Off-farm Income and Fertilizer Investments

By Smallholder Farmers in Kenya

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Abstract

Nonfarm earnings from diverse sources account for a substantial and growing share of household income among smallholder farmers in many areas of Sub-Saharan Africa, but information about the effects of these earnings on farm investments is relatively sparse. This study focuses on fertilizer investments given the importance of soil fertility in raising crop productivity, the central role of fertilizer in most recommendations for managing soils, and the high cash cost of fertilizers. We use panel data from a sample of roughly 1200 smallholder farmers in Kenya to estimate input demand for fertilizer, testing the effects of off-farm income, as well as nonfarm income, income from labor on other farms, and all off-farm income combined. We compare effects among three types of crops: a major food staple (maize), and emerging cash crop (vegetables), and traditional export crops (coffee/tea). Demand functions are estimated with double hurdle regression, a Control Function approach to handle potential endogeneity of off-farm income, and Correlated Random Effects to treat time-invariant heterogeneity. We find that, holding prices, other crops grown, locational and relevant household characteristics constant, off-farm earnings have a negative impact on fertilizer use on both staple and emerging cash crops in Kenya, and a weak, positive effect on traditional cash crops. Nonfarm income explains most of this pattern, although the effects of labor on other farms are evident in the case of vegetables, which are relatively labor-intensive throughout the growing season. Results have implications for public investments in rural development as smallholders commercialize in Kenya.

I. INTRODUCTION

Across Sub-Saharan Africa, the dynamics of economic change, rapid urbanization and the 'scramble' for survival livelihoods (Bryceson 2002) mean that nonfarm earnings from diverse sources account for a substantial and growing share of household income among smallholder farmers. Research has demonstrated that although situations vary widely, rural nonfarm earnings account for an average of one-third of total income (Reardon et al. 2007).

A vast literature on the topic provides mixed evidence of the role of nonfarm employment on rural poverty reduction (e.g., Lanjouw 2007; Barrett et al., 2001; Barrett et al., 2005; Haggblade et al., 2010). A recent study by Bezu, Barrett and Holden (2012) examines the relationship of nonfarm employment to rural social mobility. Drawing on rural household data for six countries, a set of recent studies examines the relationships among public cash transfers, private transfers, and farm decision-making (Davis et al. 2010). Similar to earlier findings that remittances are often geared toward consumption, Davis et al. (2010) conclude that migration is more likely to facilitate a transition toward less labor-intensive agriculture than to support productive investments. In Kenya, Djurfeldt (2012) explores the role of nonfarm activities in smoothing seasonal fluctuations in the income of agricultural households. She finds that while lack of such income sources aggravates seasonal variability among poorer households, wealthier households profit by taking advantage of better marketing opportunities and also utilize these earnings to meet both farm and nonfarm expenditures.

Until recently, few studies have formally tested the relationship between nonfarm employment and smallholder investment in agriculture, such as the choice of farming technology (Davis et al. 2009). Some researchers have explored the effects of off-farm work on farm investment (Ahituv and Kimhi, 2002; Chikwama, 2004; Morera and Gladwin, 2006). Though they used different approaches and analytical tools, most of these authors found a negative relationship between off-farm work and investment in agricultural production.

The direction of this effect has important implications for public policy and the design of programs to support rural communities in the process of agricultural development and change. Not all today's smallholder farms will be operational in the next generation; on the other hand, part-time farming may represent an equilibrium solution for at least some smallholder farmers. Understanding the relationship between different sources of off-farm income, and smallholder investments in different types of farming, is important for the design of public policy.

Soil fertility is a binding constraint to crop productivity in most regions of Sub-Saharan Africa, and there is a general consensus that raising productivity will require at least some mineral fertilizer in addition to other soil amendments (Bationo, 2004). Recently, in Western Kenya, Marenya and Barrett (2007) have shown that non-farm income positively affected the adoption of integrated soil fertility management practices (including mineral fertilizer, stover lines, and manure), also diminishing the probability of discontinued use of fertilizer. They applied a multivariate probit model, to accommodate the choice among several fertility-enhancing inputs. Among inputs that enhance soil fertility, cash constraints, of course, are thought to be particularly severe for fertilizer, but these depend on credit availability. Credit sources, in turn, depend very much on the crop and value chain.

We hypothesize a priori that the effects of working off the farm on fertilizer use are ambiguous. On one hand, earnings from off the farm may be used to compensate for missing and imperfect credit markets by providing ready cash for fertilizer purchases as well as other household needs. On the other, the engagement of household members in non-farm activities, including informal business, migration to towns for salaried work, and especially piece work on other farms can divert labor resources from agricultural activities and peak period tasks. This implies that the effects may depend on the type of off-farm employment.

Further, we hypothesize that farmers invest their off-farm earnings depending on the crop. Agricultural credit for smallholder farmers continues to be severely lacking in most countries of Sub-Saharan Africa, especially for staple food crops. Other arrangements are common for horticultural crops, including provision of inputs via farmer contracts with export companies. Traditional cash crops such as coffee and tea have vertically-integrated supply chains. With respect to staple food crops, agricultural intensification may be reliant on cash generated within the household.

We derive input demand functions for fertilizer, testing for the combined and separate effects of income from nonfarm sources and agricultural wage labor (usually known in Kenya as *farm kibarua*) among smallholder farmers in Kenya. We are able to exploit data collected from a panel of 1200 smallholder farm households distributed across the major agricultural zones of Kenya in four waves that span a decade (2000 through 2010). To accommodate the censored structure of the dependent variables, while controlling for potential endogeneity, we apply an instrumented Control Function Approach (CFA). To handle unobserved heterogeneity, or time-constant factors that vary across households, we employ the Correlated Random Effects model (CRE). We distinguish between the decision to use fertilizer and the decision regarding quantities of fertilizer applied by estimating double hurdle regression models, applying the same reduced form and structural models to the three crop categories.

This paper contributes to the sparse body of literature that empirically examines, and formally tests, the effects of off-farm work on the choice of farm technology. We add to the literature in two ways. First, we disaggregate off-farm income in order to examine differences between the role of nonfarm activities (informal business, salaries and wage employment, remittances from migration) and engagement of household members in piece work on other farms (called farm *kibarua*). Second, we compare the role of off-farm income among three categories of crops (dominant food staple, emergent and traditional cash crop).

Next, we summarize the conceptual model that serves as the basis of our empirical approach. Section 3 describes the empirical strategy and the data used in the analysis, and the econometric model. Results are presented in the fourth section. Conclusions are drawn in the final section.

2. CONCEPTUAL APPROACH

Our conceptual approach is adapted from that developed by Mathenge and Tchirley (2008), who depict an agricultural household that chooses to engage in a portfolio of on-farm and off-farm activities with uncertain, but imperfectly correlated income. Consistent with Modern Portfolio Theory, diversification involves the reduction of market risk through investment in several instruments with imperfectly correlated returns. Risk-averse households are likely to prefer portfolios with activities whose individual returns are uncorrelated or negatively correlated; even when households are risk-neutral and the utility function is linear, however, a higher expected returns from a combination of sources, rather than single source, can result from seasonality of cash flows, various forms of price rationing or market failures, and farm technology characteristics (such as land constraints).

In a two period decision model, the household decides at period t=0 how to allocate its time and previously earned income. Earned cash (*C*) can be spent on input purchases, on hired farm labor, or can be invested in an off-farm enterprise, among other activities. The household may also attempt in this initial period to obtain credit, which is unlikely in the case of maize. In the second period, the household earns income and repays any credit balances.

We define an on-farm production function $\boldsymbol{Q=Q(}L_f, L_h\boldsymbol{, Z; A, H, G)}$, where $\boldsymbol{L_f}$ is on-farm family labor, L_h is hired labor, ***Z*** represents a vector of purchased inputs, and ***A***, ***H***, and ***G*** are vectors relating to agro-ecological conditions, human capital, and other household and locational characteristics, respectively. ***H*** embodies both the skills and the orientation of the household. The household is endowed with a fixed quantity of labor time, $L=L_o + L_f$, where L_o represents off-farm labor. Purchased inputs and on-farm labor (both family and hired) are assumed to be complements in production.

Maximizing utility, and taking first order conditions with respect to inputs ***Z***, we solve the resulting first order conditions with respect to all the choice variables to derive input demand functions. In particular, the input demand function defined by the vector of inputs ***Z*** is given by:

$$\boldsymbol{Z}^* = f\,(w^h, w^o, P^Z, P^Q, C, \mathbf{A, H, G}) \quad (1)$$

Mathenge and Tschirley (2008) show, by mathematical derivation, that off-farm earnings have an ambiguous effect on input use. The fact that off-farm activities may differ in their relative returns and riskiness, and more importantly in how they relate to farm activities, is an indication that the probability that earnings from these activities will be invested in agriculture may also differ by type of off-farm activity as well as by crop.

In this study, we compare the effects on fertilizer intensification of two sources of off-farm earnings: nonfarm (salaried labor/pension, remittances, and other business and service activities) and farm *kibarua (*piece work on other farms). Building on the analysis by Mathenge and Tschirley, we also compare effects of off-farm earnings among three categories of crops: a food staple (maize), an emerging cash crop (vegetables), and a traditional cash crop (coffee, tea). Our findings have implications for the role of income diversification as smallholders commercialize, and for public investments to support agricultural development in rural communities.

3. EMPIRICAL STRATEGY

(a) Data

Data for this study were drawn from the Tegemeo Agricultural Monitoring and Policy Analysis Project (TAMPA) data set, collected during the 1999/00 and 2003/04 cropping seasons in 24 districts in nine agro-regional zones of Kenya. The sample used in this study consists of 1243 maize-producing rural households in 2000 and 2004, including farming areas with higher productivity potential such as the Central and Western Highlands of Kenya, low potential areas such as the coastal, eastern, and western lowlands, and other medium potential areas. Households that also produced vegetables numbered about 1200, and roughly 450 produced the traditional cash crops, tea (varying by survey year). The data record information on economic, demographic and other locational characteristics of the households.

(b) Econometric model

Input demand functions based on the reduced-form equation (1) were modeled to determine the factors that drive farmers' decisions to use inputs and to assess how engagement in off-farm work affects these decisions. Given the nature of the problem we used off-farm earnings in place of wages (w_o). The dependent variables in all regressions is the amount of fertilizer applied (kgs).

Separate regression models for fertilizer were estimated by crop category, each with combined off-farm income and income disaggregated by nonfarm and farm *kibarua* sources. To ensure identification of the coefficients of interest, we controlled for the economic incentives facing the households, household resource endowments, investment in public infrastructure, other income sources and agro-ecological and locational characteristics of households. Variable definitions are shown in Table 1.

Input prices (fertilizer, farm labor) and the output prices were included to control for variations in input use as a result of changes in economic incentives facing households. We used Simpson's index of crop diversification, a metric constructed over income shares and the number of crops grown in both seasons, as an indicator of the scope of agricultural activities from which the household obtains income annually. Distance to the fertilizer seller was included to proxy for the cost of transport from the input supplier to the farm.

The data used in this study span areas of differing agricultural potential and planting seasons. The inclusion of the long term (village) rainfall variable helps to control for heterogeneity across zones and regions. Recognizing the significance of soil quality, we have also included a village-specific dummy variable for high humus content or highly productive soils, based on detailed work by Sheahan (2011) with FAO soil classes. FAO classifies soils based on their formation process and overarching properties. High humus soils have nutrient rich material resulting from the decomposition of organic matter and are found in areas which were originally under forest or grassland. Unfortunately, household-specific soils data of this type are not available at a national scale.

We controlled for household resource endowments and characteristics using the average education of adults in the household and farm size. Consistent with other studies (Lamb 2003), our conceptual model assumes that input use and farm labor are complements in production. Thus, we included number of adult household members to control for labor availability.

We cannot form clear apriori expectations concerning the directional effect of most of our variables. For example, while education may imply more specialization in off-farm work, the ability to obtain earnings from these activities may also allow households to take on more risk from agricultural production. However, based on extensive literature showing higher returns to education in the off-farm sector (Huffman, 1980; Yang, 1997), it is plausible to expect that, holding all other factors constant, more educated households may prefer to invest their off-farm earnings outside their farms.

(c) Specification issues and estimation

Two specification issues, in particular, are encountered in estimating this model. The first is non-use of inputs, the Tobit model is widely used to estimate censored variables of this type, but suffers from the limitation that it treats the decision to use an input and the amount used as generated by the same underlying processes. This implies that the same set of parameters and variables determine both the discrete probability of adoption and the intensity of use. The "double hurdle" model relaxes the above assumption, and is used here. The specification enables the modeling of two separate decisions in this case: the decision to use an input and the intensity of use.

Second, we can potentially envision simultaneity of off-farm work and farm production and investment decisions: while input use could depend on earnings from off-farm work, involvement in off-farm work could be triggered by financial need for farm inputs or unemployment of family labor. In addition, involvement in off-farm work could compete for labor and capital with farming activities especially where input markets are missing. To test and control for potential endogeneity in such a non-linear model (Wooldridge 2010), we apply the control function approach (CFA).

As in a two- stage least squares (2SLS) model, the CFA requires use of instrumental variables to test for endogeneity. Our instrumental variables are the median kilometers from the households in the sample village to the nearest public telephone and source of electricity. The first stage involves regressing the suspected endogenous variable on the instruments and all the explanatory variables in the structural model. In the second stage, however, the structural model is estimated with the observed endogenous variable and the residual from the first stage added as explanatory variables. The test of endogeneity is the statistical significance of the coefficient of the residual, when the regression is estimated with bootstrapped standard errors. The control function approach is described in early work by Smith and Blundell (1986).

Given the difficulties in controlling for unobserved heterogeneity in non-linear models, we use the correlated random effects (CRE) model. As proposed by Mundlak (1978) and Chamberlain (1984), the CRE model helps to control for unobserved heterogeneity and its correlation with observed factors in non-linear models. Application of the model requires that the means of time-varying explanatory variables are included as additional regressors in the model.

In this study, we use the truncated normal distribution version of the double hurdle model. The advantage of the truncated normal distribution version or the double hurdle model of Cragg (1971) is that it nests the usual Tobit, thus allowing us to test whether the restrictions of the Tobit model are binding or not. For consistency, under the working hypothesis that different factors affect the binary decision to use fertilizer and the decision concerning the quantity to apply, we estimated the Cragg model with the logarithm of both dependent truncated variables in the second tier.

Although theory does not clearly point to the necessity of imposing exclusion restrictions in the double hurdle model (as with the Heckman model), we exclude distance to the respective input supplier in the second stage of the estimation. This is plausible given that distance traveled may be largely a fixed cost for the second hurdle, and is thus unlikely to affect the quantity decision. These findings are consistent with those of Ariga et al. (2006).

4. RESULTS

(a) Descriptive statistics

Fertilizer use and mean kgs applied are shown in Table 2 for maize, vegetables and coffee/tea, by year. Year differences are perceptible only for maize and vegetables, but are not statistically significant because of high variability in the data. As might be expected for traditional export crops with vertically-integrated value chains, not only do over 90% of farmers use fertilizer, but the mean quantities applied are considerably higher and stable across the two years studied. A higher percentage of smallholders apply fertilizer to maize (63% in 2000 and 65% in 2004) than to vegetables (51% in 2000 and 55% in 2004). Although not shown in this table, per hectare rates applied to maize are 70-72 kgs/ha on average in each survey year, as compared to 194 and 166 kgs/ha on vegetables in the two years, respectively. Rates are even higher on traditional export crops. For example, smallholders applied an average of well 900 kgs/ha to tea in each year.

Earnings from off-farm income, by crop, source and year, are presented in Table 3. In interpreting findings, it is important to remember that virtually all households in the sample grow maize, but only about 14% also grow traditional export crops and slightly under half also grow vegetables.

Differences in amounts earned are evident between source categories (on other farms, non-farm), but not among years. While amounts are highly variable, means amounts earned through farm *kibarua* differ meaningfully between all maize growers and those who grow traditional export crops. On average, labor on other farms constitutes a small proportion of total earnings from off-farm sources, with the major share earned from income-generating activities that are not related to farming (salaries and remittances and informal business). All earnings from off-farm sources represented about a third of total household income in either year. Labor on other farms composed only 2-3% of total household income, salaries and remittances were about 16-19 percent%, and the share of informal business was 13-14 %.

(b) Regression results

Table 4 shows regression results testing the effects of combined off-farm earnings on fertilizer demand, by crop category, holding other factors constant. Results support the hypothesis that the income diversification strategies affect crop choices differentially, depending on the farm family goals. Combined off-farm earnings are negatively associated with quantities of fertilizer applied to maize, suggesting that working off-farm, in general, competes with maize production. Off-farm earnings have no significant effect on amounts applied to vegetables, however, and a positive, although statistically weak, effect on fertilizer quantities used in production of coffee and tea.

Strong price responses underscore the increasingly commercial orientation of smallholder farmers in Kenya across crop categories, although the price response is more pronounced for traditional cash crops, as might be expected given the strength of the supply chain for these commodities. Interestingly, higher cutting prices are related to greater use of fertilizer on coffee and tea, which could be to use of improved planting materials. On the other hand, higher seed prices in maize are negatively associated with fertilizer use. Hybrid seed prices are higher in Kenya for newer releases by companies other than Kenya Seed, and newer releases are grown in less productive zones. Kenya Seed Company hybrids dominate in the higher maize potential zones of Kenya, where farmers also apply more fertilizer because of a better fertilizer response.

Larger farm sizes are found to exert a positive scale effect on the demand for fertilizer, particularly when maize growers also grow traditional export crops, but not when they grow vegetables. In fact, using fertilizer on vegetables is negative associated with farm size. Education has a strong and positive influence on maize intensification, which is broadly consistent with the agricultural development literature and with other research in Kenya. Binding labor constraints are demonstrated in the positive signs and significance of the numbers of household members in the active age group for labor, particularly for fertilizer application to maize, but also to coffee/tea. Surprisingly, the same effect is not visible on vegetables, where the higher then number of mature adults, in particular, the lower the probability that fertilizer is applied and the lower the total quantities applied. These effects may represent a life-cycle association. Across crops, more fertilizer is applied when households are located in areas with better soils. This finding is consistent with the fact that maize growers in these areas are likely to grow hybrid seed, hybrid seed has a steep yield response to fertilizer, and that soils with more organic matter and humus may also better integrate mineral fertilizers (Marenya and Barrett 2009). Crop diversification, our indicator of the portfolio of cropping activities and crop income sources aside from off-farm sources, does not appear to be important.

Regressions testing the disaggregated effects of nonfarm income and farm *kibarua* are reported by crop category in Table 5, shedding more light on differences by crop category. Nonfarm income drives the results with respect to coffee or tea, and we fail to reject the hypothesis that nonfarm and farm *kibarua* income are exogenous in fertilizer use decisions. Although these income sources appear to be endogenous in fertilizer use choices related to vegetable production, the only statistically strong effect is the negative association of farm *kibarua* with whether or not a household applies fertilizer to vegetables. Working on other farms competes with the demands of intensive vegetable production. We conclude that working in nonfarm employment is endogenous in fertilizer demand for maize, and has a strong negative relationship quantities applied to this staple food crop.

5. CONCLUSIONS

The results of our analysis suggest differences in the impacts of off-farm earnings on input use across crops and off-farm activity types. The emerging picture is that, holding prices, other crops grown, locational and relevant household characteristics constant, off-farm earnings have a negative impact on both fertilizer use on both staple and emerging cash crops in Kenya, and a weak, positive effect on traditional cash crops. Nonfarm income explains most of this pattern, although farm *kibarua* effects are evident in the case of vegetables, which are relatively labor-intensive throughout the growing season.

Price effects are strong in all regressions, exhibiting the complementarity of seed and fertilizer use as inputs. These findings support the conclusion that Kenya's commercializing smallholders respond to economic incentives in staple food as well as cash crop production.

Additional important questions for future research include whether off-farm earnings are reinvested in agriculture through purchase of farm capital, commercialization or other non-income generating activities (e.g. education, health) which too may have an impact on farming and off-farm activities in the longer run. Moreover, it would also be important to understand how the household member earning the income affects its reinvestment into agriculture. Further disaggregation of nonfarm sources to test effects of earnings from salaries, as compared to informal and business earnings, may provide further insights.

Other options might be to consider examining the relationship of other indicators of rural development in the areas where smallholders are farming, measured at a higher scale of analysis. This could lead to policy recommendations regarding local public investments in Kenya, as development strategies transition toward a more county-based focus. Some of these considerations will require constructing new and/or recombining existing data sets, and cannot be addressed solely on the basis of the household panel data.

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Table 1. Summary statistics for variables in regressions

Variable	**Definition**
Dependent variables	
Fertilizer use	1=apply fertilizer to crop, 0 otherwise
Fertilizer amount used	kgs applied to maize
Prices	
Fertilizer price	average farmgate price of fertilizer applied to maize, weighted by kgs
Seed price	average farmgate price of seed planted, weighted by kgs
Output price	average farmgate price of crop
Farm wage rate	average wage paid to farm labor
Market infrastructure	
Distance to fertilizer	kms to nearest fertilizer source
Demographics	
Farm size	ha owned by household
Education	average education of adults in household
Young adults	Number of adults 15-24 years
Mature adults	Number of adults 25-64 years
Agro-ecology	
Rainfall	Total mm rain in the main growing season associated with the survey year
Good soils	1=village has soils with high humus content according to FAO classification (see text); 0 otherwise
Income sources	
Crop diversification	Shannon crop diversity index (1- sum of squared area shares planted to each crop)
Off-farm income	Combined income from nonfarm sources and other farm labor, in nominal KES
Nonfarm income	Income from salaries, wages and remittances, in nominal KES
Farm labor	Income from farm labor on other farms (*kibarua*), in nominal KES
Instrumental variables	
Telephone	Median kms from of all village households to public telephone
Electricity	Median kms from of all village households to public telephone

Source: Authors.

Table 2. Fertilizer use, by crop, source and year

		2000		2004	
		Fertilizer use (%)	Fertilizer amounts (mean kgs)	Fertilizer use (%)	Fertilizer amounts (mean kgs)
Maize	Mean	0.63	73.51	0.65	58.69
	St dev	0.48	293.37	0.48	160.80
Vegetables	Mean	0.51	80.9	0.55	63.6
	St dev	(0.49.	(202.3)	(0.50)	(123.7)
Coffee/tea	Mean	0.91	184.9	0.92	180.2
	St dev	(.28)	(319.5)	(.25)	(284.3)

Source: Authors. Differences in % and mean amounts are significant by crop at 5%.

Table 3. Off-farm income earned, by crop, source and year

		2000			2004		
Production area		Off-farm income	Nonfarm income	Farm *kibarua* income	Off-farm income	Nonfarm income	Farm *kibarua* income
Maize	Mean	56384	54370	2014	74408	72929	1480
	St dev	92459	92596	7959	148924	149005	8652
Vegetables	Mean	65237	63338	1898	77824	76755	1069
	St dev	108496	108496	8144	172914	173178	6892
Coffee/Tea	Mean	73859	72722	1137	69274	68376	898
	St dev	151719	152039	5176	125405	125666	4892

Source: Authors

Note: All figures are in nominal KES. Differences are statistically significant at 5% between farm *kibarua* and nonfarm income for all crops, but not among crops or years, except for coffee/tea as compared to maize.

Table 4. Effect of combined off-farm income on smallholder demand for fertilizer, by crop category

	Maize		Vegetables		Coffee or tea	
	Binary	Ln (kgs)	Binary	Ln (kgs)	Binary	Kgs
Fertilizer price	15.52	-0.0712***	-0.00887***	-0.0159***	-0.124**	-178.2**
	(1,040)	(0.0149)	(0.000794)	(0.00180)	(0.0596)	(74.40)
Seed/cutting price	-5.265	-0.0205***			0.282***	257.4***
	(819.1)	(0.00436)			(0.0613)	(66.15)
Output price	2.405	-0.00285	0.104***	0.0228	0.0359***	37.01***
	(3,067)	(0.0178)	(0.0202)	(0.0287)	(0.0136)	(12.28)
Wage rate	0.367	-0.00103	-0.000771	0.00229	0.00773**	-2.113*
	(146.3)	(0.00128)	(0.00130)	(0.00185)	(0.00324)	(1.283)
Distance to fertilizer	3.844		-0.0114		-0.0882	
	(10,652)		(0.0136)		(0.0598)	
Farm size	9.754	0.0443***	-0.0323*	0.0257	-0.0158	103.3***
	(1,785)	(0.0146)	(0.0170)	(0.0287)	(0.0898)	(38.09)
Education	-1.251	0.0116***	-0.00186	-0.0414	-0.000737	-0.107
	(1,873)	(0.00306)	(0.0194)	(0.0270)	(0.00442)	(0.785)
Young adults	33.26	0.257***	-0.0795	-0.136*	0.0329	17.33
	(14,495)	(0.0659)	(0.0528)	(0.0735)	(0.0752)	(36.90)
Mature adults	104.4	0.647***	-0.250**	-0.407***	0.222**	-11.30
	(40,693)	(0.161)	(0.107)	(0.147)	(0.0865)	(41.22)
2004	-78.05	0.668***	-0.190*	-0.521***	0.268	538.9*
	(33,353)	(0.152)	(0.0973)	(0.129)	(0.289)	(297.1)
Rainfall	-0.597	-0.00102	0.00128***	0.00252***	-5.74e-05	-0.541**
	(111.3)	(0.000658)	(0.000377)	(0.000519)	(0.000473)	(0.221)
Good soils	-2.350	0.358***	0.108	0.437***	-0.0720	-213.3**
	(7,524)	(0.0693)	(0.0790)	(0.116)	(0.154)	(99.34)
Crop diversification	149.7	-0.0867	0.0472	-0.588	-1.021	-388.3
	(79,962)	(0.274)	(0.331)	(0.496)	(0.690)	(294.1)
Off-farm income	-0.00524	-2.72e-05***	4.84e-08	-2.45e-09	-7.02e-09	0.000393*
	(1.257)	(6.60e-06)	(2.61e-07)	(2.96e-07)	(5.80e-07)	(0.000213)
Residual	0.00517	2.76e-05***	1.27e-05***	1.96e-05***		
	(1.258)	(6.60e-06)	(4.27e-06)	(5.84e-06)		
Constant	595.2	7.871***	-1.021***	2.486***	2.023	2,348
	(78,265)	(0.719)	(0.385)	(0.548)	(1.556)	(1,673)
Observations	2404	2404	2,246	2,246	710	710

Robust standard errors in parentheses.*** p<0.01, ** p<0.05, * p<0.1.
Notes: Models estimated by CRE double hurdle with CFA to control for endogeneity where null hypothesis of exogeneity was rejected. Planting units were not homogeneous enough to calculate an average price across vegetable crops. All planting units are numbers of cuttings for coffee and tea.

Table 5. Effect of nonfarm income and farm kibarua on smallholder demand for fertilizer, by crop category

	Maize		Vegetables		Coffee or tea	
	Binary	Ln (kgs)	Binary	Ln (kgs)	Binary	Kgs
Fertilizer price	10.34	-0.0717***	-0.00873***	-0.0161***	-0.125**	-179.9**
	(1,130)	(0.0148)	(0.000827)	(0.00182)	(0.0597)	(74.39)
Seed/cutting price	-7.288	-0.0196***			0.282***	256.2***
	(3,631)	(0.00509)			(0.0614)	(65.93)
Output price	4.775	-0.00727	0.127***	0.0228	0.0358***	36.85***
	(9,887)	(0.0175)	(0.0210)	(0.0289)	(0.0136)	(12.23)
Wage rate	0.930	-0.000835	-0.000595	0.00240	0.00773**	-2.076
	(788.2)	(0.00142)	(0.00131)	(0.00187)	(0.00324)	(1.282)
Distance to fertilizer	12.27		-0.0176		-0.0879	
	(6,219)		(0.0137)		(0.0598)	
Farm size	5.403	0.0442***	-0.0665***	0.0332	-0.0151	101.8***
	(1,512)	(0.0146)	(0.0193)	(0.0320)	(0.0899)	(38.06)
Education	-0.224	0.0104***	-0.00274	-0.0416	-0.000731	-0.101
	(1,966)	(0.00287)	(0.0195)	(0.0270)	(0.00440)	(0.782)
Young adults	-2.605	0.230***	-0.0557	-0.133*	0.0322	18.01
	(9,678)	(0.0620)	(0.0530)	(0.0733)	(0.0752)	(36.87)
Mature adults	-83.49	0.530***	-0.158	-0.414***	0.223***	-11.80
	(52,208)	(0.170)	(0.110)	(0.151)	(0.0865)	(41.15)
2004	114.3	0.649***	-0.433***	-0.473***	0.271	542.4*
	(162,541)	(0.184)	(0.112)	(0.168)	(0.289)	(296.4)
Rainfall	0.715	-0.000356	0.000591	0.00259***	-4.40e-05	-0.544**
	(400.2)	(0.000932)	(0.000420)	(0.000593)	(0.000475)	(0.221)
Good soils	-15.88	0.366***	0.131*	0.421***	-0.0748	-212.0**
	(18,813)	(0.0694)	(0.0790)	(0.115)	(0.154)	(99.29)
Crop diversification	136.4	-0.0895	0.830**	-0.659	-1.037	-382.7
	(60,355)	(0.274)	(0.384)	(0.582)	(0.692)	(293.6)
Nonfarm income	0.00227	-2.19e-05***	8.04e-08	-3.29e-09	-1.72e-09	0.000382*
	(1.300)	(6.51e-06)	(2.65e-07)	(2.96e-07)	(5.80e-07)	(0.000213)
Residual1	-0.00229	2.23e-05***	9.04e-06**	1.91e-05***		
	(1.300)	(6.51e-06)	(4.25e-06)	(5.74e-06)		
Farm kibarua	0.0268	-3.52e-06	-1.00e-05**	-1.84e-06	3.04e-06	-0.00560
	(15.05)	(1.91e-05)	(4.17e-06)	(6.74e-06)	(9.77e-06)	(0.00826)
Residual2	-0.0263	-4.21e-06	-2.64e-05***	7.55e-06		
	(15.25)	(1.87e-05)	(7.36e-06)	(1.27e-05)		
Constant	1,392	7.582***	-2.144***	2.878***	2.044	2,388
	(655,506)	(1.031)	(0.530)	(0.758)	(1.558)	(1,672)
Observations	2404	2404	2,246	2,246	710	710

Robust standard errors in parentheses.*** p<0.01, ** p<0.05, * p<0.1.
Notes: Models estimated by CRE double hurdle with CFA to control for endogeneity where null hypothesis of exogeneity was rejected. Planting units were not homogeneous enough to calculate an average price across vegetable crops. All planting units are numbers of cuttings for coffee and tea