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

by

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EXECUTIVE SUMMARY

Despite the resurgence of parastatal marketing boards and strategic grain reserves over the last decade in eastern and southern Africa, there is little empirical evidence about how their activities affect smallholder input use and cropping decisions. This paper uses panel survey data from 1997-2007 on Kenyan smallholders to investigate the effect of Kenya's National Cereal Produce Board (NCPB) activities on farm-gate maize price expectations, output supply, and factor demand.

Results show that the NCPB pan-territorial maize purchase price has a strong, positive effect on smallholders' maize price expectations, and that smallholders respond to higher expected maize prices by increasing maize production via intensification – through increased fertilizer use as well as higher maize seeding rates within intercrops. Specifically, we find that a 10% increase in the NCPB purchase leads to: a 1.4% increase in the expected farm-gate maize sale price; a 2.5% increase in household maize production; a 0.6% increase in the probability of fertilizer use on maize; increases of 1.4% and 2.9% in conditional and unconditional quantities of fertilizer applied to maize; and a 2.6% increase in household total net crop income, on average. Increases in maize production do not appear to be coming at the expense of production of other crops, as we find no evidence to suggest that higher expected maize prices lead to reductions in either area planted to non-maize crops or non-maize crop production.

We also find that a 1% increase in the expected maize price increases total household net crop income by 1.9%. 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. More importantly, for the majority of rural Kenyan smallholders that are net buyers of maize, higher household farm income may not translate into higher expenditure (i.e., welfare) if the costs of meeting the household's food consumption needs are also higher. A study that 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, Myers, and Jayne 2011).

This study has shown that, at least in the case of Kenya, the NCPB is largely achieving its narrowly defined mandate, i.e., increasing maize prices and maize production, as well as contributing in a small way to overall agricultural growth. Thus, our findings corroborate the widely held view in Kenya that the NCPB is a powerful tool for supporting maize production specifically, and Kenyan agriculture more generally. The NCPB's activities have also been found to have a generally stabilizing effect on maize market prices in Kenya (Jayne, Myers, and Nyoro 2008). However, these benefits are being achieved at a cost that is unknown to the general public. Unfortunately, little analysis is available to assess the opportunity costs of NCPB operations and the potential impacts that could have been achieved had decades of NCPB expenditures been reallocated, partially or fully, to alternative public investments. Such analysis is impeded by restricted access to data on NCPB operating costs. Should such data become publically available, an important question for further research would be to assess the social benefits of NCPB activities in relation to their costs. It will be important for further research to be able to assess whether other marketing boards in the region are having similar effects, given major cross-country variations in their objectives and operations, as well as a better notion of the benefits relative to their costs.

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ACRONYMS

FAO	Food and Agriculture Organization of the United Nations
CRE	Correlated Random Effects
DAP	Diammonium Phosphate
ESA	Eastern and Southern Africa
FE	Fixed Effects
FEWS	Famine Early Warning System
FI	Fisher-Ideal index
GISAMA	Guiding Investments in Sustainable Agricultural Markets in Africa Project
GPS	Global Positioning System
HA	Hectare
IPW	Inverse Probability Weighting
Kg	Kilogram
ML	Modified Laspeyres Quantity Index
MP	Modified Paasche Quantity Index
MSU	Michigan State University
NCPB	Kenya's National Cereal Produce Board
USAID	United States Agency for International Development

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, Chapoto, and Govereh 2007).

Despite the importance of the topic, 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 1988; Schiff and Valdés 1991; Masters and Nuppenau 1993; Krueger 1996). With only a few exceptions (e.g., Kutengule, Nucifora, and Zaman 2006; Mason 2011), there remains little use of household-level data to provide the micro-economic foundation for understanding how the operations of state marketing boards affect the input use and cropping decisions of smallholder farmers. 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, Myers, and Nyoro (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 that has investigated the extent to which NCPB activities have affected smallholders' price expectations, behavior, and incomes.

This study uses panel survey data on 1,115 farm households in 24 districts in Kenya that 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

[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).

market on smallholder maize price expectations, and input and output decisions, and total incomes.

The study's objectives are (i) to measure the extent to which NCPB activities in the maize market influences farmers' expectations of maize prices at the farm-gate level; (ii) to measure the sensitivity of farmers' output and input decisions to changes in expected maize prices, so as to quantify the indirect effect of NCPB activities on input demand and crop output supply; and (iii) to determine how these effects vary across households given their heterogeneous capacities to respond to changing incentives.

The 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 used to investigate the effects of NCPB activities on smallholder behavior, and then discusses 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. Managing food price instability has been re-emphasized as a major policy objective since the global food price spikes of 2007-08.

Food security in Kenya has generally been viewed as synonymous with maize security because maize is not only the main staple food, but also the most common food crop grown by the rural poor. 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 (Nyoro, Kiiru, and Jayne 1999; Government of Kenya 2010).

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 NCPB since 1980, had a monopoly on internal and external trade. 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, Kiiru, and Jayne 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, Myers, and Nyoro 2008).

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 1). 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 the next year by commercial maize farmers for increased purchases. A year before the national elections, the government increased the NCPB's budget for the

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) ------ Nominal ------ Purchase price	Sale price	-- Inflation Adjusted[a] -- Purchase price	Sale price	NCPB Maize Purchases (000 mt)	NCPB Maize Sales (000 mt)
	(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.

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 1 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, with support from 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 et al. (1998). A total of 1,578 small-scale farming households were surveyed in 1997. Of these, we drop 48 households because they were either 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 less than 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 rain stations 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 Global Positioning System (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 Staff (1980).

4. METHODS

4.1. Descriptive Analysis

As described above, the goals of NCPB purchases and sale of maize are to stimulate domestic maize production and to protect consumers and producers from large seasonal and year-to-year fluctuations in the price of maize. Before beginning our econometric analysis of the effects of NCPB activities on farm-gate maize prices, rural household crop production and input decisions, we first look at mean and median household levels of crop area, crop production, and input use for evidence of recent trends.

4.2. Econometric Analysis

4.2.1. 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 that they can observe at planting. As in Mason's (2011) work in Zambia, there are four key aspects of rural maize markets in Kenya that we consider in modeling 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, Myers, and Nyoro (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

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

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 consumption decisions, such as household wealth/income or demographic characteristics (Sadoulet and de Janvry 1995).

4.2.2. Modeling Farm-gate Maize Price Expectations

Farm-gate Maize Price Prediction Model: 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 that 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 do not compute a one-period-ahead quasi-rational expectation for the farm-gate maize price in year t using only sale price observations from prior years, as in Nerlove and Fornari (2008). Instead, 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 farm-gate maize prices through three variables that we can observe and which are included in our price expectation model. The first two are the expected district-level NCPB maize purchase volume and the effective expected NCPB purchase price. Given that Jayne, Myers, and Nyoro (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 in each of the 11 prior months. Thus, if changes in wholesale maize prices are at least partially transmitted to the farm-gate level, we anticipate that the 12 wholesale maize prices will have a jointly significant partial effect on expected farm-gate maize sale prices.

The variables for 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 in transport costs between the farm and the regional market, we include the household-level variable distance from the farm 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 farm-gate 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

[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).

prevailing at the month of planting 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.[5]

Household characteristics that 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 that =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 that =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. While a limitation of this measure of market access is that it does not account for the costs of transport from the road to the relevant market itself, the majority of the total transport cost to market is likely the segment from the village to the nearest road.

Other household-level factors that may influence the household maize price received include characteristics of the buyer. We therefore 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. Another factor that may influence the household maize price received is seasonality, which we include in the form of dummies for three of the four calendar quarters of the year. Since the quarter of maize sale was not recorded in the 2000 survey, we use the district modal value of quarter of maize sale from 1997, 2004 and 2007 for the year 2000.

Because weather conditions may influence market prices, we include measures of 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.[6] We include year dummies to capture the average variation in unobserved factors from year to year.

[5] The Tegemeo surveys did not record household-specific measures of transport costs associated with maize marketing. However, the surveys did contain provincial median transport cost/kg per kilometer of fertilizer, as reported in 2004 and 2007 by the smallholders who purchased fertilizer those years (78% and 80%, respectively). To compute the hypothetical transport cost/kg of maize from the village to the nearest NCPB depot, we multiply the provincial median fertilizer transport cost/kg per kilometer by the distance from each village to the nearest NCPB depot in 2007. Due to data limitations, we have to assume that the distance to the nearest depot for 2007 holds for earlier years, and that transport costs per kilogram per kilometer in 2004 are the same as for earlier years (1997 and 2000).

[6] 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.

Finally, we also include the long-term average of each time-varying variable in the model, used to control for unobserved time-constant household heterogeneity using the correlated random effects (CRE) approach.

Testing for Potential Sample Selection Bias in Observable Farm-gate Maize Sale Prices: Before we estimate a regression of farm-gate maize prices, we first note that maize sale price data is only observed for the subsample of households that actually sells maize (n=495 out of n=1,139 panel households sold maize in 2007). If this subsample of maize sellers has non-random characteristics, it is possible that using OLS on the observed maize sale prices could produce biased results due to incidental truncation of the observable distribution of maize prices. Following Mason (2011), we test for the presence of sample selection bias using a Tobit selection equation and a method outlined by Wooldridge (2002, p. 572).

The first step in testing for potential sample selection bias is to run a Tobit regression of the dependent variable quantity of maize sold (kg) by smallholders. The second step is to take the residual from this Tobit and to include it as a regressor in the farm-gate maize price regression. If the coefficient on the residual term in the maize price model is significant, this indicates the presence of sample selection bias (and leaving the residual term in the price model controls for such bias).

The Tobit selection equation includes variables typically used to explain the household decision of how much of a given food crop to sell, including: factors related to agroecological potential, rainfall and drought shocks; household productive assets; household marketing assets; household consumption requirements; and the farm-gate price of maize. To control for spatial variation in agroecological potential, we include provincial dummies as well as provincial dummies interacted with a time dummy for the latter two panel years (2004 and 2007). Given that most maize production in Kenya is rainfed, we include the village-level variables rainfall during the main growing season and rainfall shock, which is measured as the percentage of 20 day periods during the main season with less than 40mm of rain.

Variables measuring household production assets include effective number of adults age 15-59 (a proxy for availability of family labor) and its square, the log of total household land owned and its square, and the value of irrigation equipment. To compute the effective number of adults per household, we use information on the number of months of residence in the past year to measure the number (or fraction) of full-time adults in the household.

Binary variables related to the household's negotiating ability include motorized vehicle ownership, bicycle ownership, household head is a single female, and household suffered the death of an adult age 15-59 within the past 3 years. Continuous variables related to the household's negotiating ability include value of household storage assets, and the age and education level of the household head. Distance to the nearest motorable road serves as a proxy for transport costs to the relevant market and market access. Variables related to the household consumption needs of dependent individuals in the household include the number of children age 0-4, the number of children age 5-14, and the number of adults age 60 and over.

To measure the price facing rural households during the post-harvest period, we use the district median household maize sale price. We include year dummies to capture the average variation in unobserved factors from year to year. Finally, we also include the long-term average of each time-varying variable in the model, which are collectively used to control for unobserved time-constant household heterogeneity under the CRE approach.

4.2.3. Modeling 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 farm-gate maize price. The theoretical results of utility maximization behavior in either producer models or household models predict that smallholder households will respond to higher expected farm-gate maize prices by increasing maize production. There are at least three ways in which they might do this: a) increasing area cultivated to maize by shifting area from competing crops into maize; b) increasing area cultivated to maize by bringing more total area under cultivation; and/or c) intensifying maize production via application of larger amounts of fertilizer and/or other inputs per unit of maize area cultivated.

We test the first of these predictions by estimating various models of output supply, as measured by production levels. This group of 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 that are most widely grown by smallholders in the survey data. To aggregate crop production across multiple commodities, we use a modification of the Fisher-Ideal index by Mason (2011) (details in Appendix A-1). We also group all of these non-maize crops together into one index of non-maize crop production, and we group maize plus all the non-maize crops into one index of total crop production. 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 CRE terms as described below.

Each output supply model is a function of the expected farm-gate maize price, expected prices of competing crops, prices of inputs (fertilizer and rural wages), private and public quasi-fixed factors, and other exogenous variables. To account for differences in agroecological potential across the country, we include binary variables for five of the country's six agroecological zones covered by the Tegemeo survey (these variables drop out of the fixed effects (FE) models). Given that most of Kenya's maize production is rainfed, we include 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 also include year dummies to capture the average variation in unobserved factors from year to year.

We use the coefficients from the maize price expectation model in the first stage to compute a household-specific expected post-harvest farm-gate maize price for both maize sellers and non-sellers.[7] 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 farm-gate sales prices of maize.

[7] 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).

We also include the expected post-harvest wholesale price for each competing non-maize crop. Due to data limitations, we do not replicate a price prediction model for each of the non-maize crops as we did for maize. Instead, 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. We use wholesale prices instead of farm-gate prices because data on farm-gate prices are only available for the panel household survey years. For each agroecological zone, we selected a single month during the likely marketing period for most crops following the main growing season to represent that growing month. While it would have been preferable to use the average price across several marketing months, data limitations required us to choose a single month for which we could consistently observe a price during the marketing period over time. The only available price data for coffee and sugarcane are the post-harvest farmer sale prices of these crops as observed in the Tegemeo survey (for that year). By using post-harvest prices for these two crops, we must assume that farmers have perfect foresight at planting of what prices will be for coffee and sugarcane at harvest. While this is a strong assumption, these variables merely serve as controls in several of our output supply models, and are not the focus of our research objectives.

Input prices include the log price of fertilizer, which is the district median price of diammonium phosphate (DAP) fertilizer reported by households, and the log rural wage, which is the village median wage as reported by households.[8] Prices of variable inputs (fertilizer, labor) are assumed to be known at planting time. 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, and the log of total landholding and its square. The log of the total value of household farm assets (farm equipment and livestock) serves as a proxy for both productive capacity and financial capital. Additional exogenous factors include rainfall during the main growing season, and drought shock, defined as the percentage of 20-day periods during the main growing season with less than 40 mm of rainfall.

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. We include a binary variable that =1 if the household is headed by a single female to investigate whether or not such households are at a disadvantage with respect to crop production (while controlling separately for other factors). To control for potentially adverse effects of adult mortality on household crop production, we also include a binary variable that =1 if the household suffered the death of an adult age 15-59 within the past three 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 that represent maize-production potential: a) East and West Lowlands (Low potential); b) West

[8] The Tegemeo survey instrument inquired of every household regarding the DAP fertilizer price in their village as well as the farm wage.

Transitional, West and Central Highlands (Medium); and c) 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.

4.2.4. Modeling Output Supply: Area Planted

Assuming that we find a significant response of household maize production to changes in expected farm-gate 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 it more clearly represents 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 that measure household area planted to maize and other crops, including: area planted to maize; area planted to competing crop groups; and total area cultivated.

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). 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 that 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.

4.2.5. Modeling Factor Demand

As noted above, we would expect farmers to respond to higher expected farm-gate maize prices by increasing the amount of fertilizer applied to maize, *ceteris paribus*. To investigate this hypothesis, we estimate several Cragg double-hurdle models of fertilizer demand. These include quantity of fertilizer applied to maize, quantity of fertilizer applied per hectare of maize, quantity fertilizer applied to all crops, and quantity of fertilizer applied to all crops per total hectares cultivated. For example, the first stage of the double-hurdle for the first model involves running a Probit regression on a binary variable that =1 if the household used fertilizer on maize, and zero otherwise. The second stage involves running 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 models (see more discussion of double-hurdle models below).

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 fertilizer demand 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). The soil type categories are based on information on soil type, clay or sand content, drainage, and depth and how those factors affect the fertilizer response of maize. The soil groups for which we created binary variables include those that are: a) soils that are highly humic/productive; b) Regosols; c) soils with very shallow with poor drainage; and d) soils with high clay and poor drainage. Finally, each fertilizer demand model includes the long-term average of each time-varying variable in the model, used to control for unobserved time-constant household heterogeneity using the CRE approach.

4.3. Estimation Issues

4.3.1. Panel Attrition

For our econometric work, we only use households that were re-interviewed in each of the Tegemeo panel surveys from 1997 to 2007. Panel household surveys typically have to contend with at least some sample attrition over time, given that some households move away from a village over time and others dissolve as part of a typical household life-cycle. If households that are not re-interviewed are a non-random sub-sample of the population, then using the re-interviewed households to estimate the means or partial effects of variables during one of the later panel time periods may result in biased estimates.

To test for attrition bias, we follow the regression-based approach described in Wooldridge (2002) and define an attrition indicator variable that is equal to one if the household dropped out of the sample in the next wave of the panel survey, and equal to zero otherwise.[9] This binary variable is then included as an additional explanatory variable in each regression model. If the coefficient on this binary variable is statistically different from zero, this indicates the presence of attrition bias with respect to that model.

[9] There are a very small number of households which drop out in earlier survey waves and are re-interviewed in later years. We drop these households from our analysis and assume that attrition is an absorbing state (as per Wooldridge 2002); once a household drops out, they do not return to the sample.

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

Source: Author's calculations using Tegemeo survey data.

Given that we are using four waves of panel data for rural Kenya for our analysis, we only use the first three waves in this attrition test. The models that we find to be affected by attrition bias include those for the farm-gate maize sale price, household maize production, monocropped maize area, and total fertilizer use (Table 2).

For models that are affected by attrition bias, we apply sampling weights that are adjusted for panel attrition bias using the Inverse Probability Weighting (IPW) method (Wooldridge 2002). Burke et al. (2007) computed the attrition-correction factors for the Kenya panel household dataset that we use here. The Kenya survey does not use population sampling weights, as it was not developed to be a nationally-representative sample. Where appropriate, we present econometric results in the following sections that are 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.

4.3.2. Double-Hurdle Model

An econometric concern for modeling fertilizer demand is the fact that not all households apply fertilizer to maize or other crops, thus the fertilizer demand of non-users is zero. That is, the fact that the distribution of fertilizer demand observations exhibits a large number of cases lumped at zero can create problems for standard OLS regression. The standard approach to modeling such a distribution is to use either a Tobit or a double-hurdle model. When the household's fertilizer use and quantity decisions are made simultaneously, the Tobit model is appropriate for analyzing the factors affecting the joint decision. However, based on the findings of previous research on fertilizer demand in Malawi (Ricker-Gilbert, Jayne, and Chirwa 2011) and Zambia (Xu et al. 2009), we expect that fertilizer use and quantity decisions are determined by different processes. Thus, we use the lognormal version of Cragg's (1971) double-hurdle model, which unlike Tobit, allows the decisions about whether to use fertilizer and what quantity to use to be determined by different processes.

The double hurdle model is designed to analyze instances of an event that may or may not occur, and if it occurs, takes on continuous positive values. In the case of fertilizer demand, we assume that a decision to use fertilizer or not is made first, followed by the decision on how much fertilizer to apply. The structure of our double-hurdle model is as follows:

$$d_{it}^* = \gamma x_{1t} + e_i \qquad e_i \sim N(0, \sigma^2)$$

$$\text{where } d_i = 1 \text{ if } d_i^* > 0, \text{ otherwise } d_i = 0,$$

$$y_{it}^* = \exp(\beta x_{2t} + \sigma^2/2) \qquad u_i \sim N(0, \sigma^2)$$

$$\text{where } y_i = y_i^* \text{ if } y_i^* > 0 \text{ and } d_i = 1, \text{ otherwise } y_i = 0, \qquad (1)$$

The subscript *it* refers to the *i*th household during period *t*, d_{it} is the observable discrete decision of whether or not to use fertilizer, while d_{it} is the latent (unobservable) variable of d_{it}. y_i^* is an unobserved, latent variable (desired quantity of fertilizer), and y_i is the corresponding observed variable, actual quantity of fertilizer used. x_{1t} and x_{2t} represent vectors of explanatory variables assumed to be exogenous in the participation and fertilizer quantity equations, respectively, and that need not contain the same variables (though they do in our case). γ and β are parameters to be estimated.

Estimating the Cragg double-hurdle requires the additional assumption of conditional independence for the latent variable's distribution, or that $D(y^*|d, x) = D(y^*|x)$. Thus, we assume that conditional on x, there is no correlation between the disturbances from the participation and sales equations (u_i and e_i).

4.3.3. 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 characteristics. If unobservable time-constant characteristics such as farm management ability, soil quality, social capital, etc., are correlated with observable determinants of maize and other crop output (such as total land area owned), this can lead to biased estimation of the effects of variables included in the model to the extent that they are correlated with the unobservables. The FE estimator is usually the most practical way to control for time-constant unobserved household factors, since using FE requires no assumption regarding the correlation between observable determinants (vector X_{it}) and unobservable heterogeneity (c_i). We use FE estimation for the regression 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) 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 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 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, $a_i \mid Xi \sim \text{Normal}(0, \sigma^2_a)$. 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[10] (APE) for each regressor and use a bootstrap routine to compute the standard errors.[11]

4.3.4. Generated Regressors

As noted by Mason (2011), the variable expected maize price– that is computed from an auxiliary regression – is considered 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.

[10] 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).
[11] We replicate our bootstrapping routine 500 times.

5. DESCRIPTIVE ANALYSIS

5.1. Maize and Other Crop Production

Before undertaking our econometric analysis, we first look for national-level trends in crop group participation by smallholders, area planted to maize and other crop groups, production of maize and other crops, and fertilizer use over time. We begin by looking at the percentage of households growing various crop groups, and note that there are only mild reductions in crop group participation between 2000-2007 for the root crop group and the vegetable group (Table 3). We also note that crop group participation is notably lower in 1997 for four of the non-maize crop groups, relative to later years. Because lower reporting of crop participation in 1997 might be caused by differences over time in how the survey enumerators prompted households regarding which crops they grew, we undertake our analysis of non-maize crop area and production using only data from the survey years of 2000, 2004, and 2007.

We next consider area planted by smallholders to various crop groups. Both household mean and median area planted to maize were stable between 1997 and 2007, though with an upward spike in 2000 (Table 4). Note that in this table, maize area includes the total area of fields that are either monocropped maize or maize in an intercrop. Household mean and median total area cultivated also increased dramatically in 2000, yet were remarkably stable in the other years. This should not be too surprising given that high population density in most areas of Kenya preclude increases in total farm size among the smallholder sector (without much farm consolidation). Although mean household area planted to maize varied a bit over time in some zones, the median household area planted to maize is remarkably stable over time in the medium and higher potential zones (Table 5).

Table 3. Percentage of Rural Households Growing Various Crop Groups, Kenya

	1997	2000	2004	2007	All years
Crop Group	---- % households growing crop group ----				
Maize	99.6	99.4	99.3	98.9	99.3
Beans, Cowpeas	89.6	94.8	95.6	94.3	93.6
Sweet Potato, Irish Potato, Cassava	52.5	75.7	76.8	64.9	67.5
Kale, Onion, Tomato	22.9	68.1	66.5	61.2	54.7
Coffee, Avocado, Mango	31.3	71.3	79.4	74.5	64.1
Banana, Sugarcane	50.7	80.7	84.5	78.3	73.6

Source: Tegemeo household surveys

Table 4. Mean/Median Household Area Planted by Crop and by Zone, Kenya

	1997	2000	2004	2007	All years
Crop Group		---- mean hectares -----			
Maize	0.68	0.88	0.67	0.67	0.72
Beans, Cowpeas	0.55	0.70	0.58	0.54	0.59
Sweet Potato, Irish Potato, Cassava	0.14	0.25	0.19	0.17	0.19
Kale, Onion, Tomato	0.04	0.12	0.07	0.06	0.08
Coffee, Avocado, Mango	0.10	0.40	0.23	0.30	0.26
Banana, Sugarcane	0.21	0.36	0.24	0.26	0.27
Total area cultivated	1.26	1.73	1.38	1.24	1.41
Crop Group		---- median hectares -----			
Maize	0.41	0.53	0.41	0.41	0.41
Beans, Cowpeas	0.41	0.41	0.41	0.36	0.41
Sweet Potato, Irish Potato, Cassava	0.16	0.16	0.11	0.10	0.12
Kale, Onion, Tomato	0.10	0.06	0.05	0.05	0.06
Coffee, Avocado, Mango	0.20	0.28	0.16	0.21	0.20
Banana, Sugarcane	0.20	0.20	0.10	0.15	0.16
Total area cultivated	0.86	1.11	1.06	0.91	0.98

Notes: household medians computed among households which grew the crop in a given year
Source: Author's calculations using Tegemeo survey data.

Table 5. Mean/Median Household Area Planted to Maize by Zone, Kenya

	1997	2000	2004	2007	All years
Agri-regional zones		---- mean hectares ----			
Eastern Lowlands	0.91	1.02	1.08	1.27	1.07
Western Lowlands	0.56	0.66	0.65	0.42	0.57
Western Transitional	0.61	0.69	0.66	0.48	0.61
High Potential Maize Zone	1.04	1.50	0.89	1.06	1.13
Western Highlands	0.35	0.50	0.41	0.34	0.40
Central Highlands	0.34	0.34	0.30	0.24	0.31
Total	0.68	0.88	0.67	0.67	0.72
Agri-regional zones		---- median hectares ----			
Eastern Lowlands	0.61	0.80	0.81	0.81	0.81
Western Lowlands	0.41	0.49	0.61	0.41	0.41
Western Transitional	0.41	0.41	0.41	0.41	0.41
High Potential Maize Zone	0.81	0.81	0.71	0.81	0.81
Western Highlands	0.30	0.30	0.36	0.30	0.30
Central Highlands	0.20	0.20	0.20	0.20	0.20
Total	0.41	0.53	0.41	0.41	0.41

Source: Author's calculations using Tegemeo survey data.

Given that most smallholders plant maize in an intercrop, we next consider whether the percentage of households planting maize in a monocrop or the intensity of maize seeding within intercropped fields has increased over time. We find that the percentage of smallholders planting maize as a monocrop (Category 1 in Table 6) has stayed relatively stable over time at about 15%. As we mentioned above, it appears that non-maize crops may have been undercounted by the Tegemeo survey in 1997, thus we should primarily look for trends in maize intercropping systems from 2000 forward. With this caveat in mind, we note that the percentage of households growing the two categories of intercropped maize (Category 2 and 3) also do not exhibit a trend from 2000 to 2007.

Table 6. Percentage of Households by Type of Maize Cropping System, and Mean/Median Area Planted by Maize Cropping System, Kenya

Categories of maize cropping systems	1997	2000	2004	2007	All years
	---% of households with cropping system ---				
Total maize area	99.6	99.4	99.3	98.9	99.0
Intensive maize area	64.5	80.5	50.7	52.6	62.0
Non-intensive maize area	37.9	28.8	61.2	54.8	45.6
Category (1): Maize monocrop OR maize with tree crop	16.8	13.1	14.5	15.1	14.8
Category (2): maize with beans OR maize with beans + third crop	70.3	42.8	58.6	45.2	54.2
Category (3): maize with non-bean crop OR maize with 3 other crops	18.3	66.4	47.5	57.6	47.4

Notes: Intensive maize area defined as area cultivated with a seeding rate of 10+ kg of maize seed/acre, while non-intensive maize area has <10 kg maize seed/acre. Because some households have maize planted on different fields which represent more than one category of maize area, the rows/columns in this table do not sum to 100% for any given year.
Source: Author's calculations using Tegemeo survey data

While both mean and median non-intensive maize area appear to have declined over time, this is not accompanied by a positive trend in either the mean/median of household area planted to maize in monocrop or mean/median area planted to intensive maize (Table 7). There is a slight decline in mean Category 3 maize intercrop area over time, but the median is stable. There is also no apparent trend in the mean or median of Category 3 maize intercrop area.

We next consider crop production per household, in kilograms for maize, and in terms of the Fisher-Ideal index for crop groups (see Appendix A-1 for details). We find that mean household production of maize and several other crops are highest in 2000, and seem to have been somewhat lower in 1997 relative to the other years (Table 8). However, there is a steady increase in median household maize production over time in every zone (Table 9). Though it appears that there are declines in mean/median root crop production over time, the household median of total non-maize production appears to be relatively stable (Table 8).

The clear increase in median smallholder maize production over time, combined with limited evidence of increases in maize area planted or seeding intensity, suggests that smallholders have managed to increase their maize production via increased fertilizer use. This is precisely what we find: the percentage of households using fertilizer on maize increased steadily across our panel years (Table 10), and mean household fertilizer use per hectare of maize (kg/ha of maize; computed among fertilizer users) has also increased over time (Table 11). In sum, the evidence from bivariate statistics suggests that household maize production has increased over time due to increased numbers of households that apply fertilizer to maize combined with larger quantities of fertilizer applied to maize among fertilizer users. We next move to multivariate analysis to investigate whether changes in maize production or fertilizer use over time can be attributed to NCPB activities (or not), as well as to see if increased maize production has resulted in decreased production of other crop groups.

Table 7. Mean/Median Household Area Planted by Maize Cropping System, Kenya

Categories of maize cropping systems	1997	2000	2004	2007	All years
	-------- mean area planted (ha) --------				
Total maize area	0.68	0.88	0.67	0.67	0.72
Intensive maize area	0.60	0.79	0.54	0.64	0.66
Non-intensive maize area	0.77	0.83	0.65	0.61	0.69
Category (1): Maize monocrop OR maize with tree crop	0.70	1.11	0.48	0.69	0.74
Category (2): maize with beans OR maize with beans + third crop	0.62	0.70	0.58	0.61	0.63
Category (3): maize with non-bean crop OR maize with 3 other crops	0.65	0.65	0.55	0.50	0.58
	-------- median area planted (ha) --------				
Total maize area	0.41	0.53	0.41	0.41	0.41
Intensive maize area	0.41	0.41	0.41	0.41	0.41
Non-intensive maize area	0.61	0.61	0.41	0.41	0.41
Category (1): Maize monocrop OR maize with tree crop	0.41	0.30	0.20	0.41	0.41
Category (2): maize with beans OR maize with beans + third crop	0.41	0.41	0.41	0.41	0.41
Category (3): maize with non-bean crop OR maize with 3 other crops	0.41	0.41	0.41	0.36	0.41

Notes: Mean/Median area planted computed only among households with that category of maize cropping system. Intensive maize area defined as area cultivated with a seeding rate of 10+ kg of maize seed/acre, while non-intensive maize area has <10 kg maize seed/acre.

Source: Author's calculations using Tegemeo survey data.

Table 8. Mean/Median Household Production of Various Crops, Kenya

	1997	2000	2004	2007	All years
Crop Group[1]	---- ***mean*** kg for Maize, FI index for other ----				
Maize	1,102	1,731	1,535	1,694	1,517
Beans, Cowpeas	208	216	202	163	197
Sweet Potato, Irish Potato, Cassava	79	103	76	61	80
Kale, Onion, Tomato	144	92	92	66	90
Coffee, Avocado, Mango	138	137	106	66	106
Banana, Sugarcane	555	854	478	443	588
Total non-maize crop production[1]	60	106	93	66	82
Total crop production[1]	98	149	153	130	133
Crop Group[1]	---- ***median*** kg for Maize, FI index for other ----				
Maize	450	565	689	777	604
Beans, Cowpeas	86	127	97	93	102
Sweet Potato, Irish Potato, Cassava	39	44	37	34	39
Kale, Onion, Tomato	44	31	30	29	31
Coffee, Avocado, Mango	50	28	40	30	35
Banana, Sugarcane	167	120	78	100	100
Total non-maize crop production[1]	34	53	54	44	46
Total crop production[1]	55	83	94	86	79

Notes: 1) Households not growing the crop are included with a zero index value; 2) total crops refers to all crops listed in this table. FI = Fischer-Ideal index

Source: Author's calculations using Tegemeo survey data.

Table 9. Mean/Median Household Maize Production by Zone, Kenya

	1997	2000	2004	2007	All years
Agri-regional zones		---- *mean* kg ----			
Eastern Lowlands	225	774	771	1,042	705
Western Lowlands	287	366	445	593	423
Western Transitional	725	1,221	1,609	1,526	1,269
High Potential Maize Zone	2,752	4,105	3,392	3,766	3,507
Western Highlands	416	720	616	701	614
Central Highlands	402	613	528	554	525
Total	1,102	1,731	1,535	1,694	1,517
Agri-regional zones		---- ***median*** kg ----			
Eastern Lowlands	180	474	613	718	450
Western Lowlands	180	225	251	475	270
Western Transitional	450	720	964	1,092	794
High Potential Maize Zone	1,620	1,620	2,199	2,144	1,800
Western Highlands	360	450	475	589	450
Central Highlands	360	382	397	417	378
Total	450	565	689	777	604

Source: Author's calculations using Tegemeo survey data.

Table 10. Percentage of Rural Households That Applied Inorganic Fertilizer to Maize, Kenya

	1997	2000	2004	2007
Agri-regional zones		------- % of households --------		
Eastern Lowlands	27.4	31.7	52.6	57.0
Western Lowlands	2.0	5.2	6.5	11.8
Western Transitional	40.5	64.2	70.3	80.4
High Potential Maize Zone	83.7	88.7	88.6	91.3
Western Highlands	76.0	86.0	90.7	93.8
Central Highlands	88.8	89.3	91.7	89.7
Total	60.7	67.3	71.8	75.1

Source: Author's calculations using Tegemeo survey data.

Table 11. Mean Household Fertilizer Applied per Hectare of Maize (kg/ha), Kenya

	1997	2000	2004	2007
Agri-regional zones		-------- mean kg/ha --------		
Eastern Lowlands	35	64	42	45
Western Lowlands	43	45	28	36
Western Transitional	153	149	177	263
High Potential Maize Zone	195	190	267	238
Western Highlands	104	100	139	138
Central Highlands	202	204	168	171
Total	172	167	188	189

Notes: household mean computed among fertilizer users

Source: Author's calculations using Tegemeo survey data.

6. ECONOMETRIC ANALYSIS

6.1. Household Expectations of the Farm-Gate Maize Price

Before estimating the OLS regression of the log of household maize sale prices, we first test for potential sample selection bias in the observed distribution of household maize sale prices by running a Tobit selection equation explaining the quantity of maize sold by the household (Appendix Table 1). We find that the residual term from the Tobit selection equation is significant in the OLS regression of maize price (p=0.043) (Table 12), indicating we need to leave the Tobit residual in the price prediction model to correct for sample selection bias in maize sale prices. Summary statistics of all variables used in the regression models in this paper are presented in Appendix Tables 2 and 3.

The model of household farm-gate 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 farm-gate maize price; the second is to compute household-specific expected farm-gate maize prices for use in our output supply and factor demand models. With respect to the first purpose, we find that a one-shilling increase in the effective NCPB purchase price (approximately an 8% increase) increases the expected farm-gate maize price by 1.1% (Table 12). In other words, a 1% (10%) increase in the village-level effective NCPB purchase price results in a 0.137% (1.37%) increase in the expected farm-gate sales price.

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 time-varying 12 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 farm-gate maize price.

To test the robustness of these results, we also run an OLS regression of farm-gate sales prices in levels (with wholesale prices also in levels) and find similar results. For example, a one-shilling increase in the effective NCPB purchase price leads to an 0.19 shilling increase in the expected farm-gate 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. The finding that market prices are affected by NCPB price setting, but not by NCPB purchase volumes, was also found by Jayne, Myers, and Nyoro (2008). These findings suggest that NCPB's price setting alone has sufficient gravity to affect the prices transacted between farmers and traders, and between assembly and wholesale traders.

Table 12. OLS Regression of the Log of Farm-gate Maize Price Received by Smallholders, 1997-2000-2004-2007

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 12, 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%

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

6.2. Household Maize Production

We next measure the extent to which smallholder output supply responds to changes in the expected farm-gate maize price. We begin first with an OLS regression of the log of household maize production and find that log of expected farm-gate maize price has a significant positive and strong effect on the log of maize production, as a 1% increase in the expected farm-gate maize price increases household maize output by 2.1% (Table 13). 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 13). Given our earlier result that a 10% increase in the village-level effective NCPB purchase price resulted in a 1.37% increase in the expected farm-gate maize price, this implies that a 10% increase in the NCPB purchase price leads to a 2.9% increase in household maize production.

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 13). 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.[12] We do not find a significant effect of single-female headship on maize production.

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 that 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.

[12] 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 13. OLS Regression of the Log of Household Maize Production, 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 13, 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
cases	4550	4550

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

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 14). 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 higher in the medium and high potential zones relative to the low potential zones.

Table 14. Responsiveness of Maize Production to Changes in the Log of Expected Maize Price, by Agroecological Zone and by Asset Level, 1997-2000-2004-2007

Interaction effects by subgroup	Dept variable = ln(household maize produced) 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.

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 14). 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%.

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% (Table 14). One explanation for this surprising result could be that selling maize may be one of the few means of earning cash income for households headed by a single female. For example, households headed by a single female in Kenya tend to have fewer potential cash-generating activities than those headed by men, since men tend to have higher education levels and thus more off-farm opportunities, as well as being more likely to grow and market traditional or non-traditional cash crops..

6.3. Household Area Planted to Maize

Given that we found a significant and strong response of household maize production to changes in expected farm-gate 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 15. Responsiveness of Maize Area to Changes in the Log of Expected Maize Price, by Maize Cropping system, 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	0.097	0.309	0.754
Intensive maize area	Pooled Tobit-CRE	0.736	0.229	0.001
Non-intensive maize area	Pooled Tobit-CRE	-0.640	0.260	0.014
Category (1): Maize monocrop OR maize with tree crop	Pooled Tobit-CRE	-0.150	0.193	0.438
Category (2): maize with beans OR maize with beans + third crop	Pooled Tobit-CRE	0.507	0.255	0.047
Category (3): maize with non-bean crop OR maize with 3 other crops	Pooled Tobit-CRE	-0.075	0.174	0.667

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.

While the partial effect of the expected maize price on total household area planted to maize is insignificant, results from the other regressions suggest that farmers respond to higher expected farmgate maize prices by increasing the seeding intensity of maize in intercropped fields (Table 15). For example, while there is no significant price response with respect to monocropped maize area, a 1% increase in the expected farmgate maize price leads to a 0.5 hectare increase in area planted to maize plus beans (or area planted to maize plus beans and a third crops). In addition, farmers respond to a 1% increase in the expected farmgate maize price by increasing area planted to intensive maize by 0.74 hectares and reducing area planted to non-intensive maize by 0.64 hectares (Table 15). While our measurement of maize area within intercrops is not precise, these results nevertheless suggest a general shift in the maize seeding rate from lower to higher levels in response to increases in the expected maize price.

6.4. Fertilizer Use on Maize

We next run a double-hurdle model of fertilizer applied per hectare of maize to measure the effect of changes in the expected maize price on smallholders' fertilizer use, controlling for other factors such as input prices, household productive assets, soil type, and expected rainfall and drought shocks. Results show that a 1% increase in the expected farm-gate 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 16). 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 per hectare of maize cultivated and a 2.5% increase in the unconditional quantity applied (Table 16). As expected, 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 16). Given our earlier result that a 10% increase in the village-level effective NCPB purchase price results in a 1.37% increase in the expected farm-gate maize price, this implies that a 10% increase in the NCPB purchase price leads to: a) a 0.7% increase in the probability of fertilizer use on maize; b) an increase of 1.7% in the conditional quantity of fertilizer applied per hectare of maize; and c) an 3.4% in the unconditional quantity of fertilizer applied per hectare of maize.

In previous sections, we found that smallholders respond to higher expected farm-gate 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 fertilizer use on maize. This line of reasoning is consistent with descriptive results presented above that show 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 2 and 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. Perhaps surprisingly, farm asset wealth, a measure of households' capital stock, is statistically unrelated to fertilizer use, both in the discrete and continuous parts of the demand model (Table 16). Another indicator of household wealth, landholding size, does have a significant positive effect on the probability of using fertilizer on maize, but the magnitude of the effect is very small. Moreover, The partial effect of landholding size on conditional and unconditional fertilizer quantity used is 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.

6.5. 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.

Table 16. Double-Hurdle Model of Household Fertilizer Use per Hectare of Maize, 1997-2000-2004-2007

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			Lognormal: APE (Unconditional) effect of x_j on y		
	APE	**SE**	**p-value**	**APE**	**SE**	**p-value**	**APE**	**SE**	**p-value**
1=2000	-0.072	0.077	0.352	-18.545	16.335	0.256	-16.616	11.009	0.131
1=2004	-0.026	0.053	0.633	-7.314	13.469	0.587	-6.489	9.209	0.481
1=2007	-0.003	0.053	0.953	4.123	15.686	0.793	2.665	10.722	0.804
1=high humus / highly productive soils	-0.042	0.059	0.469	13.328	10.940	0.223	6.507	9.171	0.478
1=Regosols soils	0.017	0.079	0.827	-14.037	17.233	0.415	-8.804	13.959	0.528
1=very shallow, poor drainage soils	0.053	0.060	0.378	-52.870	7.457	0.000	-35.682	6.384	0.000
1=soil with high clay & poor drainage	-0.316	0.132	0.017	-10.386	51.326	0.840	-25.386	28.640	0.375
6-year average of rainfall in main season	0.000	0.000	0.507	0.001	0.000	0.017	0.000	0.001	0.447
6-year average of drought shock in main season	0.206	0.141	0.143	0.170	0.484	0.725	0.831	0.807	0.303
ln(expected farmgate maize price)	0.409	0.148	0.006	1.266	0.441	0.004	2.577	0.751	0.001
ln(village wage)	-0.006	0.022	0.767	-0.037	0.090	0.680	-0.058	0.119	0.626
ln(village price of DAP fertilizer)	-0.162	0.120	0.177	-0.208	0.336	0.536	-0.727	0.541	0.179
distance to nearest motorable road (km)	-0.001	0.006	0.860	-0.027	0.029	0.366	-0.030	0.041	0.457
distance to nearest fertilizer seller	0.001	0.001	0.181	-0.001	0.007	0.884	0.003	0.007	0.674
ln(total land area owned)	0.016	0.006	0.007	-0.014	0.033	0.660	0.022	0.036	0.539
effective # of adults age 15-59	-0.002	0.010	0.855	0.024	0.017	0.173	0.027	0.021	0.203
ln(total farm asset value)	0.003	0.004	0.530	-0.006	0.017	0.719	0.002	0.023	0.923
Education level of the household head	0.006	0.003	0.025	0.001	0.007	0.900	0.019	0.011	0.094
Age of the household head	0.000	0.001	0.811	0.004	0.003	0.214	0.003	0.005	0.449
1=HH head is single female	-0.032	0.027	0.228	-5.539	7.598	0.466	-5.654	5.528	0.306
1=HH suffered the death of an adult age 15-59	-0.042	0.046	0.357	2.237	9.840	0.820	-1.045	6.494	0.872
# of children age 0-4	0.007	0.006	0.202	0.030	0.021	0.160	0.052	0.026	0.041
# of children age 5-14	0.000	0.004	0.911	-0.002	0.017	0.881	-0.004	0.024	0.868
# of adults age 60+	0.012	0.012	0.307	-0.050	0.051	0.323	-0.012	0.061	0.841
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).

Table 17. Responsiveness of Household Crop Group Production to Changes in the Log of Expected Maize Price, by Crop Group, 2000-2004-2007

	Dept variable = FI index of crop group production		
	Regressor: ln(expected maize price)		
Crop group	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.

We find that the expected maize price has a strong, significant positive effect on bean-cowpea production (Table 17). 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. Thus, beans and cowpeas are somewhat of a complementary crop to maize, while root crops are more of a competing crop. We will later investigate whether the increase in bean/cowpea production due to higher expected maize prices is due to increases in bean/cowpea area planted. Another possibility is that if fertilizer application on maize has increased, this may well benefit bean/cowpeas that are intercropped with maize in the same field (depending upon the nature of the intercrop).

The effect of the expected maize price on total non-maize crop production is positive and nearly significant (p=0.12), a result that 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 17 does not suggest that increases in maize production come at the expense of a decline in the production of other crops.

6.6. Area Planted to Other Crops

We next investigate the responsiveness of non-maize crop area to changes in expected maize prices. Based on the results from the previous section, we would only expect to see a positive area response for bean/cowpea (if any). We find that no crop group has a significant response in area planted to changes in the expected maize price (Table 18). The lack of bean-cowpea area response to maize price changes, coupled with the results in the previous section showing a robust bean-cowpea production response to maize price changes, must mean that improved bean-cowpea yields are driving their production increase.

Table 18. Responsiveness of Household Area Planted to Various Crops to Changes in the Log of Expected Maize Price, by Household Crop Group, 2000-2004-2007

	Dept variable = household area planted to each crop group (ha)		
Crop group	Regressor: ln(expected maize price)		
	APE	**SE**	**p-value**
Bean-cowpea	0.263	0.357	0.461
Root crops	-0.231	0.160	0.148
Vegetables	0.115	0.078	0.137
Perennials	-0.157	0.198	0.427
Short Perennials	0.254	0.210	0.226
All non-maize crops[1]	-0.703	0.716	0.326
All crops[1]	-0.417	0.974	0.669

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.

This is also consistent with the finding that maize price increases result in higher usage of inorganic fertilizer on maize fields, which are predominantly intercropped with beans and/or cowpeas.

6.7. Fertilizer Use on All Crops

Given the strong effect of the expected maize price on fertilizer applied to maize, we next look at maize price effects on household fertilizer used per hectare of *all* crops to see if additional fertilizer used on maize tends to increase total household fertilizer use or not. We estimate a double-hurdle model for total household fertilizer use per hectare of total area cultivated and find that the expected maize price does not have a significant effect on either the probability of fertilizer use on any crop or quantities applied (Table 19). These results are consistent with descriptive statistics above that demonstrate that while the percentage of smallholders using fertilizer on any crop increased from 67% in 1997 to 80% in 2007, the mean fertilizer quantity used per hectare has remained stable at around 178 kg/ha. Therefore, our descriptive and econometric evidence suggests that while the percentage of households using fertilizer on any crop has increased over time, increases in fertilizer applied to maize do not lead to significant increases in total fertilizer used by the household. We leave for further research the question of whether fertilizer applied to maize results in lower fertilizer application rates for non-maize crops.

Table 19. Double-Hurdle Model of Log Household Fertilizer Applied per Total Hectares Cultivated, 1997-2000-2004-2007

	Probit: Dept variable = 1 if HH used fertilizer on maize, 0 otherwise			Lognormal: Dept variable = ln(kgs of fertilizer applied per total hectares cultivated)					
Independent variables	APE of x_j on P(y>0)			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	0.196	0.128	0.128	-81.819	716.7	0.909	-26.024	524.6	0.960
1=2004	0.296	0.123	0.017	-58.071	2022.8	0.977	2.624	1578.9	0.999
1=2007	0.312	0.123	0.012	-127.944	6669.5	0.985	-28.432	5018.3	0.995
1=high humus / highly productive soils	-0.030	0.050	0.547	41.619	41.5	0.316	23.544	33.9	0.487
1=Regosols soils	0.009	0.066	0.896	35.517	60.9	0.560	25.822	49.8	0.604
1=very shallow, poor drainage soils	0.032	0.071	0.646	-67.700	202.7	0.738	-43.417	146.3	0.767
1=soil with high clay & poor drainage	-0.318	0.132	0.016	95.085	147.4	0.519	-16.506	116.5	0.887
6-year average of rainfall in main season	0.000	0.000	0.321	-0.001	0.001	0.378	-0.001	0.001	0.228
6-year average of drought shock in main season	0.249	0.194	0.200	0.004	0.549	0.995	0.789	0.834	0.344
ln(expected farmgate maize price)	0.196	0.136	0.150	-0.261	0.525	0.619	0.359	0.717	0.617
ln(village wage)	-0.007	0.019	0.708	-0.031	0.075	0.683	-0.053	0.091	0.562
ln(village price of DAP fertilizer)	-0.002	0.129	0.985	0.183	0.448	0.684	0.175	0.582	0.764
ln(price of beans)	0.040	0.345	0.907	0.967	0.841	0.250	1.094	1.379	0.427
ln(price of cowpeas)	0.043	0.164	0.792	-0.093	0.640	0.884	0.043	0.805	0.958
ln(price of sweet potatoes)	0.040	0.085	0.635	-0.145	0.280	0.604	-0.019	0.394	0.962
ln(price of irish potatoes)	-0.176	0.075	0.019	0.300	0.609	0.622	-0.255	0.635	0.687
ln(price of cassava)	-0.189	0.171	0.269	0.737	1.127	0.513	0.140	1.259	0.912
ln(price of kale)	-0.009	0.176	0.960	-0.080	0.251	0.750	-0.107	0.627	0.864
ln(price of onions)	-0.007	0.188	0.972	-0.003	0.539	0.995	-0.024	0.824	0.977
ln(price of tomatoes)	0.003	0.202	0.988	-0.650	0.705	0.356	-0.641	1.029	0.534
distance to nearest motorable road (km)	-0.002	0.007	0.816	0.001	0.019	0.968	-0.005	0.028	0.870
distance to nearest fertilizer seller	0.002	0.001	0.142	0.009	0.005	0.087	0.013	0.006	0.019
ln(total land area owned)	0.020	0.007	0.003	-0.091	0.033	0.007	-0.044	0.035	0.215
effective # of adults age 15-59	0.001	0.010	0.921	0.003	0.013	0.836	0.005	0.015	0.762
ln(total farm asset value)	0.005	0.004	0.132	0.016	0.015	0.270	0.033	0.019	0.080
Education level of the household head	0.005	0.002	0.031	0.000	0.006	0.947	0.015	0.009	0.091
Age of the household head	0.000	0.001	0.565	0.002	0.004	0.507	0.001	0.005	0.846
1=HH head is single female	-0.022	0.028	0.430	15.898	25.111	0.527	7.413	18.493	0.689
1=HH suffered the death of an adult age 15-59	-0.050	0.036	0.162	8.910	26.026	0.732	-2.074	17.494	0.906
# of children age 0-4	0.006	0.006	0.272	-0.004	0.019	0.846	0.016	0.026	0.528
# of children age 5-14	0.000	0.004	0.973	0.013	0.013	0.313	0.013	0.018	0.477
# of adults age 60+	0.012	0.010	0.231	-0.062	0.028	0.028	-0.023	0.045	0.609
cases		4556			3136			4556	

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). Regressions weighted by IPW method to correct for panel attrition bias.

6.8. Total Household Net Crop Income

In previous sections, we have found evidence that smallholders respond to higher expected farm-gate 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 we do not find evidence that either non-maize area planted or 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 20). Given our earlier result that a 10% increase in the village-level effective NCPB purchase price results in a 1.37% increase in the expected farm-gate maize price, this implies that a 10% increase in the NCPB purchase price leads to a 2.6% increase in household total net crop income, on average.

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, Myers, and Nyoro 2008), affect rural household welfare.

While the standard welfare analysis of policies that 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 stable 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 that 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, Myers, and Jayne 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 the reduction in maize price variation over the past decade attributable to NCPB activities has had a positive effect on fertilizer demand.

Table 20. OLS Regression of Total Household Net Crop Income, 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 20, 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
cases	4360

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

7. CONCLUSIONS

Despite the resurgence of parastatal grain marketing boards in eastern and southern Africa over the past decade, there remains little empirical work based on household-level data that investigates how marketing board activities are affecting the input use and cropping decisions of smallholder farmers in the region. Such a microeconomic foundation is necessary to meaningfully guide food policy decisions in the region. This paper uses micro-level panel survey data of smallholders in rural Kenya to investigate the effect of the activities of Kenya's NCPB on smallholders' farm-gate maize price expectations, as well as the extent to which household crop production and fertilizer use respond to changes in expected farm-gate maize prices. There are seven main findings from our econometric analysis.

First, we find that NCPB price setting has a positive and significant effect on smallholders' farm-gate maize price expectations. For example, a 25% increase in the NCPB purchase price leads to a 3.4% increase in the expected farm-gate maize price. In addition, NCPB purchases and sales appear to affect smallholder maize price expectations indirectly through a positive effect on expected farm-gate maize prices via regional wholesale maize prices. While our analysis does not test for or establish a causal link between NCPB activities and regional wholesale maize prices, we note that Jayne, Myers, and Nyoro (2008) demonstrated this for the 1995-2004 period in Kenya.

Second, we find evidence of strong responsiveness of smallholder maize production to changes in the expected farm-gate maize price. 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 are.

Third, we find significant and large positive effects of expected maize prices on the probability of smallholder fertilizer use and conditional and unconditional quantities applied per hectare of maize. A 1% increase in the expected farm-gate 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 per hectare of maize. We also find that the effects of household total farm assets and total landholding on the probability of fertilizer use on maize are of negligible magnitude, and that these factors do not significantly affect the conditional or unconditional fertilizer quantities used. This evidence, along with already widespread fertilizer use on maize in Kenya, suggests that there are only a small minority of households that appear to have financial constraints preventing them from using fertilizer on maize.

Fourth, we find that increases in the expected farm-gate maize price do not elicit increases in the area of maize under cultivation, though we do find evidence that farmers respond to higher expected maize prices by increasing the seeding rate of maize within intercropped fields. Combined with the fertilizer use results, this suggests that smallholders respond to higher expected maize prices by increasing maize production through intensification of existing maize fields, through both increased maize seeding rates and fertilizer use.

Fifth, we find no evidence to suggest that higher expected maize prices lead to reductions in either area planted to non-maize crops or non-maize crop production. This result suggests that increases in maize production do not appear to be coming at the expense of production of other crops, and that such increases are largely driven by increased fertilizer use within intercropped maize fields. This line of reasoning is consistent with our descriptive analysis that 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 expected maize price does not have a significant positive effect on the probability of household fertilizer use on all crops or on quantities applied (to all crops), which suggests that increases in fertilizer applied to maize might involve some reallocation of fertilizer use from other crops. Seventh, we find a significant positive effect of the expected farm-gate maize price on total net crop income.

In summary, we find that the NCPB pan-territorial maize purchase price has a strong, positive effect on smallholders' maize price expectations, and that smallholders respond to higher expected maize prices by increasing maize production via intensification through increased fertilizer use as well as higher maize seeding rates within intercrops. Specifically, we find that a 10% increase in the NCPB purchase leads to: a 1.4% increase in the expected farm-gate maize sale price; a 2.5% increase in household maize production; a 0.6% increase in the probability of fertilizer use on maize; increases of 1.4% and 2.9% in conditional and unconditional quantities of fertilizer applied to maize; and a 2.6% increase in household total net crop income, on average. Increases in maize production do not appear to be coming at the expense of production of other crops, as we find no evidence to suggest that higher expected maize prices lead to reductions in either area planted to non-maize crops or non-maize crop production. These findings corroborate the widely held view in Kenya that the NCPB is a powerful tool for supporting maize production specifically, and Kenyan agriculture more generally. The NCPB's activities have also been found to have a generally stabilizing effect on maize market prices in Kenya (Jayne, Myers, and Nyoro 2008).

Unfortunately, little analysis is available to assess the opportunity costs of NCPB operations and the potential impacts that could have been achieved had decades of NCPB expenditures been reallocated, partially or fully, to alternative public investments. Such analysis is impeded by restricted access to data on NCPB operating costs.[13] Should such data become publically available, an important question for further research would be to assess the social benefits of NCPB activities in relation to their costs. Such analysis would need to account for the fact that the majority of rural Kenyans (and almost all of country's urban population) are net buyers of maize and are hence adversely affected by policies that elevate food prices.

Moreover, the NCPB's support to Kenyan maize production would presumably benefit consumers if this support enabled consumers to acquire food less expensively than if that food were acquired from the world market. In recent years, however, the Kenyan staple food system has been normally operating at or above import parity levels, both due to the NCPB's price-elevating impacts on market prices and because the Government of Kenya's 50% duty on maize imported through the port of Mombasa has restricted imports that might otherwise have occurred For these reasons, it is unclear whether the NCPB's activities in support of maize self-sufficiency confer tangible benefits to the country's consumers, who continue to pay import-equivalent (or

[13] The most recent period when NCPB operating costs were publicly available was in the early 1990s, when it was estimated at roughly 5% of Kenya's gross domestic product (Jayne and Jones 1997).

higher) prices for local maize. It would be important for policy makers and the Kenyan public to know whether some of the area currently under maize could reap higher returns to other higher-valued crops and at the same time confer greater benefits to Kenyan consumers by allowing maize imports to occur when they can be landed in the major cities more cheaply than local production.

Clearly, there is a need for further study of the impacts of food marketing boards, both their sectoral effects as well as the broader general equilibrium effects, especially considering the potentially major effect of these boards on the allocation of scarce public resources. This study has shown that, at least in the case of Kenya, the NCPB is largely achieving its narrowly defined mandate, i.e., increasing maize prices and maize production, as well as contributing in a small way to overall agricultural growth. However, these benefits are being achieved at a cost that is unknown to the general public. It will be important for further research to be able to assess whether other marketing boards in the region are having similar effects, given major cross-country variations in their objectives and operations, as well as a better notion of the benefits relative to their costs.

Many governments feel a strong need to continue intervening in food markets. It is widely viewed in the region that governments are responsible for ensuring peoples' access to food (Bratton and Mattes 2003). Food prices and availability are thus highly politicized issues in most of Sub-Saharan Africa. The transition to multi-party electoral processes over the past decade may have intensified the politicized nature of food prices in some cases as political parties compete to show how they will deliver benefits to the public in times of need. This kind of environment, in which political struggles are played out in food marketing and trade policies, create major challenges for developing a market environment that provides adequate scope and incentive for private trade.

APPENDICES

APPENDIX A-1. FISHER-IDEAL INDEX

To aggregate crop production across multiple commodities, we use a modification of the Fisher-Ideal index by Mason (2011), which uses information on the individual household production (kg) and national-level prices of each crop in the crop group. The Fisher-Ideal (FI) index is a combination of two indices, the Modified Laspeyres Quantity Index (ML) and the Modified Paasche Quantity Index (MP) (Diewert 1992; Diewert 1993).

For each crop j=1 to J, we use the national median production quantity as the base quantity in the denominator of both the ML and MP indices. We use the median national-level price in the first year of the Tegemeo panel household dataset (1997) as the base year price, $p_{j,base}$. Thus, changes in the ML index are driven by changes in quantities of each commodity produced over time, as prices do not vary from the base year, nor across households.

For p_j in the MP index, we use the national median price for each year. Thus, the MP index allows price variation by year but not across households.

Modified Laspeyres Quantity Index (LQI*)

$$LQI^*_{i,t} = \frac{\sum_{j=1}^{J} q_{i,j,t}\, p_{j,base}}{\sum_{j=1}^{J} q^*_{j,base}\, p_{j,base}}$$ where *t=base* is the base period

Modified Paasche Quantity Index (PQI*)

$$PQI^*_{i,t} = \frac{\sum_{j=1}^{J} q_{i,j,t}\, p_{j,t}}{\sum_{j=1}^{J} q^*_{j,base}\, p_{j,t}}$$

Fisher-Ideal Quantity Index (FIQI*)

$$FIQI^*_{i,t} = \sqrt{(LQI^*_{i,t} \times PQI^*_{i,t})}$$

Appendix Table A1. Tobit Regression of the Household's Quantity of Maize Sold, Kenya 1997-2000-2004-2007

	Dependent Variable is the HH quantity of maize sold >=0
Independent variables	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 A1, 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%

Source: Author's calculations using Tegemeo survey data.

Appendix Table A2. Summary Statistics of Dependent Variable

Dependent variables	Obs.	1996/97 mean	1996/97 SE	1999/00 mean	1999/00 SE	2003/04 mean	2003/04 SE	2006/07 mean	2006/07 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

Source: Author's calculations using Tegemeo survey data.

Appendix Table A3. 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

Source: Authors' computations from Tegemeo survey data. Notes: A = auxiliary regressions (maize quantity sold; maize sale price); O = output supply regressions; F = fertilizer demand regressions

Appendix Table A3, Continued

Independent variables	Model	1996/97 mean	1996/97 SE	1999/00 mean	1999/00 SE	2003/04 mean	2003/04 SE	2006/07 mean	2006/07 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
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1=buyer type: other household	A	0.242	0.022	0.263	0.021	0.218	0.018	0.240	0.019
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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

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