Off-farm Work and Fertilizer Intensification among Smallholder Farmers in Kenya: A Cross-Crop Comparison

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Abstract

Off-farm work accounts for a substantial and growing share of household income among smallholder farmers in most of Sub-Saharan Africa, but evidence on the effects of these earnings on farm investments remains sparse. We use panel data from a sample of smallholder farmers in Kenya to estimate input demand for fertilizer, testing the effects of earnings from nonfarm activities, agricultural wage labor on other farms, and combined off-farm sources. We compare effects among three types of crops: a major food staple (maize), and emerging cash crop (vegetables), and a traditional export crop (tea). We find that, holding other factors constant, off-farm work detracts from fertilizer application rates on maize and vegetables. Nonfarm income drives these results. Off-farm work has no effect on fertilizer application to tea. Results suggest competition for household resources between farm and nonfarm sectors, with implications for public investments in rural development as Kenyan smallholders commercialize.

I. INTRODUCTION

The dynamics of economic change, rapid urbanization and the 'scramble' for survival (Bryceson 2002) mean that off-farm earnings from diverse sources account for a substantial and growing share of household income among smallholder farmers across sub-Saharan Africa. Reardon et al. (2007) estimated that nonfarm income represented an average of 34% of rural household income based on surveys undertaken in 23 countries during the 1990s and 2000s. Bryceson (2000) reported survey estimates ranging from 55% to 80%. Matsumoto et al. (2006) reported that off-farm income represented less than30% of total household income in Uganda and Ethiopia, and 45% in Kenya. In Kenya, most off-farm income was generated by earnings from local sources rather than migration. In all three countries, agricultural wage income was negligible in magnitude.

The relative importance of farm and non-farm income in reducing poverty is debated. The experience of the Green Revolution in Asia suggests that agricultural development stimulates the growth of the nonfarm rural economy. Multiplier effects transmitted via factor and production markets favor households that are net consumers and labor suppliers. Empirical evidence of such transformations in sub-Saharan Africa remains sparse (Barrett et al. 2001; Otsuka and Yamano 2006; Lanjouw 2007). Instead, some policy makers view the rural non-farm economy as a pathway out of poverty, but such growth does not occur automatically (Haggblade et al. 2010).

Bezu, Barrett and Holden (2012) examined the relationship of nonfarm employment to the social mobility of rural households in Ethiopia, concluding that income growth is positively associated with the nonfarm share of income. In the Oromia region of Ethiopia, van den Berg and Kumbi (2006) found that land-poor households are pushed into nonfarm activities, reducing income inequality. According to Mathenge (2008) smallholder farmers engage in off-farm work as a long-term strategy to deal with anticipated weather risks; households in more productive agricultural zones of Kenya earned more from off-farm work than those in less productive areas. In Mozambique, Cunguara et al. (2011) concluded that nonfarm work is a coping strategy for farm households when faced with drought, concurring that poorer households were more likely to engage in less remunerative activities. In Western Kenya, Djurfeldt (2012) finds that while lack of nonfarm earnings aggravates the seasonal variability of income among poorer households, wealthier households 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). 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. Some researchers have explored the effects of off-farm work on farm investment. Though they used different approaches and analytical tools, some researchers have found a negative relationship between off-farm work and investment in agricultural production (Ahituv and Kimhi, 2002; Chikwama, 2004; Morera and Gladwin, 2006). Others have found a positive effect (e.g. Lamb 2003) indicating that farm and off-farm work complement each other.

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). In their study of 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). Among inputs that enhance soil fertility, cash constraints 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 off-farm earnings on fertilizer use are diverse and depend on crop type and nature of off-farm work. On one hand, earnings from off the farm may 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. Further, 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 tea and some export-oriented vegetables have vertically-integrated supply chains in which credit services are bundled with inputs and marketing arrangements. By contrast, in production of staple crops like maize, agricultural intensification may rely more directly on cash generated by the household.

We derive input demand functions for fertilizer, testing for the combined and separate effects 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 fertilizer application in the case of maize, while controlling for potential endogeneity, we apply an instrumented Control Function Approach (CFA).We employ the Correlated Random Effects (CRE) model to handle unobservable heterogeneity. We use Fixed Effects, two-stage least squares (FE2SLS) in the cases of vegetables and tea, which are continuous variables. Models are estimated in terms of total kgs of fertilizer applied to crops and N nutrient kgs, per ha. The physical quantity is the decision variable observed by farmers, but N nutrient kgs is a more precise measure of nitrogenous fertilizer application.

This paper contributes to a relatively small body of literature that empirically examines, and formally tests, the effects of off-farm work on farm production and investment decisions. In this study, we compare the role of off-farm work among three categories of crops: a major food staple (maize), an emerging cash crop (vegetables), and a traditional export crop (tea). We also 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*).

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 based on the agricultural household model and adapts a derivation developed by Mathenge and Tschirley (2008). Mathenge and Tschirley (2008) depict an agricultural household that chooses to engage in a portfolio of on-farm and off-farm activities with uncertain, but imperfectly correlated returns. Consistent with the 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 $\boldsymbol{Q}=\boldsymbol{Q}(L_f, L_h, \boldsymbol{Z}; \boldsymbol{A}, \boldsymbol{H})$, where L_f is on-farm family labor, L_h is hired labor, $\boldsymbol{Z}$ represents a vector of purchased inputs, and $\boldsymbol{A}$, $\boldsymbol{H}$, and $\boldsymbol{G}$ are vectors relating to agro-ecological conditions, human capital and other household characteristics, and other structural features of local markets. $\boldsymbol{H}$ 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. The household faces a vector of prices for labor (**w**), inputs and outputs (**P**).

Maximizing utility, and taking first order conditions with respect to inputs $\boldsymbol{Z}$, 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 $\boldsymbol{Z}$ is given by:

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

By mathematical derivation, Mathenge and Tschirley (2008) show that off-farm earnings (embedded in *C*) 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. Capacity to generate earnings off-farm is constrained by household labor supply, and some inputs, such as fertilizer, are complements with labor in crop production.

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 (*agricultural wage labor, or piece work on other farms). Building on the analysis by Mathenge and Tschirley (2008), we also compare the effects of off-farm earnings among three categories of crops: a food staple (maize), an emerging cash crop (vegetables), and a traditional cash crop (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 and growth of the rural non-farm sector.

3. METHODS

(a) Data

Data for this study were drawn from the Tegemeo Agricultural Policy Research and Analysis (TAPRA) Program data set, collected during the 1999/00, 2003/04, 2006/07 and 2009/10 cropping seasons in 24 districts in nine agro-regional zones of Kenya. The sample used in this study consists of a panel of rural households observed in 2003/04, 2006/07 and 2009/10 (1225 to 1232 for maize, 587 to 670 for vegetables, and 163 to 189 for tea, depending on the year). The data record information on economic, demographic and other locational characteristics of the households. Data collected in 1999/00 were not as complete, but are used in this study for the construction of lagged farm size.

(b) Econometric model

Input demand functions based on the reduced-form equation (1) were estimated to identify the determinants of farmer demand for fertilizer by crop and to assess how engagement in off-farm work affects these decisions. The dependent variables in all regressions reported in the main text are i) the amount (kgs) of fertilizer applied per hectare (kgs), and ii) N (nitrogen) nutrient kgs per ha. The first variable expresses the average application rate for the crop and intensity of fertilizer use, and is the decision variable observed by farmers. The second is a more precise estimate of the amount of nitrogen applied to the crop.

Separate regression models were estimated by crop category. Vegetables include those primarily grown for cash (green beans, tomatoes, snap and snow peas, peppers, spinach, okra, eggplant, carrots, onions, cucumber, and cauliflower). To ensure identification of the coefficients of interest, we controlled for the economic incentives facing the households, household resource endowments ($\boldsymbol{H}$), other structural features of the decision-making context infrastructure (***G***) and agro-ecological characteristics of the area (***A***). Variable definitions are shown in Table 1.

We also controlled for household resource endowments and characteristics ***H*** using the average education of adults in the household, supply of household labor, female headship, farm size, and assets. 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 (in two age group categories) to control for labor availability.

Female headship is also included as a dummy variable, reflecting the widespread evidence that across sub-Saharan Africa, female-headed households generally face cash and labor constraints that influence their farm investments. In Western Kenya, Marenya and Barrett (2007) found no effect of female headship on use of inorganic fertilizer, although a recent paper by Kamau et al. (2013), based on a relatively large dataset in the 'grain basket' of Kenya reports a strong negative effect on both fertilizer use and the application rates applied, particularly for maize.

Input prices (fertilizer, farm labor; **w**) were included to control for variations in input use as a result of changes in economic incentives facing households. Prices for planting material and outputs were not included in the models. With respect to maize, seed, grain, and seed-to-grain price ratios were highly and significantly correlated with the fertilizer price, which was measured at the farmgate, and weighted by the share of each type in total kgs applied. Farmgate fertilizer prices, weighted by type share, were also used in the vegetable and tea models. Vegetable models do not include product prices given the heterogeneity of units observed across products. Tea input and product prices were also significantly correlated, and only the fertilizer price and wage rate are included in the models.

Other income sources (**C**) were measured by several variables. Separate models were estimated that included total off-farm earnings and earnings disaggregated into nonfarm and agricultural wage categories. Nonfarm sources include earnings from business and work in the informal sector, earnings from salaries and wages in nonfarm occupations, and remittances. Agricultural wage labor refers to work on other farms (*kibarua*). As noted in the introduction, labor allocation among farm-related and non-farm activities is expected to influence investments in crop production differentially. In addition to these variables, 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, or the relevant market infrastructure ($\boldsymbol{G}$). The data used in this study span areas of differing agricultural potential and planting seasons ($\boldsymbol{A}$). 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). Sheahan utilized the soil classes developed by FAO from data collected in 1980, obtained from the Kenya Soil Survey and the Ministry of Agriculture. We include a dummy variable for soils with high humus content. 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. According to sources cited by Sheahan (2011), soil depth could be an indicator of potential root depth, meaning deeper soils could yield higher growth levels, and is also included.

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. On the other hand, economic theory predicts that the relationship of the fertilizer price to fertilizer demand should be negative, as well as the price for labor, which is a complementary input.

(c) Specification issues and estimation

Two characteristics of our data constraint our choice of econometric models: i) potential endogeneity of off-farm work, and ii) the structure of the dependent variable. We can 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.

The structure of the dependent variables differs by crop. In vegetable and tea production, all growers use fertilizer and regression models are linear. To test for the potential endogeneity of off-farm earnings in these models, we used Fixed Effects Two-Stage Least Squares (FE2SLS). Model diagnostics include i) the evaluation of the joint F-test for excluded instruments in the first stage regression; ii) Hansen's J test for overidentifying restrictions; and iii) the Wu-Hausman test of endogeneity. Failure to reject the null hypothesis in the Hansen-J test indicates that the 'extra' instrumental variables are exogenous in the structural equation, supporting the validity of the instruments.

In maize production, because about one-third of farmers do not apply fertilizer, the regression model is non-linear. When both the dependent variable and the potentially endogenous variable are non-linear, 2SLS is inappropriate because it implies that, in the second stage, a nonlinear function of an endogenous variable is replaced with the same nonlinear function of fitted values from the first-stage estimation (Wooldridge 2010).

To test and control for potential endogeneity in the maize model, we apply the control function approach (CFA). The control function approach is described by Wooldridge (2010) and in early work by Smith and Blundell (1986). As in a two- stage least squares (2SLS) model, the CFA requires use of instrumental variables to test for endogeneity. 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. In the CFA, the test of endogeneity is the statistical significance of the coefficient of the residual in the structural regression. Failure to reject the null hypothesis of exogeneity implies that the decision to work off-farm can be treated as if it were exogenous to fertilizer use.

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 the maize models, we estimate a Tobit model with Correlated Random Effects Model (Tobit CRE). Application of the CRE approach requires that the means of time-varying explanatory variables be included in the regression.

Our instrumental variables in all models are of two types. The first, which is an indicator of village labor supply, is uniform across crops and type of off-farm work. Village labor supply is measured as the total number of adult equivalent persons per village divided by total farm area. While household labor supply is endogenous to fertilizer decision-making, the structure of the local labor market should affect fertilizer use only through decisions to allocate labor between farm and off-farm activities. The second variable, location earnings share, differs by type of off-farm work. The share is calculated as the total amount of earnings by source divided by total household income at the scale of the location. In Kenya, the location is an administrative area containing multiple villages. Thus, these variables are indicators of the structure of income in the broader decision-making context of the farm household.

4. RESULTS

(a) Descriptive statistics

Fertilizer use and application rates per ha are shown in Table 2 for maize, vegetables and tea, by year. Around two-thirds of maize growers applied fertilizer over the survey years. Fertilizer was applied by all vegetable and tea growers.

Year differences in applications rates per ha are perceptible for all crop categories, but appear to be more pronounced for vegetables, where they decline sharply over time. This decline could reflect the changing profitability of vegetable crops, and the shifting combination of crops included in the category over survey years. As might be expected for a traditional export crop with a vertically-integrated value chain, mean quantities applied are many times higher and more stable across the years studied than for vegetables sold as cash crops, although rates also decline sharply in 2010. Mean application rates on tea are above 900 kgs/ha in three of the four survey years, compared to a high of 193 kgs/ha on and a low of 118 kgs/ha on vegetables. Mean application rates on maize vary almost imperceptibly between 67 and 73 kgs/ha across survey years.

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. Mean amounts are highly variable over the survey years, and appear to differ more across years than crop categories.

Table 4 shows that 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). Considering all survey years, earnings from off-farm sources represented about a third of total household income among maize-growing and vegetable-growing households, but closer to one-fifth among tea-growing households. 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 %. Thus, our data indicate that income from farming constituted an average of 66-77% of total household income among smallholders, which is higher than the estimates reported by Matsumoto et al. (2006).

(b) Regression results

Table 5 shows diagnostic statistics for all models estimated with total kgs of fertilizer per ha as the dependent variable. Statistical significance paralleled these for the models explaining kgs of N nutrients applied. In the FE2SLS regressions, the significance of the F statistics and lack of significance of the Hansen-J statistics support the validity of the instruments in both sets of vegetable and tea models. The null hypothesis of exogeneity is rejected for combined off-farm earnings and nonfarm earnings, but cannot be rejected in the case of agricultural wage labor. The lesser importance of agricultural wage labor in off-farm earnings may explain this result, since working nonfarm, which represents the largest share of off-farm earnings, necessitates substantial re-allocation of household labor resources. With respect to maize intensification, we rejected the null hypothesis of exogeneity regardless of source of off-farm earnings. Maize is the major staple for all households included in the survey, and occupies family labor at the same time of the season that household members would seek wage labor on neighboring farms. The complementary nature of family labor and fertilizer use in maize production explains this result. The significance of the coefficient on the residual is weaker (10% as compared to 1%) for wage earnings from agricultural labor than for off-farm and nonfarm earnings.

Tobit CRE models testing the effects of off-farm earnings on maize intensification are shown in Tables 6 and 7, for total kgs of fertilizer per ha and N nutrient kgs per ha. The marginal effects of all three types of off-farm earnings are significant at the 1% level, and larger in magnitude for agricultural wage labor than for nonfarm earnings. This is evidence of the direct competition for family labor between maize production and work on nearby farms during the growing season. The magnitudes are similar for nonfarm earnings and combined off-farm earnings, again reflecting the relative importance of nonfarm earnings in the total income from off-farm sources.

Other results include strongly significant, negative effects of fertilizer price and distance to fertilizer source on fertilizer demand, as predicted by theory and the increasingly commercial orientation of smallholder farmers in Kenya. Female headship also has a dramatic downward effect on fertilizer application rates on maize, consistent with Kamau et al. (2013). Long-term average rainfall is positively associated with fertilizer use, as are good soils. Human capital, expressed in both education and in the supply of mature adults, is positively associated with fertilizer use. Overall, the only difference between the models with total kgs of fertilizer per ha and N nutrient kgs per ha as dependent variables is the magnitude of the regression coefficients.

Vegetable models are presented in Tables 8 and 9. Off-farm earnings and non-farm earnings have a negative association with fertilizer application rates on vegetables (coefficients are almost identical in magnitudes and significance), with no observed effect of agricultural wages. In the agricultural wage model, in which we failed to reject the hypothesis of exogeneity, female head is positively related and farm size is negatively related to fertilizer application rates. Otherwise, in the off-farm and nonfarm models, family labor and asset values increase the intensity of fertilizer use, as predicted by the conceptual model of the household farm. Surprisingly, the fertilizer price effects are weak in these models—either because of the heterogeneity of the products included in this group, or because use of fertilizer is essential to vegetable production and thus growers are not particularly responsive to price. Rainfall effects are strongly significant in all vegetable models. Again, there is little discernible difference between the total kgs of fertilizer per ha and N nutrient kgs models. Similarities between the magnitudes of coefficients suggest that N is the dominant nutrient in the fertilizers applied.

Off-farm earnings have no observable effect on fertilizer application rates on tea, regardless of source. Over time, tea-growing households have more consistent expectations about their input supply and product market, leading to a more stable environment in terms of decisions about farm investments and labor allocation between farm and nonfarm activities. The strong price responses in the tea models underscore the commercial orientation of smallholder growers of this traditional export crop in Kenya. The vertical integration of the value chain may explain why distance to fertilizer source is not statistically significant, since inputs are supplied through the services of the Kenya Tea Development authority. Among household characteristics, assets are negatively associated with intensity of fertilizer use in both total kgs and N nutrient kg models. Long-term average rainfall has no significant effect on fertilizer application rates, perhaps because of the relative homogeneity of tea production environments in the higher rainfall areas. There are statistically significant year effects, however.

5. CONCLUSIONS

Our analysis shows differences in the way that off-farm earnings influence investments in fertilizer across crops categories and types of off-farm activity. The emerging picture is that, holding other factors constant, off-farm earnings has no discernible effect on fertilizer use on tea, a traditional cash crop in Kenya, regardless of whether it is derived from nonfarm sources or agricultural labor on other farms. By contrast, off-farm earnings, which are dominated by nonfarm earnings, have a strong and negative effect in vegetable production. All sources of off-farm earnings are negatively associated with the intensity of fertilizer use in maize production, but the magnitude of the effect is strongest for agricultural wage labor, which competes directly with maize for family labor during the growing season. While we sought to render estimates more precise through specifying the dependent variable in terms of N nutrient kgs rather than total kgs per ha, the only difference in results /reflects the relative dominance of N nutrients in the fertilizer applied.

Negative effects of fertilizer price in demand for fertilizer are evident in maize and tea models, consistent with economic theory and supporting the conclusion that Kenya's commercializing smallholders respond to economic incentives in staple food as well as cash crop production. The weak relationship between fertilizer price and use in the vegetable models may express the heterogeneity among products included in this category. Despite strong price effects, household characteristics play some role in most of the models, consistent with the notion that fertilizer markets remain imperfect. Household characteristics are particularly prominent in the maize models. Maize is both a staple food and a source of cash. Female headship has major negative effect on fertilizer application rates in maize production. Also, distance to fertilizer source is important in the maize models but not in the vegetable or tea models. Unlike maize growers, vegetable and tea growers often work under contracts in which inputs and other services are provided.

The direction of the relationship between off-farm employment and on-farm investment has important implications for public policy to support rural communities during the process of economic change. Not all of today's smallholder farms will be operational in the next generation of farmers; on the other hand, part-time farming may represent an equilibrium solution for at least some smallholder farmers. Ironically, the future of smallholder farming may lie in the measures taken to stimulate the rural nonfarm economy and provide jobs for those exiting farming—a favorable rural investment climate, provision of public goods, institutional development (Wiggins et al. 2010).

This paper provides empirical evidence of the potential competition in resource commitments by smallholder farm families to farm and nonfarm sectors as Kenya's rural areas develop. and investments importance of off-farm work in promoting agricultural intensification in Kenya. The results generally support the view that nonfarm work may detract from, rather than complement production of staple food crops and emerging, labor-intensive cash crops by drawing labor resources away from the farm, particularly the work involves piecework or agricultural labor on other farms. curbing the capacity of smallholders to invest and raise productivity on their own farms. We found no impact on the traditional export crop, however, given its highly structured, vertically-integrated supply chain and predictable investment schedule.

Moreover, it would also be important to understand how the household member earning the income affects whether or not investment in agricultural production occurs. Further disaggregation of nonfarm sources to test effects of earnings from salaries, as compared to informal and business earnings, may provide further insights. Other inputs, and other crops, warrant investigation.

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. Variable definitions

Variable	Definition
Dependent variables	
Fertilizer use	1=apply fertilizer to crop, 0 otherwise
Fertilizer rate	kgs applied to crop per hectare
Market characteristics	
Fertilizer price	average farm-gate price of fertilizer applied to crop, weighted by share of type in total kgs
Farm wage rate	average wage paid to farm labor in village
Distance to fertilizer	kms from farm-gate to nearest fertilizer source
Household characteristics	
Assets	Total nominal value (KES) of all household and farm assets, including farm and transport equipment, livestock, buildings, consumer durables
Farm size	ha owned by household in previous survey season
Female head	household headed by female=1, 0 else
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	Average main season rainfall at village scale from 1996 to survey year, in total mm
Good soils	1=village has soils with high humus content according to FAO classification (see text); 0 otherwise
Depth	Soil depth (FAO classification)
Income sources	
Crop diversification	Shannon crop diversity index (1- sum of squared area shares planted to each crop)
Off-farm earnings	Combined income from nonfarm sources and other farm labor, in nominal KES '000
Nonfarm earnings	Income from business, salaries, wages and remittances, in nominal KES '000
Agricultural wages (Farm *kibarua*)	Income from farm labor on other farms, in nominal KES '000
Instrumental variables	
Location earnings share	Total earnings by type of off-farm work, divided by total income, measured at location scale
Village labor supply	Total adult equivalent persons per village divided by total village farm area

Source: Authors.

Table 2. Fertilizer use, by crop and year

		Maize		Vegetables		Tea	
		Mean	S.D.	Mean	S.D	Mean	S.D.
2000	%	0.63	0.48	1	0	1	0
	Kgs/ha	70.8	196	193	308	913	653
2004	%	0.66	0.47	1	0	1	0
	Kgs/ha	72.8	190	169	268	943	1071
2007	%	0.69	0.46	1	0	1	0
	Kgs/ha	67.4	72.9	118	137	918	716
2010	%	0.68	0.46	1	0	1	0
	Kgs/ha	72.1	71.5	125	192	706	365
All years	%	0.66	0.47	1	0	1	0
	Kgs/ha	70.8	146	152	239	871	753

Source: Authors.

Table 3. Off-farm earnings (nominal KES), by source, crop and year

		Off-farm		Nonfarm		Agricultural wage	
		Mean	S.D.	Mean	S.D	Mean	S.D.
2000	Maize	55779	91886	53745	92012	2034	7955
	Vegetables	67963	106646	65898	107018	2056	7627
	Tea	73860	151720	72722	152040	1137	5176
2004	Maize	74219	148595	72726	148675	1493	8689
	Vegetables	74636	157517	73136	157565	1499	8452
	Tea	69275	125405	68376	125667	898	489
2007	Maize	78833	128789	76295	129587	2538	8579
	Vegetables	86017	148608	83781	149462	2236	7252
	Tea	81277	140416	78596	141227	2683	10157
2010	Maize	116022	221019	112769	221901	3253	1009
	Vegetables	147507	240844	145144	241841	2363	7631
	Tea	112853	1672534	109833	168330	3020	1138

Source: Authors.

Table 4. Distribution of total household income by income source and crop, all years

		Nonfarm					
		Business/ informal	Salaries/ remittances	Farm *Kibarua*	All Off-Farm	All On-Farm	Total
		(1)	(2)	(3)	(1+2+3)	(4)	(1+2+3+4)
Maize	Mean	0.142	0.175	0.027	0.344	0.656	1.00
	S.D.	0.217	0.242	0.097	0.281	0.281	
Vegetables	Mean	0.137	0.164	0.021	0.322	0.678	1.00
	S.D.	0.216	0.228	0.082	0.274	0.274	
Tea	Mean	0.085	0.133	0.012	0.230	0.770	1.00
	S.D.	0.156	0.191	0.050	0.227	0.227	

Source: Authors

Table 5. Summary of diagnostic tests for instrumental variables

Model	F -test	Endogeneity test	Hansen J Statistic
Total kgs of fertilizer			
Vegetables			
Off-farm	10.06(0.000)	6.049(0.0139)	0.310(0.577)
Nonfarm	10.08(0.000)	6.062(0.0138)	0.304(0.581)
Farm kibarua	5.99(0.0026)	0.623(0.4301)	0.307(0.579)
Tea			
Off-farm	9.94(0.001)	5.195(0.0277)	0.181(0.670)
Nonfarm	9.96 (0.001)	5.204(0.0225)	0.178(0.673)
Agricultural wage	5.91(0.0028)	0.555(0.4563)	0.154(0.695)
	LLR test	Endogeneity test	
Maize			
Off-farm	60.63(0.000)	0.244(0.009)	
Nonfarm	63.69(0.000)	0.230(0.007)	
Agricultural wage	46.18(0.000)	0.584(0.096)	

Source: Authors.

Note: Value of test statistic, with p-values reported in parentheses. The Hansen J test is relevant only in FE2SLS models. Log-likelihood ratio tests were used to evaluate the significance of the instruments in the maize models.

Table 6. Effects of off-farm earnings on total kgs of fertilizer applied per ha of maize

	Off-farm	Nonfarm	Agricultural wage
Fertilizer price	-0.965***	-0.956***	-0.698***
	(0.232)	(0.230)	(0.212)
Female head	-13.02***	-12.88***	-6.106**
	(4.477)	(4.379)	(2.834)
Farm wage rate	0.281	0.283	0.223
	(0.231)	(0.232)	(0.156)
Distance to fertilizer	-0.905**	-0.907**	-0.486
	(0.427)	(0.422)	(0.377)
Assets	2.60e-05	2.52e-05	-3.79e-05**
	(2.11e-05)	(2.06e-05)	(1.73e-05)
Farm size	-0.102	-0.0719	-0.291
	(0.221)	(0.215)	(0.367)
Education	0.159**	0.161**	0.0101
	(0.0700)	(0.0696)	(0.0415)
Young adults	0.538	0.357	-0.263
	(1.524)	(1.577)	(1.779)
Mature adults	6.344*	5.858*	0.822
	(3.431)	(3.236)	(3.176)
2004	2.382	2.657	-4.545
	(6.863)	(6.840)	(10.83)
2007	2.251	1.576	1.355
	(5.214)	(5.433)	(6.011)
2010	31.63***	29.86***	16.81*
	(7.375)	(7.365)	(9.468)
Rainfall	0.0628***	0.0638***	0.0633***
	(0.0134)	(0.0134)	(0.0105)
Good soils	20.80**	20.28*	28.04***
	(10.30)	(10.43)	(7.613)
Depth	2.251	2.115	3.941**
	(2.303)	(2.330)	(1.533)
Crop diversification	1.257	-0.0421	6.911
	(18.40)	(18.64)	(14.01)
Off-farm earnings	-0.243***		
	(0.0943)		
Residual 1 (stage 1)	0.244***		
	(0.0938)		
Nonfarm earnings		-0.229***	
		(0.0866)	
Residual 2 (stage 1)		0.230***	
		(0.0860)	
Agricultural wages			-0.684**
			(0.339)
Residual 3 (stage 1)			0.584*
			(0.351)
Observations	3,079	3,079	3,079

Source: Authors.

Note: Tobit CRE model. Unconditional standard errors. Coefficients are average partial effects.

*** p<0.01, ** p<0.05, * p<0.1

Table 7. Effects of off-farm earnings on N nutrient kgs applied per ha of maize

	Off-farm	Nonfarm	Agricultural wage
Fertilizer price	-0.266***	-0.264***	-0.214***
	(0.0414)	(0.0412)	(0.0402)
Female head	-2.523***	-2.499***	-1.166**
	(0.851)	(0.834)	(0.567)
Farm wage rate	0.0487	0.0491	0.0408
	(0.0424)	(0.0424)	(0.0286)
Distance to fertilizer	-0.251***	-0.251***	-0.161**
	(0.0868)	(0.0861)	(0.0786)
Assets	5.71e-06	5.57e-06	-6.46e-06**
	(3.90e-06)	(3.80e-06)	(3.21e-06)
Farm size	-0.0226	-0.0167	-0.0488
	(0.0623)	(0.0615)	(0.0848)
Education	0.0313**	0.0317**	0.00262
	(0.0129)	(0.0128)	(0.00781)
Young adults	0.178	0.142	0.00425
	(0.289)	(0.299)	(0.334)
Mature adults	1.333**	1.240**	0.180
	(0.640)	(0.605)	(0.588)
2004	0.323	0.379	-1.006
	(1.278)	(1.274)	(1.990)
2007	0.936	0.804	0.579
	(1.075)	(1.112)	(1.204)
2010	8.517***	8.174***	5.285***
	(1.596)	(1.608)	(1.975)
Rainfall	0.0100***	0.0102***	0.00993***
	(0.00257)	(0.00258)	(0.00207)
Good soils	4.098**	3.993**	5.482***
	(1.901)	(1.924)	(1.431)
Depth	0.515	0.487	0.857***
	(0.431)	(0.436)	(0.298)
Crop diversification	1.088	0.832	1.997
	(3.414)	(3.457)	(2.641)
Off-farm earnings	-0.0488***		
	(0.0172)		
Residual 1 (stage 1)	0.0483***		
	(0.0172)		
Nonfarm earnings		-0.0460***	
		(0.0158)	
Residual 2 (stage 1)		0.0457***	
		(0.0158)	
Agricultural wages			-0.124**
			(0.0629)
Residual 3 (stage 1)			0.104
			(0.0646)
Observations	3,079	3,079	3,079

Source: Authors.

Note: Tobit CRE model. Unconditional standard errors. Coefficients are average partial effects. *** p<0.01, ** p<0.05, * p<0.1

Table 8. Effects of off-farm earnings on total kgs of fertilizer applied per ha of vegetables

	Off-farm	Nonfarm	Agricultural wage
Fertilizer price	0.000334	0.000334	0.000548*
	(0.000581)	(0.000582)	(0.000312)
Female head	0.115	0.110	0.276**
	(0.162)	(0.164)	(0.137)
Farm wage rate	-0.000338	-0.000296	-0.00127
	(0.00139)	(0.00139)	(0.00109)
Distance to fertilizer	0.000238	0.000588	-0.00462
	(0.0135)	(0.0135)	(0.0111)
Assets	4.36e-07*	4.35e-07*	8.95e-08
	(2.52e-07)	(2.51e-07)	(8.53e-08)
Farm size	-0.00714	-0.00707	0.0122*
	(0.0243)	(0.0243)	(0.00702)
Education	0.00356	0.00326	-0.000631
	(0.0144)	(0.0144)	(0.0127)
Young adults	-0.00353	-0.00491	-0.0208
	(0.0255)	(0.0254)	(0.0214)
Mature adults	0.120*	0.118*	0.00229
	(0.0670)	(0.0661)	(0.0240)
2004	0.105	0.107	0.0140
	(0.0856)	(0.0858)	(0.0720)
2007	-0.0312	-0.0355	-0.110
	(0.0939)	(0.0930)	(0.0730)
2010	0.214	0.206	-0.0331
	(0.164)	(0.161)	(0.0920)
Rainfall	0.00249***	0.00248***	0.00222***
	(0.000730)	(0.000728)	(0.000589)
Crop diversification	-0.182	-0.181	-0.283
	(0.274)	(0.274)	(0.192)
Off-farm earnings	-0.00368**		
	(0.00174)		
Nonfarm earnings		-0.00367**	
		(0.00174)	
Agricultural wages			-0.000846
			(0.00312)
Constant			3.453***
			(0.403)
Observations	2,078	2,078	2,286
Number of hhid	682	682	890

Source: Authors.
Note: FEIV2SLS for off-farm, nonfarm; FE for farm kibarua, although results are similar with FE2SLS.
Robust standard errors in parentheses.*** p<0.01, ** p<0.05, * p<0.1

Table 9. Effects of off-farm earnings on N nutrient kgs applied per ha to vegetables

	Off-farm	Nonfarm	Agricultural wage
Fertilizer price	0.000135	0.000135	0.000337
	(0.000708)	(0.000708)	(0.000348)
Female head	0.104	0.0991	0.257*
	(0.161)	(0.162)	(0.136)
Farm wage rate	-0.000521	-0.000481	-0.00140
	(0.00137)	(0.00138)	(0.00108)
Distance to fertilizer	0.00108	0.00139	-0.00337
	(0.0133)	(0.0134)	(0.0113)
Assets	4.51e-07*	4.51e-07*	1.22e-07
	(2.45e-07)	(2.45e-07)	(8.63e-08)
Farm size	-0.00517	-0.00511	0.0132*
	(0.0234)	(0.0234)	(0.00701)
Education	0.00246	0.00218	-0.00150
	(0.0147)	(0.0147)	(0.0133)
Young adults	0.00410	0.00278	-0.0122
	(0.0256)	(0.0255)	(0.0219)
Mature adults	0.114*	0.112*	0.00206
	(0.0665)	(0.0657)	(0.0246)
2004	0.0876	0.0891	0.000483
	(0.0855)	(0.0858)	(0.0729)
2007	-0.0282	-0.0324	-0.103
	(0.0934)	(0.0926)	(0.0744)
2010	0.206	0.199	-0.0280
	(0.163)	(0.160)	(0.0920)
Rainfall	0.00259***	0.00258***	0.00233***
	(0.000725)	(0.000724)	(0.000596)
Crop diversification	-0.138	-0.137	-0.231
	(0.267)	(0.267)	(0.193)
Off-farm earnings	-0.00349**		
	(0.00174)		
Nonfarm earnings		-0.00348**	
		(0.00173)	
Agricultural wages			-0.000859
			(0.00298)
Constant			1.697***
			(0.404)
Observations	2,073	2,073	2,281
Number of hhid	681	681	889

Source: Authors.

Note: FE2SLS for off-farm, nonfarm; FE for farm kibarua, although results are similar with FE2SLS. Robust standard errors in parentheses.*** p<0.01, ** p<0.05, * p<0.1

Table 10. Effect of off-farm earnings on total kgs of fertilizer applied per ha of tea

	Off-farm	Nonfarm	Agricultural wage
Fertilizer price	-0.0309**	-0.0306**	-0.0359***
	(0.0125)	(0.0127)	(0.0115)
Female head	-0.0662	-0.0723	0.113
	(0.504)	(0.512)	(0.411)
Farm wage rate	-0.00123	-0.00142	0.000468
	(0.00442)	(0.00466)	(0.00320)
Distance to fertilizer	0.0548	0.0536	0.0548
	(0.0445)	(0.0445)	(0.0380)
Assets	-4.28e-07**	-4.30e-07**	-3.62e-07***
	(1.88e-07)	(1.92e-07)	(1.30e-07)
Farm size	0.0519*	0.0520*	0.0453
	(0.0292)	(0.0293)	(0.0289)
Education	-0.00842	-0.00770	-0.00164
	(0.0364)	(0.0364)	(0.0338)
Young adults	0.0521	0.0536	0.0669
	(0.0797)	(0.0790)	(0.0709)
Mature adults	-0.0321	-0.0324	0.0778
	(0.193)	(0.195)	(0.0766)
2004	0.339	0.340	0.237
	(0.530)	(0.532)	(0.477)
2007	1.318***	1.322***	1.288***
	(0.434)	(0.436)	(0.426)
2010	1.614***	1.621***	1.698***
	(0.531)	(0.530)	(0.573)
Rainfall	0.00183	0.00181	0.00214
	(0.00219)	(0.00220)	(0.00185)
Crop diversification	-0.190	-0.204	-0.211
	(0.494)	(0.494)	(0.460)
Off-farm earnings	0.00238		
	(0.00367)		
Nonfarm earnings		0.00244	
		(0.00380)	
Agricultural wages			0.00383
			(0.00497)
Constant			4.647***
			(1.417)
Observations	397		420
Number of hhid	174		197

Source: Authors.

Note: FEIV2SLS for off-farm and nonfarm models FE for farm kibarua.

Robust standard errors in parentheses.*** p<0.01, ** p<0.05, * p<0.1

Table 11. Effects of off-farm earnings on N nutrient kgs applied per ha of tea

	Off-farm	Nonfarm	Agricultural wage
Fertilizer price	-0.0306**	-0.0305**	-0.0334***
	(0.0122)	(0.0123)	(0.0115)
Female head	-0.0346	-0.0363	0.0634
	(0.464)	(0.472)	(0.371)
Farm wage rate	-0.000940	-0.00103	6.91e-05
	(0.00432)	(0.00455)	(0.00312)
Distance to fertilizer	0.0492	0.0486	0.0499
	(0.0436)	(0.0434)	(0.0391)
Assets	-3.87e-07**	-3.88e-07**	-3.51e-07***
	(1.78e-07)	(1.80e-07)	(1.31e-07)
Farm size	0.0311	0.0310	0.0276
	(0.0242)	(0.0242)	(0.0249)
Education	0.00300	0.00346	0.00613
	(0.0336)	(0.0335)	(0.0321)
Young adults	0.0654	0.0664	0.0723
	(0.0810)	(0.0799)	(0.0717)
Mature adults	0.0127	0.0135	0.0708
	(0.198)	(0.199)	(0.0752)
2004	0.251	0.250	0.196
	(0.546)	(0.547)	(0.497)
2007	1.245***	1.247***	1.226***
	(0.449)	(0.451)	(0.440)
2010	1.516***	1.520***	1.556***
	(0.551)	(0.551)	(0.591)
Rainfall	0.00218	0.00218	0.00236
	(0.00190)	(0.00189)	(0.00179)
Crop diversification	0.390	0.382	0.387
	(0.457)	(0.454)	(0.441)
Off-farm earnings	0.00129		
	(0.00360)		
Nonfarm earnings		0.00130	
		(0.00372)	
Agricultural wages			0.00351
			(0.00530)
Constant			2.890**
			(1.383)
Observations	397	397	420
Number of hhid	174	174	197

Source: Authors.

Note: FE2SLS in off-farm and nonfarm models; FE in farm kibarua model

Robust standard errors in parentheses.*** p<0.01, ** p<0.05, * p<0.1