Intensification and Intra-Household Decisions:
Fertilizer Adoption on Collective and Individual Fields in Burkina Faso

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Abstract

We contribute to the understanding of technology adoption decisions by complex farm households in the Sudano-Sahelian region of West Africa, where production is organized collectively under the leadership of a senior head who also allocates individual fields to members. Farm families span generations and encompass several nuclear households. We examine the nature of the linkage between fertilizer use decisions on collective and individual plots based on a conceptual model of intra-household bargaining that enables us to draw inferences about efficiency of input allocation. Although the share of individual maize plots receiving fertilizer is lower, use rates on maize tend to be higher than on collective fields. Adoption of fertilizer on a collective plot contributes to a 0.32 rise in adoption probability on an individual plot, but the converse is not true. The marginal effect of application rates on collective plots is positively associated with intensity of use on individual plots but of a magnitude consistent with inefficiency of resource allocation. Determinants of adoption differ between individual and collective fields, and between the decision to use fertilizer and the intensity of use. Findings have implications for the design of extension programs and policies to support agricultural intensification in the region.

I. Context

Rural households in much of Sudano-Sahelian region of West Africa often have a complex organization that spans multiple generations and encompasses several nuclear households. Farming activities of the family are organized collectively under the leadership of the senior head or designate. Family members grow multiple crops on numerous plots. Historically, this social organization may reflect the fact that in dryland farming areas with harsh growing conditions, limited use of equipment and purchased inputs, success in averting hunger has depended on how effectively labor and land resources are pooled and dispatched. Risk and uncertainty have been invoked to explain various forms of collective farming (e.g., Chayanov 1991; Fafchamps 2001).

Cultural norms—although these are not fixed—dictate that the head, who has ultimate responsibility for ensuring household food security, supervises input and labor use on major fields of cereal crops, which are collectively (commonly, or "communally") farmed on behalf of the extended family. Labor is contributed by each member to production on collective fields and harvests are shared as meals consumed in common or in grain allocations by the head, who 'holds the keys' to the family granaries. Sons and younger brothers of the head, as well as wives and in some cases, widows, are allocated fields which they manage individually to supplement their personal needs, or to contribute to the needs of the group in times of duress (Thorsen 2002; Van der Broek 2009). Allocation of land, labor and other inputs to individuals is the outcome of a negotiation process.

Applied economists have long recognized the empirical challenge of microeconomic analysis based on decision-making units such as these. For example, Folbre (1984) proposed a bargaining model as an alternative to Becker's (1981) theory of household decision-making, which was based on the notion of a unitary household acting as an individual. From Folbre's perspective, family altruism coexists with conflict of interest over the distribution of goods and time; individual income shares (here, resource allocation) are determined in part by individual bargaining. Over time, bargaining positions change, as do the prices of goods in the family. McElroy and Horner (1981), among others, proposed a cooperative bargaining model; Jones (1983) specified a Nash bargaining model to explore allocative inefficiency in rice growing families of Northern Cameroon. Chiappori (1992) suggested a model of collective bargaining in intra-household resource allocation that was based on fewer assumptions than the cooperative bargaining model and a weaker assumption of Pareto efficiency.

Udry (1996) postulated an intra-household model based on production of public and private goods (output from collective and individual fields, respectively). Applying the model to data collected by the International Crops Research Institute of the Semi-Arid Tropics (ICRISAT) from 1981-1985 (a panel of 150 households in 6 villages), he found that controlling for crop, household and plot characteristics, yields were 20% higher on plots managed by men compared with those managed by women. The data led him to reject the assumption that resource allocations among household members were Pareto-efficient. Udry (1996) argued that the source of differential productivity was input intensity—for example, he contended that "virtually all fertilizer is concentrated on plots controlled by men"(1996:1028), despite that the marginal product of fertilizer is diminishing. Udry (1996) was referring to use of manure rather than chemical fertilizer, and focused on gender comparisons rather than comparisons between collective and individual fields.

Employing the same data, following the same general econometric approach as Udry's (1996), Akresh et al. (2011) tested the effects of polygyny (two or more wives) on yield differentials. The authors concluded that polygyny reduces yield differentials associated with the gender of the plot manager, either by enhancing efficiency, or through preferences of co-wives for altruistic or cooperative behavior. More recently, also in Burkina Faso and using the same data, Kazianga and Wahhaj (2013) demonstrated that yields on the collective plots managed by household heads were higher than those managed individually. Although men obtained higher yields on the plots they managed than did women in the household, no difference existed between individual plots managed by men and women. They concluded that "the social institution that places a particular obligation on the head of the household—and the fact that the household head is usually a man—can account entirely for the gendered pattern in agricultural production documented in the existing literature" (2013: 540).

In the Sudano-Sahelian region of Mali, following a specification similar to Udry's (1996), Ouedraogo (2015) found more intensive use of labor, and higher productivity, on collective as compared to individual plots. By contrast, also in Mali, Guirkinger et al. (2015) concluded that plots managed by individuals had higher productivity than those managed collectively by heads, especially for cash crops. In a related article, Guirkinger and Platteau (2014) explicitly aim to explain the acceleration of individual plots as a response of the patriarchal head to declining land endowments and the inefficiencies (resulting from moral hazards of team work) of collective farming. The authors recognize that technology change or the presence of well-developed, off-farm labor markets which provide economic opportunities for youth might also explain increasing individualization of production. Unfortunately for this region, as noted by Guirkinger and Platteau (2014), there is limited evidence of such transformations.

In this paper, we ask a related, but different, question. Most of the studies above, which include models derived from Udry (1996), compare labor use or productivity differentials but do not explicitly test the linkage between input use rates on collectively and individually-managed plots. Kazianga and Wahhaj (2013) postulate a voluntary social norm as an explanation for yield differentials, supporting their model with the finding that heads have a higher propensity to spend on household public goods out of their agricultural income than do other household members. Guirkinger et al. (2015) again compare productivity on collective and individual plots, finding higher productivity on individual plots controlled by men than on collective plots. None of these papers focuses on use of chemical fertilizer, but on labor allocation and yields. The two studies based on the ICRISAT data were conducted before much chemical fertilizer was used on cereal crops. Guirkinger et al. (2015) report that chemical input use is greater on collective than on individual fields, but combine chemicals as expenditures and do not control for field size (application rates).

We develop a conceptual model to depict fertilizer allocation decisions between collective plots managed by the household head and individual plots managed by other members of the household. Extending a model proposed by Fafchamps (2001) to analyze intra-household efficiency in labor use, we examine the linkages between fertilizer use on the two types of plots. Depending on our assumptions about the shape of the production technology, we are able to derive inferences concerning the efficiency of fertilizer use.

The context, and our conceptual model, provides strong reasons for us to hypothesize that technology adoption decisions on collective and individual plots within the same household are interlinked and simultaneous. Simultaneity could reflect either unobserved, correlated errors in the stochastic structure of the decisions, or systematic linkages in adoption decisions, or both. Systematic relationships could occur jointly; that is, fertilizer use on collective plots could influence use on individual plots, and vice versa. Alternatively, systematic relationships could be recursive, or unidirectional; the decision to adopt fertilizer on collective (individual) plots influences adoption on individual (collective) plots, even though converse does not hold true. In this paper, pairing collective and individual plots within the same household, we apply empirical tests to examine the nature of the linkage. We test whether the unobserved error structures between the fertilizer use decisions are related, and whether observed fertilizer use on one type of field affects use on the other. For robustness, we estimate a seemingly-unrelated, recursive, bivariate probit model, as well as Tobit and Cragg (1971) models. The probit treats the likelihood of use, while the Tobit and Cragg represent both the likelihood of use and intensity of use decisions. Time-invariant, unobserved heterogeneity is handled with the Mundlak-Chamberlin device.

Next, we lay out the conceptual elements of our analysis. In the third and fourth sections, we present the data and the econometric strategy. Econometric findings are discussed in the fifth section. We draw conclusions and consider policy implications in the sixth, and final section.

II. Conceptual model

We develop a conceptual model to understand the allocation of fertilizer between the plots managed collectively by the household head and individual plots managed by other members of the household. The model builds on Fafchamps (2001), who analyzed conditions under which intra-household transfers of labor among plots achieved productive efficiency. Here, our research interests are to examine the linkages between fertilizer adoption on plots managed collectively and individually, although we can also draw inferences from our results concerning the efficiency of fertilizer use.

Household members are endowed with land, labor and fertilizer. Members derive utility from a vector of consumption goods produced on farm and purchased, and from leisure. The utility functions are member-specific, non-altruistic and separable in consumption and leisure. The separability assumption is a standard simplifying assumption, and implies that the marginal utility of consumption does not depend on the level of leisure and that the marginal utility of leisure does not depend on the consumption level.

All members of the household utilize the same production technology to produce crops, which is a function of land, total labor and fertilizer. Intra-household resource transfer need not take the form of an explicit contract, and may simply be informal transfers of a similar magnitude or implicit value as a wage in an explicit contract.

The structure of the model is similar to Fafchamps (2001), with the addition of a variable representing the fertilizer endowment of members. But while Fafchamps (2001) explored conditions under which productive efficiency would be achieved, we focus on deriving an estimable equation for plot specific fertilizer demand and link the two.

We assume that household member i maximizes his/her utility as follow:

$$Max\ U^i(c_i) + V^i(T_i - \sum_j L_{ij}) \qquad \textbf{(i)}$$

$$s.t. \qquad pc_i = F(A_i + \sum_j \hat{A}_{ji} - \sum_j \hat{A}_{ij}\ , \sum_j Z_{ji}\ , \sum_j L_{ji}) + \sum_j (g_{ji} + g_{ij})$$

$$L_{ij}, g_{ij}, Z_{ij}, \hat{A}_{ij} \geq 0,\ \sum_j Z_{ij} \leq \bar{Z}_i \text{ and } \sum_j L_{ij} \leq \bar{L}_i,$$

where c is a vector of consumption and p is associated prices, T is the total time endowment, L_{ij} is the amount of labor household member i provides to household member j. Leisure for member *i*, l_i, equals $T_i - \sum_j L_{ij}$. F is the production function, A is the land endowment of the household, Z_{ji} is the fertilizer transferred from j to *i*, L_{ji} is the labor transferred from j to i and $\widehat{A}_{ji}$ is the land temporarily transferred from j to i. Hence output depends on total land managed by *i*, and the total amount of fertilizer and labor used (including net transfers). $\bar{Z}_i$ and $\bar{L}_i$ is the total endowment of fertilizer and labor of member i. g_{ji} is the gift/transfer from j to i. These gifts may be used instead of explicit contracts within the household. L_{ji} and g_{ji} are taken as given when solving the optimization problem.

Household members solve the optimization problem subject to a full income constraint. We will compare this autarky solution with the solution under cooperation to derive conditions under which cooperation can be sustained.

When the members fail to sustain cooperation with one another, the usual first order conditions are found for consumption and leisure.

$[c_i]$: ${\partial U^i(c_i)}/{\partial c_i} - \lambda_i\, p = 0 \Rightarrow {\partial U^i(c_i)}/{\partial c_i} = \lambda_i\, p$

$[l_i]$: $-{\partial V^i}/{\partial l_i} + \lambda_i e_i\, {dF}/{dL_i} = 0 \Rightarrow {\partial V^i}/{\partial l_i} = \lambda_i e_i\, {dF}/{dL_i}$ where $L_i = \sum_j L_{ij})$

In equilibrium, $L_{ij} = Z_{ij} = g_{ij} = 0\ \forall\ i \neq j$ since these intra-household transfers do not increase member i's utility. However, this resource allocation is not efficient in general; inputs may need to be transferred across household members for efficient production. For example, members with low quantity of land and high quantity of labor may need to allocate their labor to others with more land.

We now examine conditions under which the household can efficiently allocate resources for production, and describe what those allocations may look like. From the second welfare theorem, we know that a Pareto efficient resource allocation can be represented as a price system combined with lump-sum transfers. Hence the model below solves for an efficient bargained outcome.

Each member *i* faces the problem:

$$Max\ U^i(c_i) + V^i(T_i - \sum_j L_{ij}) \qquad \textbf{(ii)}$$

$$s.t. \qquad pc_i = F(A_i + \sum_j \hat{A}_{ji} - \sum_j \hat{A}_{ij}\ , \sum_j Z_{ji}\, , \sum_j L_{ji}) + \sum_j (r\,\hat{A}_{ij} - r\hat{A}_{ji} + p_z Z_{ij} - p_z Z_{ji} + wL_{ij} - wL_{ji} + g_{ji} - g_{ij})$$

with non-negativity constraints $L_{ij}, g_{ij}, Z_{ij}, \hat{A}_{ij} \geq 0$, and resource constraints $\sum_j Z_{ij,t} \leq \bar{Z}_{i,t}$ and $\sum_j L_{ij,t} \leq \bar{L}_{i,t}$.

The notation is similar to above. Also, r is the rental rate of land, p_z is the price of fertilizer and w is the wage for a unit of labor. Efficiency can be obtained if member i is rewarded $r\hat{A}_{ij}$, $p_z Z_{ij}$ and wL_{ij} for land, fertilizer and labor contributed to other members' productive activities, and provides transfers equivalent to $r\hat{A}_{ji}$, $p_z Z_{ji}$ and wL_{ji} for their land, fertilizer and labor transfers.

Since household members cannot be coerced into cooperation, voluntary participation can be ensured if the individual participation constraints are met. This means they have higher welfare under cooperation than under autarky i.e. $W_i^c > W_i^a$, where

$$W_i^c = \sum_{t=0}^{\infty} \delta_i^t [U^i(c_i^c) + V^i(T_i - \sum_j L_{ij}^c)] \quad and$$

$$W_i^a = \sum_{t=0}^{\infty} \delta_i^t [U^i(c_i^a) + V^i(T_i - L_{ii}^a)]$$

where c_i^c is the consumption under cooperation (solution to equation **ii**), c_i^a is the consumption under autarky (solution to equation **i**, shown below), δ is the discount factor and t is time.

The resource allocations in the cooperative equilibrium, such as the amount of fertilizer available for use on the collective plot by the household head and on individual plots by other members of the household, depend in part on the properties of the production function. We discuss three possible cases.

Case 1: If the production function is increasing at an increasing rate in fertilizer ($\partial F / \partial Z > 0$ & $\partial^2 F / \partial Z^2 \geq 0$), then all fertilizer is applied to a single plot. Hence the optimal level of fertilizer equals the total fertilizer available at the household for one plot and zero for others, ceteris paribus. This is because it is optimal to allocate an infinite amount of fertilizer on a single plot.

Will all of the fertilizer be applied to collective plots managed by the household head or individual plots managed by other members of the household? The answer is likely to depend on the bargaining power (i.e., function of elasticity of demand and supply of resources, social norms) between the household head and other members. Also, if the initial allocation is that the household head has a positive fertilizer endowment while others have no fertilizer, we may expect the household head to have more bargaining power. If case 1 holds true, then we will expect most of the fertilizer to be applied to a collective plot managed by the household head. However, it is unrealistic to expect case 1 to occur since production functions are never globally convex.

Case 2: It may be more reasonable to expect that the production function is first increasing at an increasing rate, and then increasing at a decreasing rate in fertilizer ($\partial \mathrm{F}/_{\partial \mathrm{Z}} > 0$ & $\partial^2 \mathrm{F}/_{\partial \mathrm{Z}^2} > 0\ \forall \mathrm{Z} < \dot{\mathrm{Z}} \gg 0,$ then $\partial^2 \mathrm{F}/_{\partial \mathrm{Z}^2} < 0\ \forall\ \mathrm{Z} > \dot{\mathrm{Z}}$). In this case, we may expect to see a large proportion of fertilizer applied to a single plot and perhaps no fertilizer applied to some plots.

Case 3: If the production function is increasing in fertilizer at a decreasing rate ($\partial \mathrm{F}/_{\partial \mathrm{Z}} > 0$ & $\partial^2 \mathrm{F}/_{\partial \mathrm{Z}^2} < 0$), we expect fertilizer to be equally distributed across plots managed by the household, ceteris paribus. Due to decreasing returns to scale of fertilizer, it is optimal to allocate fertilizer equally across plots. Case 3 is the usual case assumed in the applied literature. For example, tests of Pareto efficiency invoked by Udry (1996) and Kazianga and Wahaj (2013) are derived based on the same assumptions about the curvature of the production function. Cerrato and Blackmer (1990) contended that inadequate attention had been paid to choice of functional form in modeling yield response in the presence of concerns for overfertilization, finding that a quadratic plateau model, as compared to the commonly employed quadratic model, was less likely to overestimate optimal rates. In a recent analysis of data from Burkina Faso's Agricultural Census (2008-09), Koussoubé and Nauges (2015) found a concave relationship between maize yield and nitrogen (N) application rates (kg/ha), with a positive effect of nitrogen until 60 kg/ha and then, a strong negative effect at more than 150 kg of N per ha.

From this conceptual model, we can derive a reduced form of the fertilizer adoption:

Fertilizer_individual= f(crop, fertilizer_collective, plot manager characteristics, plot characteristics, household characteristics, market characteristics, and weather)

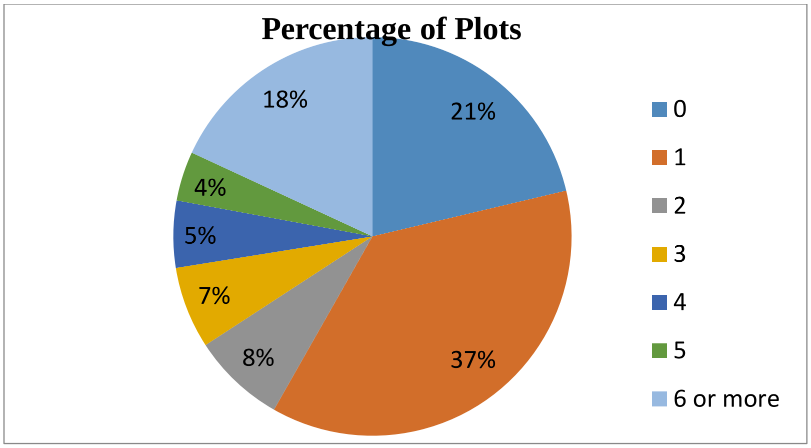
Controlling for all other factors, we expect the coefficient on *fertilizer_collective* (assuming linear functional form) to equal zero in case 1. In other words, if fertilizer is being applied on a collective plot, all fertilizer should be applied to that plot and none to the individual plots. For case 2, if the available fertilizer is greater than $\dot{Z}$ but less than $n\dot{Z}$ (where n is total number of plots managed by household), we will expect to see fertilizer applied across plots but not evenly distributed. In this case, the coefficient would be greater than zero, but less than one.

In case 3, the coefficient on *fertilizer_collective* should equal one. An equal distribution of fertilizer across plots implies for every one kg increase in amount of fertilizer used on the collective plot, there is a one unit increase in the fertilizer used on individually managed plots.

Other variables also determine the allocation of fertilizer. Plot characteristics matter since plots with a higher fertilizer response should be allocated more fertilizer. The crop matters because some crops have a larger marginal revenue product of fertilizer than others. Maize, for example, accounts for a large share of the fertilizer applied to crops in Sub-Saharan Africa and exhibits a higher response rate than other cereal crops such as sorghum or millet (Yanggen et al. 1998). The preferences of household members also enter the equation, since they determine the shadow prices of fertilizer, labor/leisure and land. These are captured by plot manager characteristics. Shadow prices are influenced in part by transactions costs associated with market infrastructural development. We also expect more experienced and efficient producers may be allocated more fertilizer. We may also expect specialization in specific crops if experience increases from 'learning by doing'. This would result in household members growing a specific type of crop over time and not others. But this factor is controlled by crop and plot manager. Finally, weather characteristics also determine the amount of fertilizer applied.

We focus on the cooperative solution since we observe that labor is traded within the household. Figure 1 shows that about 80 percent of plots across years receive labor input from one or more household members apart for the plot manager him/herself, suggesting that input sharing is frequent. Another reason for high amounts of labor sharing is that some members have comparative advantage in certain tasks; men may be more efficient in clearing land since it requires more physical strength while women and children may be more effective at weeding and harvesting (Prasad and Ram, 1990; Fafchamps 2001).

Figure 1: Percentage distribution of plots receiving labor contributions from household members other than the plot manager, by numbers of members



Such division of tasks across members indicates that households are trying to allocate inputs with the aim of improving productive efficiency, and not composed of members that are producing under autarky. Even though fertilizer-sharing transactions within the household are not recorded in the data, we argue that similarly to land and labor, it is likely that fertilizer is transacted within the household to increase allocative efficiency in production.

III. Data

We utilize data from the Continuous Farm Household Survey (*Enquête Permanente Agricole* (EPA)) of Burkina Faso, which are collected by the General Research and Sectoral Statistics Department (*Direction Générale des Études et des Statistiques Sectorielles* (DGESS)) of the Ministry of Agriculture and Food Security (*Ministère de l'Agriculture et de la Sécurité alimentaire* (MASA)). The sampling frame for the EPA is based on the 2006 Population Census, and consists of 4130 household farms in 826 villages across all 45 provinces. The EPA is used to estimate farm input use, production, area and yield of rainfed crops, and provides information about livestock holdings, income and expenditures of rural households.

In this analysis, we utilize data covering the 3-year period from 2009/10 through 2011/12. These are the last years for which fully cleaned data are available. After dropping households that were not continuously surveyed throughout the three year period and missing observations for variables of interest, we are left with over 2700 households. Focusing on maize only, taking only two largest collective and individual plots per household and year restricts our analytical sample to 513 households and 1026 plots. We chose maize because the likelihood and rates of fertilizer use are higher on this cereal than on other major cereals, sorghum and millet.

Rainfall estimates from the National Oceanic and Atmospheric Administration's Climate Prediction Center at the commune level are used to control for rainfall variability. Next, we discuss the conceptual basis of our empirical model and specify the regressions.

IV. Econometric strategy

We use both a seemingly unrelated, bivariate probit model and a recursive formulation to test the nature of the relationship between the decision to use fertilizer on collectively-managed fields and on individually-managed fields. We estimate the equations only for maize plots to control for the effect of crop type on fertilizer. Following Maddala (1983), the dependent variables in the regression system represent latent variables for which only the dichotomous outcomes are observed.

We can represent the decisions to apply fertilizer to collectively managed and individually managed plots by the unobserved latent variables model:

$$y_1^* = x_1\beta_1 + e_1$$
$$y_2^* = x_2\beta_2 + e_2$$

where y_1^* is the underlying profitability of using fertilizer on collectively managed plots while y_2^* is the underlying profitability of using fertilizer on individually managed plots. x_1 and x_2 are the set of variables that explain the utility of income from fertilizer use on collectively and individually managed plots.

The bivariate probit model defines the outcomes as:

$$
\begin{aligned}
y_1 &= 1 \; if \; y_1^* > 0, \\
&= 0 \; otherwise \\
y_2 &= 1 \; if \; y_2^* > 0, \\
&= 0 \; otherwise
\end{aligned}
$$

and

$$
\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \end{bmatrix} \mid X \sim \mathcal{N}\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & \rho \\ \rho & 1 \end{bmatrix} \right)
$$

y_1 indicates whether fertilizer was applied to a collectively managed plot and y_2 indicates whether fertilizer was applied to an individually managed plot.

The seemingly-unrelated, bivariate probit specification addresses potential simultaneity by taking into account the correlation between the residuals of the two equations in the system. The appropriateness of the bivariate model as compared with the separate probit models can be evaluated with a likelihood ratio test. The independent univariate models are nested within the multi-equation model, which represents the unconstrained regression. The Wald test indicates whether the error structures are related, as represented by the estimated correlation coefficient ρ-hat. Failure to reject the null hypothesis that ρ equals zero leads to separate estimation of the probit equations.

The recursive formulation introduces the potential for a causality in one direction. In addition to a shared vector of exogenous variables in each pair of equations, the fertilizer use equation for individually-managed plots includes the binary variable indicating use of fertilizer on collectively-managed plots (Z). In our recursive formulation, we posit that decisions on collectively-managed fields supersede or precede those taken on individually-managed fields according to the goal of 'family welfare first.' Generally, in this social organization of production, access to inputs, including fertilizer, accrues initially to the patriarchal decision-maker or team leader who is responsible for ensuring household food security. The statistical test on the coefficient of the regressor (Z), which indicates fertilizer use on collectively-managed fields, would provide evidence of a systematic relationship. According to Wilde (2000), in contrast to linear simultaneous equations with only continuous endogenous variables, in recursive multiple equation probit models with endogenous dummy regressors, no exclusion restrictions for the exogenous variables are needed if there is sufficient variation in the data. That condition is ensured by the assumption that each equation contains at least one varying exogenous regressor, although this is an assumption that is rather weak in economic applications. However, we also address the exclusion restriction by including plot characteristics in the equations, which differ for individually and collectively managed plots.

We also wish to test whether application rates for fertilizer on collective plots are related to application rates of fertilizer on individual plots. Since a significant proportion of the sample does not use any fertilizer, OLS is not appropriate. Hence we estimate a tobit regression to test this relationship for nitrogen nutrient kg per hectare on individually and collectively managed plots.

The fertilizer use (nitrogen nutrient kg per hectare) model is represented by:

$$y_1 = x_1\beta_1 + e_1$$
$$y_2 = \alpha_1 y_1 + x_2\beta_2 + e_2$$

where y_1 is the nitrogen nutrient kg per hectare on collectively managed plots while y_2 is the nitrogen nutrient kg per hectare on individually managed plots. x_1 and x_2 are the set of variables that explain fertilizer use on collectively and individually managed plots.

We first test whether y_1 is endogenous in the equation for y_2 using a control function approach (CFA). Collective plot characteristics are included in x_1 but not in x_2, hence they are the instruments used for identification. If we fail to find evidence that y_1 is endogenous in the equation for y_2 , we can estimate the equation for y_2 directly and obtain consistent estimates of α_1. If we find evidence of endogeneity, we will rely on the control function approach for consistent estimates of α_1. In each of our nonlinear models, we also employ the Mundlak-Chamberlain (also known as the correlated random effects-CRE) device to address time-invariant unobserved effects that may be related to household decision-making. Recommended for nonlinear models, this technique involves including the means of variables constructed at the household level that vary over time. Other panel estimation methods, such as fixed effects, are not compatible with probit estimation. Also, we do not have a panel at the plot level limiting our ability to control for plot level unobserved variables.

Exogenous explanatory variables are operationally defined and summarized in Table 1. Plot manager characteristics include the age, primary education, headship, and marriage status of the plot manager. These variables are closely interrelated, although we seek to control for each of these factors in our analysis. For example, only married women can control plots, and very few women are heads. Thus, only 2 percent of collective plots are managed by women, although women manage 42 percent of individual plots. Overall, they manage about one-fifth of the maize plots in our analytical sample. At the mean, all plot manager characteristics except education differ between collectively and individually managed plots.

Plot characteristics include distance from the house, whether the plot is located in the lowlands and the size of the plot in hectares. On average, collectively-managed plots are twice the size of individually-managed maize plots (0.73 v. 0.36 ha, respectively), and slightly (but significantly) less likely to be found in the lowlands.

Key household characteristics are the total area endowment of the household, the value of non-farm income sources, whether the plot manager had access to credit, and years since the last contact with extension agents. These last two factors vary by plot type, but we consider them to be strongly predetermined by household behavior and especially decision-making led by the head. The head is typically the legal representative of the household and thus the first contact for credit and extension services.

As a measure of market infrastructure, we employ the number of agro-dealers in the province. The rainfall variable is constructed as the coefficients of variation in total annual rainfall at the commune level over the last three years, which we consider the pertinent decision-making period for farmers because it is recent in their memories.

Table 1. Definitions and descriptive statistics of explanatory variables

		All	Collectively Managed	Individually Managed	p-value
		mean (SD)			
Male plot manager	If the plot manager is female=1; Otherwise=0	0.22	0.02	0.42	0.000
		(0.42)	(0.14)	(0.02)	
Age of plot manager	Age of the plot manager (years)	45.6	51.1	40.1	0.000
		(16.9)	(0.71)	(0.70)	
Primary education of plot manager	If the plot manager has a primary education=1; Otherwise=0	0.15	0.13	0.16	0.137
		(0.35)	(0.34)	(0.37)	
Plot manager is head	If the plot manager is the household head=1; Otherwise=0	0.58	0.95	0.21	0.000
		(0.49)	(0.22)	(0.41)	
Married plot manager	If the plot manager is married=1; Otherwise=0	0.84	0.93	0.76	0.000
		(0.36)	(0.26)	(0.43)	
Plot far from home	If the plot is far from the house=1; Otherwise=0	0.46	0.44	0.48	0.26
		(0.5)	(0.5)	(0.5)	
Plot in lowlands	If it is a lowland plot=1 Otherwise=0	0.09	0.07	0.11	0.034
		(0.29)	(0.26)	(0.32)	
Plot size (ha)	Size of the plot (hectares)	0.55	0.73	0.36	0.000
		(0.88)	(1.1)	(0.5)	
No. of educated adults in household	Number of educated adults in the household (persons)	1.16			
		(1.4)			
Household area (ha)	Total land cultivated by the household (ha)	4.2			
		(3.88)			
Non-farm income	Value of non-farm income at the household level (ln 000 CFA)	3.21			
		(2.53)			
Credit	If the plot manager has had access to credit=1; Otherwise=0	0.098	0.15	0.05	0.000
		(0.27)	(0.36)	(0.21)	
Years since contact with extension	Number of years since the plot manager has received any extension services (yrs)	4.78	4.7	4.84	0.003
		(0.81)	(0.92)	(0.69)	
No. of agro-dealers	Number of agrodealers in each province (units)	27.6			
		(29.1)			
Rainfall	Coefficient of variation of rainfall in each commune (mm) over last three years	920.3			
		180			

Source: As prepared by authors. N=1026

V. Findings

A. Descriptive statistics

In the analytical sample, 15 percent of households chose to apply fertilizer to the collective field but not to the individual plot, consistent with either case 1 or case 2 in our conceptual model. Overall, 46% of collective maize plots received fertilizer, while only 39% of individual maize plots were fertilized.

Unconditional mean rates of use appear to be slightly higher on the small plots managed individually than on collectively-managed maize plots, although the difference is not statistically significant (Table 2). Once fertilizer is applied, however, mean rates are significantly higher on individual than on collective maize plots. At first glance, this finding contrasts with that reported by Guirkinger et al (2015), although their data aggregated expenditures on chemical inputs and did not control for plot size as we do here. Dividing mean chemical use by mean plot areas in the data they present, use rates would also appear higher on individual plots managed by men but not by women relative to collective plots.

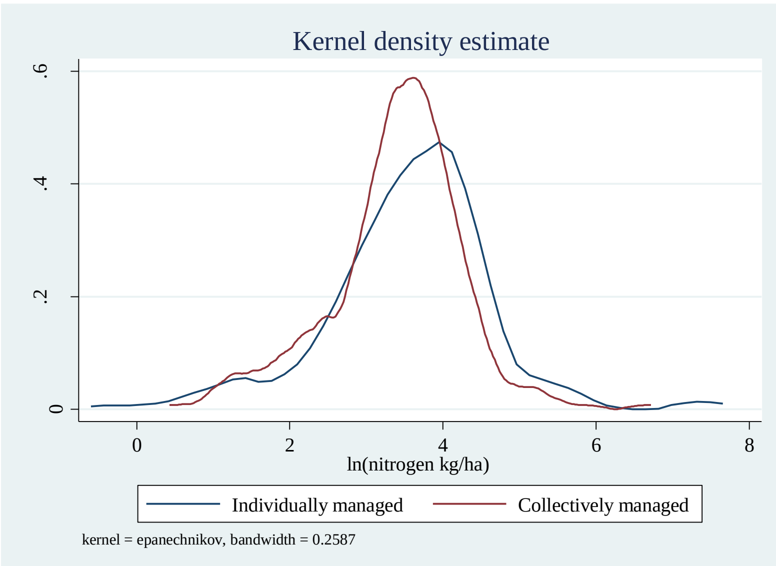
Table 2: Intensity of Fertilizer Use (nitrogen kg/ha)

	Mean	Standard Error	p-value
Unconditional Mean			
Collectively Managed	19.82	2.09	0.138
Individually Managed	25.4	4.67	
Conditional Mean			
Collectively Managed	43.09	4.07	0.024
Individually Managed	65.8	11.54	

Source: Authors.

Full distributions of values for use positive use rates of nitrogen on maize plots managed collectively and individually are shown in Figure 2.

Figure 2: Distributions of fertilizer use rates on collectively and individually-managed plots



The Kolmogorov-Smirnov test supports differences in underlying distributions with a p-value of 0.007. The distribution of positive values on individual plots lies slightly to the right of those corresponding to collective fields, with a mode at higher values.

B. Regression results

The seemingly-unrelated bivariate probit regressions for individually- and collectively-managed plots are shown in Table 3, columns 1 and 2. With respect to our major hypotheses, we fail to reject the null hypothesis that the two equations are uncorrelated with a Wald test (p-value=0.840)). Thus, we estimate the final recursive models as two independent probit models. Marginal effects for collective and individual plots are shown in columns 3 and 4. We find a positive, statistically significant coefficient that systematically relates the likelihood of fertilizer use on collectively-managed to fertilize use on individually-managed plots. The effect is large: adoption of fertilizer on a collective plot contributes to an average of a 0.32 rise in adoption probability on an individual plot. However, the converse does not hold true: fertilizer use on individual plots does not determine use on collective plots (we fail to reject the null hypothesis on the coefficient). Not reported here for brevity, these results are available from the authors.

Next, we explore the linkages in fertilizer use intensity. The results from the Tobit model (using the control function approach) are shown in Table 4. The residual from the first stage regression is statistically insignificant, leading us to conclude that we may again treat fertilizer use intensity on collective fields as an exogenous regressor in the fertilizer use model for individual fields. The marginal effect of fertilizer applied to collective fields on use rates applied to individual fields is 0.19 nitrogen nutrient kgs/ha.

The test of the Tobit as compared to the Cragg model in the second stage leads us to prefer the Cragg model. The value of the log-likelihood ratio test comparing the two models is 1829, which is significant at any level. Second-stage, two-tier regressions are shown in Table 5. The first tier coefficients tell us the direction (positive or negative) of effect of the explanatory variable on probability of using some fertilizer, $d(P[y>0|x])/dx$. The second tier coefficients tell us the direction of effect of the explanatory variable on quantity of fertilizer, provided positive amount of fertilizer is used i.e. $d(E[y|y>0, x])/dx$. While we cannot interpret the magnitudes of the coefficients, we readily see that the determinants of the decision to adopt fertilizer differ from

Table 3: Bivariate Probit (CRE) Regressions for Fertilizer Use, Individual and Collective Plots

	Seemingly unrelated, recursive model		Independent, recursive model	
	Individual plots	Collective plots	Individual plots	Collective plots
			(APEs)	
Fertilizer used on collective plot	1.411**		0.326***	
	(0.598)		(0.0278)	
Female plot manager	-0.281	0.362	-0.0664	0.114
	(0.555)	(0.563)	(0.139)	(0.161)
Primary education of plot manager	0.273	0.185	0.0659	0.0562
	(0.224)	(0.224)	(0.0545)	(0.0633)
Married plot manager	-0.31	0.507*	-0.0744	0.159*
	(0.329)	(0.278)	(0.0789)	(0.0937)
Plot manager is head	-0.036	0.0958	-0.00849	0.0303
	(0.335)	(0.278)	(0.0811)	(0.095)
Age of plot manager	0.00523	-0.00883**	0.00122	-0.00278**
	(0.00575)	(0.00431)	(0.00117)	(0.00134)
Individual plot far from home	0.366**		0.0955***	
	(0.180)		(0.0371)	
Individual plot in lowlands	-0.981***		-0.253***	
	(0.243)		(0.0597)	
Individual plot size	0.667***		0.171***	
	(0.213)		(0.0451)	
No of educated adults in household	-0.00787	0.124**	-0.000534	0.0383***
	(0.0527)	(0.0529)	(0.0139)	(0.0154)
Household area	-0.00391	0.0213	-0.000318	0.00637
	(0.0473)	(0.0449)	(0.0129)	(0.0150)
Non-farm income	-0.0941	-0.0173	-0.0236	-0.00546
	(0.0730)	(0.0519)	(0.0179)	(0.0196)
Credit	0.107	0.493**	0.0344	0.153**
	(0.229)	(0.211)	(0.0549)	(0.0639)
Years since contact with extension	-0.0764	-0.225**	-0.02194	-0.0689***
	(0.0868)	(0.0912)	(0.0205)	(0.0249)
No of agro-dealers	0.00445*	0.00276	0.00114**	0.000835
	(0.00254)	(0.00217)	(0.000584)	(0.000702)
Rainfall	0.000391	0.000117	0.000102	0.0000361
	(0.000481)	(0.000398)	(0.000113)	(0.0001292)
Collective plot far from home		0.426***		0.129***
		(0.144)		(0.0412)
Collective plot in lowlands		-0.403		-0.121
		(0.270)		(0.0762)
Collective plot size		0.439***		0.135***
		(0.150)		(0.0315)

Robust standard errors in parentheses. N=506. Year effects, constant term and means of time-varying household variables not reported. ***p<0.01; **p<0.05; *p<0.10

Table 4: Tobit-Tobit CFA (CRE) Regressions for Fertilizer Use on Individual Plots

	CFA	Exogenous (APEs)
Residual	-1.046	
	(1.149)	
Fertilizer used on collective plot	1.632	0.186*
	(1.417)	(0.101)
Female plot manager	-131.2	-29.8
	(267.2)	(30.0)
Primary education of plot manager	38.49	13.3
	(37.75)	(9.55)
Married plot manager	-141.4	-29.4
	(119.1)	(29.8)
Plot manager is head	13.33	7.64
	(53.89)	(10.9)
Age of plot manager	1.280	0.176
	(1.299)	(0.310)
Individual plot far from home	3.565	8.43
	(30.02)	(5.69)
Individual plot in lowlands	-105.8*	-31.8**
	(55.49)	(12.9)
Individual plot size	19.99	7.9
	(16.71)	(5.12)
No of educated adults in household	-3.887	0.96
	(11.27)	(2.17)
Household area	16.76*	4.39*
	(8.703)	(2.56)
Non-farm income	-5.839	-1.67
	(9.886)	(2.57)
Credit	23.99	12.9
	(44.14)	(10.5)
Years since contact with extension	-7.480	-5.9
	(17.35)	(4.36)
No of agro-dealers	0.679	0.266
	(0.678)	(0.172)
Rainfall	0.117	0.034
	(0.0731)	(0.024)

Notes: Delta method standard errors in parentheses. N=513. Year effects, constant term and means of time-varying household variables not reported. ***p<0.01; **p<0.05; *p<0.10
Source: Authors

Table 5. Tobit-Cragg CFA (CRE) Regressions for Fertilizer Use on Individual Plots

	CFA		Exogenous	
	Tier1	Tier2	Tier1	Tier2
Residual	-0.00395	0.00280		
	(0.0102)	(0.00748)		
Fertilizer used on collective plot	0.0183	-0.000363	0.0145***	0.00236*
	(0.0117)	(0.00779)	(0.00402)	(0.00135)
Female plot manager	-0.464	-0.267	-0.341	-0.321
	(0.886)	(0.587)	(0.536)	(0.483)
Primary education of plot manager	0.259	0.0301	0.263	0.00330
	(0.306)	(0.221)	(0.202)	(0.185)
Married plot manager	-0.320	0.106	-0.171	-0.0241
	(0.491)	(0.583)	(0.292)	(0.453)
Plot manager is head	-0.0473	-0.224	0.000716	-0.249
	(0.452)	(0.335)	(0.315)	(0.279)
Age of plot manager	0.00394	0.000962	0.00157	0.00305
	(0.00818)	(0.00609)	(0.00491)	(0.00490)
Individual plot far from home	0.349	-0.284	0.448***	-0.337**
	(0.255)	(0.212)	(0.160)	(0.151)
Individual plot in lowlands	-0.795***	0.234	-0.820***	0.214
	(0.296)	(0.274)	(0.239)	(0.233)
Individual plot size	0.580***	-0.541***	0.604***	-0.551***
	(0.215)	(0.159)	(0.198)	(0.121)
No of educated adults in household	-0.00567	0.0753	0.0216	0.0554
	(0.0807)	(0.0673)	(0.0502)	(0.0411)
Household area	0.0407	0.0175	0.0328	0.0227
	(0.0529)	(0.0429)	(0.0486)	(0.0348)
Non-farm income	-0.0671	-0.0381	-0.0689	-0.0415
	(0.0742)	(0.0982)	(0.0621)	(0.0884)
Credit	0.145	-0.0475	0.221	-0.0927
	(0.321)	(0.225)	(0.195)	(0.166)
Years since contact with extension	-0.0801	-0.124	-0.124*	-0.0890
	(0.122)	(0.107)	(0.0738)	(0.0678)
No of agro-dealers	0.00294	0.00279	0.00366	0.00227
	(0.00318)	(0.00322)	(0.00226)	(0.00224)
Rainfall	0.000197	0.000708	0.000209	0.000731*
	(0.000510)	(0.000475)	(0.000473)	(0.000413)

Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. N=513.
Source: Authors

those influencing the intensity, or rate of use. We fail to reject the exogeneity of rates of fertilizer use on collectively-managed plots in decisions concerning rates of use on individually-managed plots (column 1), since the residual of the first-stage control function is not statistically significant.

Estimating the relationship with fertilizer use on the collectively-managed plot treated exogenously, we again find a positive and statistically significant relationship in both Tier 1 and Tier 2, although the Tier 2 effect is statistically weak (< 10%) and the Tier 1 effect is strong (<1%). This second finding is consistent with the bivariate probit model. We cannot, however, directly compare the coefficient values in Table 5 to those average partial effect coefficients (APEs) in Tables 3 and 4. We also computed unconditional APEs with Delta standard errors computed by bootstrapping with 100 iterations, following Burke's (2009) procedure (available on request). These are available on request. This regressions also shows a strongly significant (at less than 1%), positive linkage between fertilizer use on collective and individual fields.

Aside from the main tests of hypotheses, we see that the determinants of fertilizer adoption also differ on individual and collective fields (Table 3). Plot characteristics are important in magnitude and significance, as we would expect. While neither gender of the plot manager nor headship in and of itself bears a significant relationship with fertilizer adoption, marriage has a strongly positive effect and older age, a negative influence. Primary education of the manager does not appear to matter, but the number of educated adults in the family appears to have major effects on adoption in collective fields. The length of time since contact with an extension agent has a significant negative effect on the likelihood of fertilizer application to collective fields, but no discernible linkage to individual plots. The same is true for the strong and positive effect of credit availability. This is consistent with the fact that the first point of contact by formal institutions such as extension services or credit in complex households such as these is the head, whose responsibility it is to represent the extended family. The positive sign suggests that credit does constraint adoption (by 0.15 percentage points, which is large), as was concluded in the analysis of Koussoubé and Nauges (2015). An interesting finding is that the density of agrodealers in the area is positively and significantly related to the likelihood of fertilizer use on individual fields—suggesting that availability could be a constraint to use particularly on these fields. The magnitudes of these coefficients are small, however. Other household-level factors, such as total area farmed and non-farm income, which might serve to relieve cash constraints, do not play a role. Nonfarm opportunities appear to be limited in these families. A third of households received no nonfarm income at all, and the overall mean was 203,000 CFA per annum (350 USD at current exchange rates).

Turning to overall comparisons between factors that affect the likelihood of use vs. those that affect intensity of use on individual plots only (Table 5), we see that distance from the house has conflicting effects on use and rates of use. The further from the home, the lower the use rates but the higher the probability of use. Plot size reduces intensity (because of scale effects) but increases likelihood of use. Larger fields are more likely to be those allocated to members with more seniority and/or negotiating power. This finding was also reported by Koussoubé and Nauges (2015). Among household-level variables, only the length of time since the last extension visit is statistically significant (negatively) in the likelihood of use on individual plots. Rainfall is a significant factor, as we would expect to be the case, in the use intensity model.

Moreover, our findings show that an additional unit of fertilizer use on collective plots is associated with higher likelihood of use and rates of fertilizer use on individual plots. There are two plausible explanations for this result. Assuming that case 3 of the conceptual model holds true (global concavity in the response function), and that the assumption of a common production technology holds true, our findings would be consistent with the hypothesis of inefficient outcomes in household bargaining because the value of the coefficient is far from 1. The household may simply fail to allocate inputs, here fertilizer, effectively across plots, as previously suggested by Udry (1996), Akresh (2011) and Kazianga and Wahaj (2013). Some frictions may exist within the household that hinders members from producing efficiently as a unit. Or, case 3 does not hold true and an alternative explanation can be derived from the conceptual framework about why it may be efficient to unequally distributed fertilizer across plots. If the curvature of the production function does not simply follow a global concavity, then there may be increasing returns to scale for fertilizer at very low levels, especially for soils that are extremely depleted in nutrients.

VI. Conclusions

In this article, we examine the linkages between fertilizer adoption decisions on plots that are collectively managed by the head of the household and those that are individually managed by other household members. We contribute to the literature on the intra-household input allocation by developing a conceptual framework that allows us to derive inferences on the efficiency of fertilizer use and by empirically analyzing the nature of the linkage between collective and individual plots using a recent nationally representative panel dataset of farm household in Burkina Faso.

Pairing collective and individual plots within the same household while controlling for crop (maize), we apply several empirical tests to examine the nature of the linkage. First, we predict the likelihood of fertilizer use on the two plot types with a seemingly-unrelated, recursive, bivariate probit model. Second, we explain the intensity of fertilizer use by combining a Cragg model and a Control Function Approach. We test both stochastic and systematic relationships between these decisions on collective and individual fields, considering also the characteristics of the plot, plot manager, household, market and rainfall. Time-invariant, unobserved heterogeneity is handled with the Mundlak-Chamberlin device.

The seemingly-unrelated bivariate probit model is preferred to the bivariate probit model, reflecting the systematic linkages in fertilizer use between collective and individual plots. Results from the seemingly-unrelated bivariate probit model show that a systematic recursive relationship exists for fertilizer use decision between individually and collectively- managed plots. The decision to use fertilizer on collective plots affect the decision to use fertilizer on individual plots. However, the inverse does not hold true.

The marginal effect of the coefficient on fertilizer use on collective plots is statistically significant and different than one in the regression explaining use on individual plots. This finding suggests that fertilizer is not equally distributed across household plots, after controlling for a set of covariates, and is broadly consistent with previous literature which found inefficiency in intra-household input allocations. Or, it may suggest that the production function is not concave as often assumed in the intra-household input allocation literature. Future work should focus on deriving the production function and expanding the analysis to other crops than maize.

Further, our descriptive data demonstrate that compared to collective plots, fertilizer is applied less frequently on individual plots than on collective plots of maize, but once applied, use rates are more intense on individual than on collective plots. This result may reflect plot sizes, which are vastly different between the two types, or may suggest distinct production technologies. Outside the scope of this paper, testing this hypothesis via a production function would be another avenue for future research.

Similarly, results from the Cragg model, which is preferred to the Tobit model, show that fertilizer use intensity on collective plots influences fertilizer use intensity on individual plots and this relationship is also unidirectional. Moreover, the determinants of fertilizer use and use intensity differ across individual and collective plots. Better access to credit and extension services positively influence fertilizer adoption on collective plots. This reflects that the heads is the official point of contact of extension agents and development programs. The finding suggests that an increase in total household fertilizer will "trickle down" to individuals within the households, and may explain why so many agricultural development programs and policies target household heads. Doing so is more cost-effective. However, inputs may not be equally distributed among household members and, thereby, among plots. If cost-effectiveness is not the most desired outcome, then targeting individual household members may be more appropriate. For instance, if reducing youth rural-urban migration through increasing agricultural productivity (and income) is the objective, then programs and policies to improved fertilizer access and use should target young, male and female managers of individual plots. The design and implementation of effective agricultural programs and policy depends on a better understanding of the decision-making within households.

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