replicate our bootstrapping routine 500 times.

Table 3. OLS regression of log of farmgate maize price received by sellers, 1997-2000-2004-2007, Kenya

Independent variables	Dept Variable = ln(farmgate maize price)
1=year 2000	-0.062
	(0.43)
1=year 2004	-0.014
	(0.13)
1=year 2007	-0.277
	(1.59)
6-year average of rainfall during main season	-0.000+
	(1.88)
6-year average of drought shock during main season	0.131
	(0.72)
1=sale quarter is Apr-June	0.019
	(1.07)
1=sale quarter is July-Sept	-0.017
	(0.82)
1=sale quarter is Oct-Dec	-0.027+
	(1.82)
distance to regional wholesale market (km)	0
	(0.82)
distance to nearest motorable road (km)	0.005
	(0.97)
1=buyer type: NCPB	0.069+
	(1.75)
1=buyer type: processor/miller	0.059*
	(2.11)
1=buyer type: other	0.137
	(1.07)
1=buyer type: other household	0.057**
	(3.13)
1=HH owns motorized vehicle	0.019
	(0.53)
1=HH owns bicycle	-0.019
	(1.10)
ln(value of storage assets)	0.003
	(1.29)
ln(total landholding)	0.004
	(0.48)
ln(total value of farm assets)	0.017**
	(3.32)
Age of the HH head (years)	-0.001
	(1.16)
Education level of the HH head (years)	-0.003
	(1.28)

Table 3, Continued

1=HH suffered a prime-age death in previous 4 years	0.022
	(0.64)
1=HH headed by single female	0.063*
	(2.12)
village-level effective NCPB purchase price at planting, KSH/kg	0.011+
	(1.84)
ln(NCPB district-level purchases, last year)	0.005
	(0.46)
ln(NCPB district-level purchases, last year), squared	-0.001
	(0.67)
ln(regional wholesale price in planting month)	-0.657
	(1.11)
ln(regional wholesale price in planting month), t-1 (months)	0.874+
	(1.83)
ln(regional wholesale price in planting month), t-2	-0.164
	(0.74)
ln(regional wholesale price in planting month), t-3	-0.376**
	(3.50)
ln(regional wholesale price in planting month), t-4	0.680*
	(2.04)
ln(regional wholesale price in planting month), t-5	-0.524
	(1.33)
ln(regional wholesale price in planting month), t-6	0.672
	(1.11)
ln(regional wholesale price in planting month), t-7	-0.089
	(0.26)
ln(regional wholesale price in planting month), t-8	-0.358
	(0.88)
ln(regional wholesale price in planting month), t-9	-0.032
	(0.09)
ln(regional wholesale price in planting month), t-10	0.481+
	(1.73)
ln(regional wholesale price in planting month), t-11	-0.227
	(0.69)
residual from Tobit of quantity of household maize sales	0.000*
	(2.02)
Constant	-1.516
	(0.64)
Province dummies included	yes
Correlated Random Effect time-average terms included	yes
Observations	1,658
R-squared	0.25
F-tests	
H_0: Province dummies=0	9.1 (0.000)
H_0: Lagged regional prices=0	4.0 (0.000)
H_0: Buyer types=0	3.8 (0.000)
Overall F(66, 760)	10.5 (0.000)

Notes: Robust t statistics in brackets; + significant at 10%; * significant at 5%; ** significant at 1%

lagged log regional wholesale prices is 0.28, which indicates that a 1% increase in the 12 lagged regional wholesale prices (combined) results in a 0.28% increase in the expected farmgate maize price.

To test the robustness of these results, we also run an OLS regression of farmgate sales prices in levels (with wholesale prices also in levels) and find similar results. For example, we find that a one-shilling increase in the *effective NCPB purchase price* leads to an 0.19 shilling increase in the expected farmgate maize price (p=0.011). As with our first model, we also find that the 12 lagged regional wholesale prices have a jointly significant effect on the expected maize price (F(12, 760)=3.25; p-value (0.000)). The sum of the partial effects of these 12 wholesale prices indicates that a one-shilling increase in the wholesale prices (combined) results in a 0.18 shilling increase in the expected maize price. As before, the *expected district-level NCPB purchase volume* does not have a significant effect on the expected maize price.

This evidence suggests that there are two means by which NCPB activities have a significant effect on smallholders' expectations regarding the farmgate maize price. First, the NCPB purchase price has a direct positive effect on smallholder maize price expectations. Second, NCPB purchases and sales appear to also indirectly affect smallholder maize price expectations indirectly through the positive effect of wholesale price increases on farmgate maize prices. We note that while our analysis does not test for or establish a causal link between NCPB activities and wholesale prices, this was demonstrated by Jayne et al (2008) for the 1995-2004 period in Kenya.

5.2 Household maize production

The second stage of our analysis of the effects of NCPB activities on smallholder behavior concerns how smallholders' factor demand and output supply respond to changes in the expected farmgate maize price. We begin first with an OLS regression of the log of household maize production and find that *log of expected farmgate maize price* has a significant positive and strong effect on the log of maize production, as a 1% increase in the expected farmgate maize price increases household maize output by 2.1% (Table 4). The significance and magnitude of the responsiveness of household maize production to changes in the expected maize price is robust to use (or not) of attrition correction weights (Table 4).

We also find a strong link between fertilizer prices and maize output, as a 1% increase in the *log of fertilizer price* results in a 1.2% decrease in maize output (Table 4). The results also highlight the sensitivity of maize production to rainfall, as we find that a 20% increase in the *percentage of 20-day periods with less than 40 mm rain* leads to a 14% decrease in maize output.[10] We do not find a significant effect of single-female headship on maize production.

[10] Because this variable is a percentage which ranges from 0 to 1, a one-unit change in this variable represents its entire range of this variable and thus an unreasonably large change. Thus, standard practice when dealing with a fractional variable is to multiply a smaller change (say 20%, or the variable's standard deviation) by the coefficient to arrive at something closer to a marginal effect. In this case, 0.20*0.72 = 0.14.

Table 4. OLS regression of household maize production, Kenya, 1997-2000-2004-2007

Independent variables	Dept variable = household maize produced)	
	Without attrition correction	With attrition correction
1=year 2000	-0.012	-0.021
	0.996	0.993
1=year 2004	2.294	2.263
	0.172	0.171
1=year 2007	1.210	1.173
	0.746	0.751
rainfall in the main season	0.000	0.000
	0.427	0.460
drought shock in the main season	-0.729	-0.715
	0.016	0.018
ln(expected farmgate maize price)	2.178	2.141
	0.017	0.019
ln(village agricultural labor wage)	-0.020	-0.020
	0.813	0.813
ln(price of DAP fertilizer)	-1.238	-1.212
	0.073	0.078
ln(regional wholesale price of beans)	2.749	2.672
	0.350	0.360
ln(regional wholesale price of cowpeas)	1.622	1.637
	0.130	0.124
ln(regional wholesale price of sweet potatoes)	0.699	0.657
	0.420	0.444
ln(regional wholesale price of irish potatoes)	-1.943	-1.912
	0.005	0.005
ln(regional wholesale price of cassava)	-1.454	-1.402
	0.288	0.299
ln(regional wholesale price of kale)	-0.965	-0.938
	0.182	0.192
ln(regional wholesale price of onions)	-3.016	-2.953
	0.076	0.080
ln(regional wholesale price of tomatoes)	2.301	2.252
	0.012	0.013
ln(district median farmgate price of coffee cherries)	0.093	0.098
	0.469	0.454
ln(regional wholesale price of avocado)	0.018	0.036
	0.977	0.954
ln(regional wholesale price of mangos)	0.896	0.893
	0.053	0.053
ln(regional wholesale price of banana)	-0.030	-0.069
	0.941	0.866

Table 4, Continued

ln(district median farmgate price of sugar cane)	-0.882	-0.835
	0.433	0.455
ln(land area owned)	0.223	0.221
	0.000	0.000
ln(land area owned, squared)	0.027	0.028
	0.176	0.166
effective # of adults age 15-59	0.118	0.118
	0.034	0.036
effective # of adults age 15-59, squared	-0.010	-0.011
	0.139	0.138
ln(total value of farm assets)	0.012	0.013
	0.514	0.468
1=HH owns animal traction	0.165	0.171
	0.091	0.080
head's age	0.004	0.005
	0.323	0.303
head's education	0.012	0.012
	0.198	0.190
1=HH head is a single female	-0.116	-0.113
	0.302	0.316
1=HH suffered the death of an adult age 15-59	-0.078	-0.075
	0.606	0.617
# of children age 0-4	-0.014	-0.017
	0.467	0.397
# of children age 5-14	0.020	0.021
	0.127	0.115
# of adults age 60+	0.098	0.098
	0.011	0.012
Constant	-10.103	-10.013
	0.646	0.646
Observations	4550	4550

Notes: Model includes household-level fixed effects. Results include the partial effect of each variable and its p-value underneath

We next investigate whether or not the maize price responsiveness of household maize production varies by agroecological zone, terciles of total landholding, and headship status. *A priori*, we might expect farmers in higher potential zones to be more responsive to changes in expected maize prices given that their land is likely to be more productive. We may also expect those in higher landholding terciles to be more responsive to maize prices due to larger land endowments as well as the financial means to obtain additional land and labor as needed. However, because we are separately controlling for long-term average landholding and total farm asset value, a significant effect of a maize price-tercile interaction term would indicate that households in higher landholding terciles are more responsive to changes in the expected maize price due to unobserved factors (such as farm management skill or soil quality). Finally, if households headed by a single female are disadvantaged in terms of factors which are not already controlled for in this specification (i.e. landholding, total asset value, head's education, etc), such as farm management skills, we might expect to find that they are less price responsive than male-headed households.

To test the hypothesis that maize price responsiveness varies by zone, we interact zonal dummies with the expected maize price variable. Our results show that the partial effect of the expected maize price on maize production for the base category – households in the lower potential zones – is not significant and relatively small in magnitude (Table 5). While the maize price-zonal interaction terms for both the medium and high potential zones are not significant (the interaction term for the medium zone is nearly significant at p=0.12), the magnitude of their partial effects suggests that maize responsiveness is considerably higher in the medium and high potential zones relative to the low potential zones.

We next interact dummies for households in the upper two terciles of total household landholding (i.e. the long-term average of total landholding across the panel years) with the expected maize price. While we find that households with more land have significantly higher responsiveness to maize prices, the magnitude of these interaction effects are quite small (Table 5). For example, compared with a household in the lowest land tercile, who responds to a 1% increase in the expected maize price by increasing maize production by 2.07%, a household in the middle tercile increases maize production by 2.13%.

Table 5. Responsiveness of maize production to changes in expected maize prices by agroecological zone and by asset level, Kenya, 1997-2000-2004-2007

	Dept variable = ln(household maize produced)		
Interaction effects by subgroup	Regressor: ln(expected maize price)		
	PE	**SE**	**p-value**
Low potential zones (base)	0.266	1.493	0.858
Medium potential zones	2.415	1.562	0.122
High potential maize zone	2.145	1.669	0.199
Land tercile-low (base)	2.068	0.925	0.025
Land tercile-med	0.059	0.033	0.075
Land tercile-high	0.096	0.047	0.041
Male-headed (base)[1]	1.997	0.926	0.031
Female-headed, single	1.052	0.602	0.081

Notes: 1) Male-headed category also includes a small number of female-headed households with a non-resident spouse. Regressions includes all variables in the model presented in Table 6.2 and household fixed effects. PE=partial effect, SE=standard error. Standard errors bootstrapped to account for generated regressor.

Finally, we interact the binary variable for single-female-headed households with the maize price variable, and find that while a male-headed household responds to a 1% increase in the expected maize price by increasing maize production by 2.0%, those headed by a single female increase maize production by 3.0%. One explanation for this surprising result could be that if households headed by a single female have fewer potential cash-generating activities than those headed by men (since men tend to have higher education and thus more off-farm opportunities, as well as being more likely to grow and market traditional or non-traditional cash crops), selling maize may be one of the few means of earning cash income for households headed by a single female.

5.3 Household area planted to maize

Given that we earlier found a significant and strong response of household maize production to changes in expected farmgate maize prices, this suggests that such production increases area due to expanded maize area, increased intensification (via fertilizer use), or both. We next use Tobit regressions to investigate how maize area responds to changes in expected maize prices. We run separate regressions for different types of intensity of maize cultivation – such as for maize monocrop and different types of maize intercrops – as described in Section 4.2.4.

Table 6. Responsiveness of household maize area to changes in the log expected farmgate maize price, by maize cropping system, Kenya, 1997-2000-2004-2007

Categories of maize area	Estimator	Dept variable = hectares planted to maize Regressor: ln(expected maize price)		
		APE	**SE**	**p-value**
Total maize area	OLS-FE	-0.223	0.768	0.772
Intensive maize area	Pooled Tobit-CRE	1.701	0.556	0.002
Non-intensive maize area	Pooled Tobit-CRE	-1.714	0.676	0.011
Category (1): Maize monocrop OR maize with tree crop	Pooled Tobit-CRE	-0.327	0.402	0.417
Category (2): maize with beans OR maize with beans + third crop	Pooled Tobit-CRE	1.771	1.156	0.126
Category (3): maize with non-bean crop OR maize with 3 other crops	Pooled Tobit-CRE	-0.300	1.024	0.769

Notes: Regressions include all variables in Table 6.2, though the rainfall variables are in this case expected rainfall and expected rainfall shock, and the Tobit regressions include time-average terms as well. APE=average partial effect, SE=standard error.

The partial effect of the expected maize price on total household maize area is insignificant and surprisingly has a negative sign (Table 6). The only significant effects of expected maize prices on area planted to maize appear to be found in the regressions of intensive and non-intensive maize area; these results suggest that households shift from non-intensive maize area to intensive maize area as the expected maize price increases (Table 6). Given these two results, it is surprising that household area planted to maize monocrop does not respond positively to an increase in the expected maize price. Yet, given that only 15% of households plant maize in a monocrop, it is perhaps more instructive to focus on the response of the two different categories of maize intercrops – those with maize/beans and potentially a third crop (Category 2), or those with maize with a non-bean crop or 3 other crops (or more) (Category 3) (Table 6). While the maize price partial effect is not significant for either group, the effect on Category 2 maize intercropped area has a positive sign, a rather large magnitude, and is nearly significant (p=0.126). The partial effect of the expected maize price is also insignificant for area planted to Category 3 (a less intensive maize intercrop), yet its sign is negative. While neither of these latter two results is significant, they nevertheless appear to be consistent with a general shift in the maize seeding rate from lower to higher levels as the expected maize price increases.

5.4 Fertilizer use on maize

Given that we earlier found a significant and strong response of household maize production to changes in expected farmgate maize prices, and that the responsiveness of smallholders' maize area to maize price is limited to higher seeding rates within maize intercrops, this suggests that maize production increases are due to increased fertilizer use on maize. We next investigate the extent to which smallholder fertilizer use on maize responds in the expected maize price. Results from our double-hurdle model of household fertilizer applied to maize show that the average partial effect (APE) of fertilizer price on probability of fertilizer use on maize is negative though insignificant (Table 7). Fertilizer price has a strong and significant negative effect on quantity of fertilizer used, as a 1% increase in the fertilizer price decreases fertilizer applied to maize by -0.87% among current fertilizer users (the conditional quantity effect) and by -1.39% among any given household (i.e. among current users or non-users; the unconditional effect) (Table 7).

Our principal partial effect of interest is that of the expected maize price. We find that a 1% increase in the expected farmgate maize price leads to a significant 0.4 point increase in the probability of fertilizer use, which amounts to approximately a 0.5% increase in the probability of fertilizer use on maize (Table 7). The partial effects of the expected maize price on quantities of fertilizer applied to maize are also significant and large, as a 1% increase in the expected maize price leads to a 1.2% increase in the conditional quantity of fertilizer applied to maize and a 2.5% increase in the unconditional quantity applied (Table 7).

In previous sections, we have found evidence that smallholders respond to higher expected farmgate maize prices by increasing maize production. These increases appear to be driven by a combination of higher maize seeding rates (within maize intercrops) and increased quantities of fertilizer applied to maize. This line of reasoning is consistent with descriptive results which demonstrate that mean household maize production, the percentage of households using fertilizer on maize, and quantities of fertilizer applied have all increased steadily between 1997 and 2007, while total maize area planted (not adjusted for seed rate) has remained relatively stable over time (Appendix Tables A-2 & A-3).

An important and timely question for policymakers is the issue of whether poorer households require financial assistance in order to gain access to fertilizer, such as through a subsidized input voucher. While both asset levels and landholding have a significant positive effect on the probability of using fertilizer on maize (Table 7), the magnitudes of the effects are very small. In addition, the partial effects of both farm asset levels and total landholding on conditional and unconditional fertilizer quantity used are not significant. Given these results and the fact that 75% of rural smallholders in Kenya used fertilizer in maize in 2007, this suggests that there is only a relatively small minority of households who appear to face financial constraints to using fertilizer on maize.

Table 7. Double-hurdle model of log household fertilizer applied per hectare of maize, 1997-2000-2004-2007, Kenya

Independent variables	Probit: Dept variable = 1 if HH used fertilizer on maize, 0 otherwise — APE of x_j on P(y>0)			Lognormal: Dept variable = ln(kgs of fertilizer applied per hectare of maize) — APE (Conditional) of x_j on y, given y>0			APE (Unconditional) effect of x_j on y		
	APE	**SE**	**p-value**	**APE**	**SE**	**p-value**	**APE**	**SE**	**p-value**
1=2000	-0.069	0.078	0.377	-17.284	16.656	0.299	-15.636	11.146	0.161
1=2004	-0.022	0.054	0.685	-6.342	13.795	0.646	-5.624	9.380	0.549
1=2007	0.000	0.054	0.997	5.280	16.170	0.744	3.643	10.988	0.740
1=high humus / highly productive soils	-0.040	0.060	0.508	13.735	10.994	0.212	6.955	9.255	0.452
1=Regosols soils	0.017	0.080	0.826	-14.100	17.365	0.417	-8.842	14.063	0.530
1=very shallow, poor drainage soils	0.046	0.062	0.458	-53.146	7.265	0.000	-36.008	6.247	0.000
1=soil with high clay & poor drainage	-0.319	0.133	0.016	-9.963	51.624	0.847	-25.490	28.648	0.374
6-year average of rainfall in main season	0.000	0.000	0.554	0.001	0.000	0.019	0.000	0.001	0.425
6-year average of drought shock in main season	0.215	0.143	0.133	0.197	0.480	0.681	0.885	0.799	0.268
ln(expected farmgate maize price)	0.409	0.151	0.007	1.232	0.438	0.005	2.542	0.748	0.001
ln(village wage)	-0.007	0.022	0.752	-0.038	0.091	0.679	-0.060	0.119	0.613
ln(village price of DAP fertilizer)	-0.156	0.121	0.198	-0.183	0.342	0.593	-0.683	0.539	0.205
distance to nearest motorable road (km)	-0.001	0.006	0.832	-0.026	0.030	0.377	-0.031	0.040	0.448
distance to nearest fertilizer seller	0.001	0.001	0.194	-0.001	0.007	0.845	0.003	0.007	0.711
ln(total land area owned)	0.016	0.006	0.007	-0.016	0.033	0.628	0.021	0.036	0.556
effective # of adults age 15-59	-0.002	0.010	0.851	0.025	0.017	0.141	0.029	0.021	0.171
ln(total farm asset value)	0.003	0.004	0.542	-0.005	0.017	0.785	0.004	0.023	0.876
Education level of the household head	0.006	0.003	0.027	0.001	0.007	0.923	0.019	0.011	0.099
Age of the household head	0.000	0.001	0.823	0.004	0.003	0.213	0.004	0.005	0.444
1=HH head is single female	-0.034	0.027	0.206	-4.927	7.723	0.524	-5.364	5.613	0.339
1=HH suffered the death of an adult age 15-59	-0.042	0.046	0.363	2.562	9.831	0.794	-0.829	6.520	0.899
# of children age 0-4	0.007	0.006	0.245	0.029	0.021	0.180	0.050	0.026	0.054
# of children age 5-14	-0.001	0.004	0.864	-0.004	0.017	0.823	-0.006	0.024	0.802
# of adults age 60+	0.012	0.012	0.298	-0.046	0.051	0.362	-0.007	0.061	0.904
cases		4524			3136			4524	

Model includes dummies for zone and for the years 2000, 2004, 2007. Also included are time-average terms for each of the time-varying regressors. APE= average partial effect, SE= standard error (bootstrapped). Attrition-correction weights applied.

5.5 Production of other crops

Our finding of strong effects of expected maize prices on maize production, combined with mixed evidence of shifts towards higher maize seeding rates within maize intercropped area, begs the question of whether such increases are coming at the expense of the production of other crops, either through less area planted or fertilizer applied to non-maize crops. Alternatively, if maize production increases are accomplished without reducing either area planted or fertilizer applied to other crops, it is possible that increased maize production could result in an increase in total crop production. In this section, we investigate whether or not changes in the expected maize price affect household output of other crops as well as total crop production. As noted in the descriptive analysis section, we only consider production of non-maize crops in 2000, 2004 and 2007 due to apparent under-reporting of non-maize crops in 1997.

We find that the expected maize price has a strong, significant positive effect on bean-cowpea production (Table 8). None of the other non-maize crop groups respond significantly to changes in the expected maize price, though the sign on the maize price effect on root crop production is negative. These results are consistent with the fact that beans and cowpeas are often intercropped with maize in Kenya, while root crops are less likely to be so. Another potential explanation is that as fertilizer application on maize has increased, this may have benefited bean/cowpeas which are intercropped with maize in the same field (depending upon the nature of the intercrop).

Table 8. Responsiveness of household crop production to changes in the expected maize price, by household crop group, Kenya, 2000-04-07

Crop group	Dept variable = FI index of crop group production; Regressor: ln(expected maize price) APE	SE	p-value
Bean-cowpea	579.1	198.8	0.004
Root crops	-19.9	57.5	0.729
Vegetables	51.3	62.5	0.411
Perennials	24.1	49.7	0.628
Short Perennials	317.3	431.9	0.463
Total non-maize crop production[1]	95.3	62.7	0.128
Total crop production[1]	331.2	121.3	0.006

Notes: 1) Total non-maize and crop output regressions use OLS with household fixed effects. All other results are derived from pooled Tobit regressions with CRE. Regressions use all variables reported in the maize output model. APE=average partial effect; SE=standard error. n=3402 cases in each regression.

The effect of the expected maize price on total non-maize crop production is positive and nearly significant (p=0.12), a result which appears to be driven by the high responsiveness of beans/cowpeas to the expected maize price. The effect of the expected maize price on total crop production (including maize) is significant, positive and large, which is not surprising given the strong response of both maize and bean/cowpea production to changes in the expected maize price. In summary, the evidence in Table 8 does not suggest that increases in maize production are not resulting in a decline in production of other crops.

5.6 Total household net crop income

In previous sections, we have found evidence that smallholders respond to higher expected farmgate maize prices by increasing maize production, and that these increases appear to be driven by a combination of higher maize seeding rates (within maize intercrops) and increased quantities of fertilizer applied to maize. Because the mean of total household area cultivated is approximately the same in 2007 as it was in 1997 (Appendix Table A-2), and because we do not find evidence that non-maize crop production has fallen significantly, this suggests that increases in maize production have largely been driven by increases in fertilizer applied to maize. While we would expect that rural households would only apply additional fertilizer to maize if the net benefit of doing so were positive, we can test this assumption by investigating whether or not higher expected maize prices lead to increases in total household net crop income.

Defining total net crop income as gross household crop income minus costs incurred for land preparation and fertilizer, we estimate an OLS regression of the log of total net crop income. We find that the expected maize price has a large and significant effect on total net crop income, as a 1% increase in the expected maize price increases total household net crop income by 1.9% (Table 9). This result is perhaps not surprising given that maize is grown by 99% of rural households and is the principal food staple crop. However, our ability to infer changes in the welfare of rural households from changes in total net crop income is limited, as this variable only measures the total value of crops produced by a rural household – not household total income, which also includes income from livestock and non-farm activities. In addition, because the majority of rural Kenyan smallholders are net buyers of maize, higher household farm income may not translate into higher expenditure if the costs of meeting the household's food consumption needs are also higher.

A question for further research is how NCPB price support policies, which have been shown to result in higher and more stable maize prices (Jayne et al, 2008), affect rural household welfare. While the standard welfare analysis of policies which increase a commodity's price usually predicts a transfer of economic surplus from consumers to producers, as well as a net reduction in societal welfare due to dead-weight losses, there would likely be some societal benefit from more stabile maize prices. In addition, analysis of the effects of higher maize prices on rural household welfare is complicated by the fact that nearly every rural Kenyan smallholder produces and consumes maize. Nevertheless, a study which takes this into consideration found that higher maize prices (due to NCPB price support policies) lead to increased poverty headcounts and/or lower household income in every region except for the high potential zone (Mghenyi, 2011). This finding is not surprising given that only 40% of Kenyan smallholders are net maize sellers, and that most of the net sellers are in the high potential zone. Another question for future research is whether or not the reduction in maize price variation over the past decade attributable to NCPB activities has had a positive effect on fertilizer demand.

Table 9. OLS regression of total household net crop income, Kenya, 1997-2000-2004-2007

Independent variables	Dept variable = ln(total household net crop income)
1=year 2000	-0.046
	0.979
1=year 2004	1.115
	0.411
1=year 2007	-0.730
	0.805
rainfall in the main season	0.000
	0.080
drought shock in the main season	-0.077
	0.754
ln(expected farmgate maize price)	1.934
	0.014
ln(village wage)	-0.002
	0.981
ln(price of DAP fertilizer)	0.113
	0.808
ln(price of beans)	3.165
	0.154
ln(price of cowpeas)	1.505
	0.040
ln(price of sweet potatoes)	0.430
	0.526
ln(price of irish potatoes)	-1.349
	0.019
ln(price of cassava)	-0.174
	0.871
ln(price of kale)	-0.400
	0.430
ln(price of onions)	-2.751
	0.024
ln(price of tomatoes)	1.275
	0.066
ln(price of coffee cherries)	0.068
	0.457
ln(price of avocado)	-0.750
	0.123
ln(price of mangos)	1.017
	0.002
ln(price of banana)	-0.269
	0.432

Table 9, Continued

ln(price of sugar cane)	0.843
	0.321
ln(land area owned)	0.256
	0.000
ln(land area owned), squared	0.040
	0.081
effective # of adults age 15-59	0.014
	0.597
effective # of adults age 15-59, squared	0.002
	0.524
ln(total value of farm assets)	0.022
	0.208
1=HH owns animal traction	-0.046
	0.581
head's age (years)	0.008
	0.040
head's education (years)	0.010
	0.083
1=HH head is single female	-0.195
	0.043
1=HH suffered the death of an adult age 15-59	-0.036
	0.763
# of children age 0-4	0.003
	0.882
# of children age 5-14	-0.003
	0.777
# of adults age 60+	0.035
	0.236
Constant	-16.386
	0.326
Observations	4360

Notes: Model includes household-level fixed effects. Results presented are the the partial effect of each regressor and its p-value underneath.

6. CONCLUSIONS

Despite the resurgence of parastatal grain marketing boards in eastern and southern Africa over the past decade, there remains little empirical research based on household-level data which investigates how marketing board activities affect the input use and cropping decisions of smallholder farmers in the region. This paper uses micro-level panel survey data of smallholders in rural Kenya from 1997 to 2007 to investigate the effect of the activities of Kenya's National Cereal Produce Board (NCPB) on smallholders' farm-gate maize price expectations, input use and cropping decisions. There are six main findings from our econometric analysis.

First, we find that NCPB activities have both a direct and indirect effect on smallholders' farmgate maize price expectations. For example, an 8% increase in the NCPB purchase price leads to a 1.1% increase in the expected farmgate maize price. In addition, NCPB purchases and sales appear to indirectly affect smallholder maize price expectations through the positive effect of regional wholesale maize prices on expected farmgate maize prices. We note that while our analysis does not test for or establish a causal link between NCPB activities and regional wholesale maize prices, this was demonstrated by Jayne et al (2008) for the 1995-2004 period.

Second, we find evidence of strong responsiveness of smallholder maize production to changes in the expected farmgate maize price, as a 1% increase in the expected maize price increases household maize production by 2.1%. Though the magnitude of the partial effects of the expected maize price on maize production are considerably larger for smallholders in medium and higher potential agroecological zones (relative to those from lower potential zones), the differences are not significant. While we find that households in the upper two terciles of total landholding have significantly higher responsiveness to maize prices, the magnitude of these interaction effects are quite small. Surprisingly, we find that households headed by a single female have significantly larger maize price responsiveness relative to male-headed households. Because our analysis controls for landholding, farm assets and education of the head separately, this may indicate that households headed by a single female are more likely to use maize as a cash-generating activity than other households.

Third, we find significant and large positive effects of expected maize prices on the probability of smallholder fertilizer use on maize and conditional and unconditional quantities applied. For example, we find that a 1% increase in the expected farmgate maize price leads to a 0.5% increase in the probability of fertilizer use on maize, and increases of 1.2% and 2.4% in conditional and unconditional quantities of fertilizer applied. We also find that the effects of household total farm assets and total landholding probability of fertilizer use on maize are positive and significant but of negligible magnitude, and that these factors do not have significant effects on conditional or unconditional fertilizer quantities used. This evidence, along with widespread fertilizer use in Kenya, suggests that there are only a small minority of households which appear to have financial constraints preventing them from using fertilizer on maize.

Fourth, we find that while increases in the expected farmgate maize price do not elicit increases in total maize area cultivated, we do find evidence that smallholders increase their maize seeding rates in intercropped fields in response to higher expected maize prices. Fifth, while we find that smallholders respond to higher expected maize prices by increasing maize production, we do not find evidence that higher expected maize prices lead to reductions in non-maize crop production. This suggests that increases in maize production do not appear to be coming at the expense of production of other crops, and are instead largely driven by increased fertilizer use on maize. This line of reasoning is consistent with descriptive analysis which demonstrates that mean household maize production, the percentage of households using fertilizer on maize, and quantities of fertilizer applied have all increased steadily between 1997 and 2007, while total maize area planted has remained relatively stable over time. Sixth, the net benefits of increased fertilizer use appear to be positive, as we find a significant positive effect of the expected farmgate maize price on total net crop income.

In summary, we find that NCPB activities have a significant effect on smallholders' expected farmgate maize prices, which combined with our other results implies that a one-unit (8%)

increase in the NCPB purchase price leads to: a) a 2.1% increase in household maize production; b): an 0.5% increase in the probability of fertilizer use on maize; and c) increases of 1.2% and 2.4% in conditional and unconditional quantities of fertilizer applied to maize. Increases in smallholder maize production appear to be coming primarily from increased fertilizer use on maize, and to a lesser extent from increased maize seeding rates within intercropped fields. Remaining questions for further research include how NCPB activities, which have been shown to result in higher and more stable maize prices (Jayne et al, 2008), affect societal welfare and fertilizer demand.

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Appendix Table A-1. Tobit regression of the household quantity of maize sold, Kenya 1997-00-04-07

Independent variables	Dependent Variable is the HH quantity of maize sold >=0 Unadjusted coefficients
1=year 2000	317.25
	(1.12)
1=year 2004	92.415
	(0.35)
1=year 2007	261.433
	(0.76)
Rainfall during main season (mm)	0.738
	(1.20)
% of 20-day periods during main season with <40 mm rain	-1,829.792**
	(2.78)
distance to nearest motorable road (km) (village median)	169.280**
	(3.20)
farmgate maize price (district median), KSH/kg	189.551**
	(3.08)
village-level effective NCPB purchase price at planting, KSH/kg	88.990*
	(2.19)
ln(NCPB district-level purchases, last year)	-86.209
	(1.25)
ln(NCPB district-level purchases, last year), squared	10.342
	(1.45)
effective # adults age 15-59	-94.158
	(1.00)
effective # adults age 15-59, squared	6.714
	(0.63)
ln(total household land owned)	337.416**
	(3.82)
ln(total household land owned), squared	117.720+
	(1.75)
ln(total farm asset value)	104.513*
	(2.52)
ln(value of irrigation equipment)	609.712+
	(1.79)
1=HH owns motorized vehicle	359.192
	(0.96)
1=HH owns bicycle	330.079*
	(2.15)
ln(value of storage assets)	45.833**
	(2.72)
Education of the HH head	28.721
	(1.38)

Appendix Table A-1, Continued

Age of the HH head	4.046
	(0.45)
# of children 0-4	-106.897
	(1.41)
# of children 5-14	-103.078**
	(2.61)
# of adults 60+	17.247
	(0.14)
1=HH headed by single female	833.756**
	(2.66)
1=HH suffered a prime-age death in previous 3 years	395.924
	(1.10)
Constant	3,064.71
	(0.96)
District dummies included	yes
Correlated Random Effect Time-average terms included	yes
Observations	4,464

Notes: Robust t statistics in brackets; + significant at 10%; * significant at 5%; ** significant at 1%

Appendix Table A-2. Summary statistics of dependent variables

		1996/97		1999/00		2003/04		2006/07	
Dependent variables	Obs.	mean	SE	mean	SE	mean	SE	mean	SE
Auxilary regressions									
Quantity of maize sold (kg)	4,464	495.9	1919.7	676.6	2746.6	728.1	1827.8	814.2	2196.0
Farmgate maize sale price (Ksh/kg)	1,658	2.402	0.261	2.495	0.235	2.551	0.221	2.488	0.204
Output supply regressions (production)									
maize production (kg)	4,550	1080.7	2513.8	1386.2	3527.7	1519.9	2503.7	1672.1	3037.0
ln(maize production)	4,550	5.9	1.6	6.2	1.6	6.5	1.4	6.7	1.3
bean production (FIQI)	4,556	176.9	321.0	198.6	386.4	189.6	306.2	150.8	219.9
root production (FIQI)	4,556	39.6	90.0	75.2	233.7	56.7	111.5	37.9	73.2
vegetable production (FIQI)	4,556	31.3	152.0	62.0	191.9	60.7	185.5	39.9	124.0
perennial production (FIQI)	4,556	38.7	157.0	81.8	273.3	68.4	203.2	43.0	99.6
short-perennial production (FIQI)	4,556	243.6	800.7	635.3	1858.0	354.5	1341.7	311.5	980.4
total non-maize crop production (FIQI)	4,556	97.7	144.1	148.2	235.7	152.5	191.8	130.0	156.4
total crop production) (FIQI)	4,556	57.1	83.9	104.1	182.3	92.7	164.9	64.8	75.9
total net crop income (Ksh)	4,556	42310	74039	77808	107030	67817	82244	72070	78247
ln(total net crop income)	4,360	9.90	1.36	10.64	1.21	10.58	1.13	10.72	1.01
Maize area planted (ha)	4,556	1.697	2.149	1.969	2.451	1.675	1.786	1.631	2.137
Intensive maize area planted (ha)	4,556	0.967	1.914	1.423	2.328	0.684	1.380	0.822	1.734
Less-intensive maize area planted (ha)	4,556	0.737	1.500	0.558	1.272	1.003	1.539	0.826	1.645
Monocrop maize + tree crop	4,556	0.308	1.571	0.252	1.645	0.184	0.824	0.263	1.153
Intercrop category 2 area (ha)	4,556	1.099	1.508	0.696	1.341	0.852	1.306	0.667	1.470
Intercrop category 3 area (ha)	4,556	0.290	1.035	1.021	1.541	0.639	1.238	0.701	1.387
Bean area planted (ha)	4,556	0.560	0.841	0.674	0.784	0.575	0.749	0.566	0.930
Root crop area planted (ha)	4,556	0.134	0.256	0.243	0.445	0.203	0.356	0.167	0.367
Vegetable area planted (ha)	4,556	0.042	0.138	0.126	0.398	0.073	0.137	0.060	0.115
Perennial crop area planted (ha)	4,556	0.104	0.281	0.389	0.676	0.233	0.381	0.298	0.468
Short perennial crop area planted (ha)	4,556	0.205	0.443	0.358	0.589	0.245	0.485	0.261	0.510
Total cultivated area planted (ha)	4,556	1.357	1.706	1.597	2.903	1.455	1.457	1.324	1.315
Factor demand regressions									
1=HH used inorganic fertilizer on maize	4,524	0.609	0.014	0.682	0.014	0.723	0.013	0.759	0.013
Fertilizer use on maize (kg/ha of maize)	4,524	48.2	3.3	45.9	2.6	59.6	3.9	65.2	4.0
ln(fertilizer use on maize, kg/ha)	4,524	2.311	0.060	2.570	0.058	2.781	0.058	2.956	0.056
1=HH used inorganic fertilizer	4,556	0.679	0.014	0.748	0.013	0.775	0.012	0.813	0.012
Total fertilizer use (kg/ha)	4,556	120.9	5.4	146.3	5.6	136.7	4.9	146.6	4.7
ln(total fertilizer use, kg/ha)	4,556	3.163	0.070	3.555	0.069	3.610	0.066	3.872	0.063

Appendix Table A-3. Summary statistics of independent variables by model

		1996/97		1999/00		2003/04		2006/07	
Independent variables	Model	mean	SE	mean	SE	mean	SE	mean	SE
Village-level variables									
rainfall in the main season		645.4	242.1	622.1	255.5	736.8	261.9	626.8	196.2
extent of drought shock in main season		0.235	0.232	0.242	0.227	0.227	0.242	0.283	0.203
6-year average of main season rainfall	A, F	568.2	196.7	618.3	149.6	581.3	144.0	521.6	181.7
6-year average of extent of main season drought shock	A, F	0.311	0.221	0.274	0.207	0.276	0.197	0.327	0.223
distance to regional wholesale market (km)	A	76.1	47.5	76.3	47.3	76.1	47.6	75.6	47.4
distance to nearest motorable road (km)	A, F	1.1	0.0	1.0	0.0	1.0	0.0	0.5	0.0
distance to nearest fertilizer seller (km)	F	6.3	0.3	4.4	0.2	3.1	0.1	2.9	0.1
1=high humus / highly productive soils	F	0.183	0.011	0.185	0.012	0.183	0.012	0.185	0.012
1=Regosols soils	F	0.246	0.013	0.243	0.013	0.247	0.013	0.248	0.013
1=very shallow, poor drainage soils	F	0.022	0.004	0.021	0.004	0.022	0.004	0.021	0.004
1=soil with high clay & poor drainage	F	0.069	0.008	0.068	0.007	0.069	0.008	0.069	0.008
Household maize sale characteristics									
1=sale quarter is Jan-Mar	A	0.109	0.016	0.139	0.016	0.371	0.021	0.369	0.021
1=sale quarter is Apr-June	A	0.068	0.013	0.042	0.009	0.220	0.018	0.190	0.017
1=sale quarter is July-Sept	A	0.272	0.023	0.000	0.000	0.143	0.016	0.148	0.016
1=sale quarter is Oct-Dec	A	0.552	0.026	0.819	0.018	0.267	0.020	0.292	0.020
1=buyer type: NCPB	A	0.027	0.008	0.013	0.005	0.024	0.007	0.023	0.007
1=buyer type: processor/miller	A	0.019	0.007	0.004	0.003	0.025	0.007	0.012	0.005
1=buyer type: other	A	0.005	0.004	0.000	0.000	0.004	0.003	0.000	0.000
1=buyer type: other household	A	0.242	0.022	0.263	0.021	0.218	0.018	0.240	0.019
Household productive/marketing assets and demographics									
ln(total landholding)	A, O, F	0.300	1.024	0.144	1.015	0.448	0.892	0.393	0.885
ln(total landholding), squared	A, O, F	1.137	1.485	1.049	1.373	0.994	1.528	0.937	1.441
ln(total value of farm assets)	A, O, F	10.2	1.7	9.8	2.6	10.2	2.1	10.4	1.9
1=HH owns animal traction	A	0.095	0.009	0.138	0.010	0.065	0.007	0.092	0.009
ln(value of irrigation equipment)	A	0.120	0.325	0.133	0.340	0.108	0.311	0.104	0.305
1=HH owns motorized vehicle	A	0.032	0.175	0.043	0.203	0.047	0.213	0.049	0.216
1=HH owns bicycle	A	0.415	0.493	0.436	0.496	0.470	0.499	0.498	0.500
ln(value of storage assets)	A	3.392	4.209	3.383	4.147	3.206	4.207	3.122	4.303
Age of the HH head (years)	A, O, F	6.3	4.3	6.4	4.2	6.8	5.5	8.0	3.7
Education level of the HH head (years)	A, O, F	51.0	13.3	53.4	13.1	56.6	13.2	58.9	13.2
1=HH headed by single female	A, O, F	0.120	0.325	0.120	0.325	0.193	0.395	0.221	0.415
1=HH suffered a prime-age death in previous 4 years	A, O, F	0.000	0.000	0.065	0.247	0.057	0.232	0.048	0.214

Notes: A = auxiliary regressions (maize quantity sold; maize sale price); O = output supply regressions; F = fertilizer demand regressions

Appendix Table A-3, Continued.

		1996/97		1999/00		2003/04		2006/07	
	Model	mean	SE	mean	SE	mean	SE	mean	SE
effective # of adults age 15-59	A, O, F	3.24	1.60	3.38	1.89	3.13	1.78	3.10	1.88
effective # of adults age 15-59, squared	A, O, F	13.07	13.23	14.96	16.83	12.97	14.12	13.12	14.73
# of children age 0-4	O, F	0.86	1.09	0.60	0.89	0.63	0.89	0.53	0.82
# of children age 5-14	O, F	2.37	1.78	2.10	1.64	1.97	1.71	1.83	1.73
# of adults age 60+	O, F	0.43	0.02	0.53	0.73	0.70	0.80	0.75	0.81
Prices and NCPB activities									
village-level effective NCPB purchase price (KSH/kg)	A	4.36	2.57	8.02	2.32	7.96	2.34	10.83	3.86
ln(NCPB district-level purchases, last year)	A	3.31	5.15	5.07	4.48	5.05	4.52	5.68	5.20
ln(NCPB district-level purchases, last year), squared	A	37.52	60.54	45.78	45.62	45.91	53.80	59.28	61.91
ln(regional wholesale price in planting month)	A	2.01	0.01	2.44	0.00	2.56	0.00	2.58	0.00
ln(regional wholesale price in planting month), t-1 (months)	A	1.96	0.01	2.42	0.01	2.50	0.00	2.66	0.00
ln(regional wholesale price in planting month), t-2	A	1.95	0.01	2.25	0.01	2.51	0.01	2.61	0.00
ln(regional wholesale price in planting month), t-3	A	1.94	0.01	2.26	0.01	2.53	0.01	2.64	0.00
ln(regional wholesale price in planting month), t-4	A	1.96	0.01	2.33	0.01	2.47	0.01	2.64	0.00
ln(regional wholesale price in planting month), t-5	A	1.95	0.00	2.42	0.00	2.43	0.01	2.63	0.00
ln(regional wholesale price in planting month), t-6	A	1.98	0.00	2.39	0.00	2.30	0.00	2.65	0.00
ln(regional wholesale price in planting month), t-7	A	2.05	0.00	2.44	0.00	2.21	0.00	2.62	0.00
ln(regional wholesale price in planting month), t-8	A	2.11	0.00	2.47	0.00	2.30	0.00	2.77	0.00
ln(regional wholesale price in planting month), t-9	A	2.12	0.00	2.42	0.01	2.33	0.01	2.79	0.00
ln(regional wholesale price in planting month), t-10	A	2.09	0.00	2.51	0.00	2.38	0.01	2.75	0.00
ln(regional wholesale price in planting month), t-11	A	2.07	0.00	2.53	0.00	2.24	0.01	2.69	0.00
post-harvest farmgate maize price (district median), KSH/kg	A	11.46	1.32	12.44	1.10	12.97	1.66	12.58	1.43
ln(expected farmgate maize price)	O, F	2.42	0.11	2.50	0.10	2.56	0.10	2.50	0.11
ln(village agricultural labor wage)	O, F	4.82	0.27	4.16	0.34	4.61	0.38	4.40	0.35
ln(price of DAP fertilizer)	O, F	4.10	0.14	3.41	0.04	3.61	0.05	3.56	0.03
ln(regional wholesale price of beans)	O	7.46	0.08	7.87	0.23	7.59	0.07	8.07	0.07
ln(regional wholesale price of cowpeas)	O	7.72	0.11	8.04	0.22	7.62	0.14	8.39	0.15
ln(regional wholesale price of sweet potatoes)	O	6.46	0.29	6.89	0.40	6.88	0.44	7.29	0.34
ln(regional wholesale price of irish potatoes)	O	6.42	0.24	7.03	0.16	6.96	0.12	7.19	0.46
ln(regional wholesale price of cassava)	O	5.98	0.19	6.49	0.26	7.05	0.32	7.22	0.07
ln(regional wholesale price of kale)	O	5.39	0.27	5.75	0.54	6.52	0.26	6.60	0.74
ln(regional wholesale price of onions)	O	5.61	0.10	5.74	0.25	5.80	0.11	6.12	0.25
ln(regional wholesale price of tomatoes)	O	6.63	0.19	6.62	0.41	7.04	0.39	7.16	0.33
ln(district median farmgate price of coffee cherries)	O	2.22	0.27	3.26	0.17	1.31	0.75	2.49	0.41
ln(regional wholesale price of avocado)	O	6.40	0.31	6.53	0.52	6.66	0.28	6.47	0.48
ln(regional wholesale price of mangos)	O	6.37	0.22	6.47	0.29	6.77	0.07	6.80	0.31
ln(regional wholesale price of banana)	O	4.91	0.22	4.99	0.24	5.42	0.23	5.53	0.39
ln(district median farmgate price of sugar cane)	O	0.33	0.10	0.54	0.02	0.56	0.02	0.74	0.04

Notes: A = auxiliary regressions (maize quantity sold; maize sale price); O = output supply regressions; F = fertilizer demand regressions