Where and why is Fertilizer (Un)Profitable in sub-Saharan Africa? A Spatial Econometric Analysis of Fertilizer Use in Malawi

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Introduction

Improving agricultural productivity is widely regarded as a channel for ameliorating poverty and food insecurity in sub-Saharan Africa (Future Agricultures, 2010). This view is based on the heavy reliance of poor and food insecure households on agriculture. Unfortunately, agricultural productivity has been very low in SSA: since the 1960s, average per capita annual growth in agricultural productivity has been less than 1% for the continent as a whole, and – at times – negative for some sub-regions (FAO statistics, 2013).

Malawi's situation is typical. For the past two decades, the productivity of most agricultural crops in the country has increased only modestly. Even now, the already modest increase in productivity is further undermined by population growth (MoAFS, 2010). The Ministry of Agriculture and Food Security (2010) estimates that the country's yield gap, i.e. the difference between potential yield and the actual yield of the average farmer ranges from 38-53% for cereals, and 40-75% for legumes (Lobell et al., 2009). This implies substantial room for productivity improvements. Yield improvements likely will be essential for reducing poverty and improving food security in Malawi because there is limited room for area expansion among smallholders (Dorward 2006; Ricker-Gilbert et al. 2014).

A major factor accounting for low agricultural productivity among Malawian smallholders is low rates of modern input use, particularly inorganic fertilizer.[1] Between 2002 and 2011, for example, average fertilizer use in Malawi was about 50 kg per hectare of agricultural land, compared to about 174 kg per hectare in Vietnam, and about 194 kg per hectare in Thailand (FAO statistics, 2013). Low uptake of inorganic fertilizer in Malawi is likely linked, in part, to low levels of fertilizer profitability. Figure 2.1 provides an illustration of the possible determinants of the profitability of fertilizer. Profitability is influenced by three main factors – crop response rate, fertilizer price and output price. Crop response rate is in turn influenced by soil and weather conditions as well as complementary agronomic factors such as the application of organic fertilizer and the adoption of irrigation. Fertilizer and output prices are affected (via transaction cost) by the availability of public good such as roads and input markets.

Fertilizer use is especially important because nutrient depletion has rendered a majority of the nation's arable land poor in soil nutrients. The Government of Malawi has been implementing the large-scale Farm Input Subsidy Program (FISP) since the 2005/06 agricultural season that provides its beneficiaries (approximately 50 percent of the agricultural household population) with coupons that allow for inorganic fertilizer and improved maize seed purchases at up to a 90% discount. The subsidy program has helped increase average fertilizer application among smallholders. However, evidence suggests subsidized fertilizer crowds out demand for commercial fertilizer (Ricker-Gilbert et al. 2011). This is a key policy issue, because if the subsidy program in Malawi were to end or be reduced, the private sector would have to fill the void.

With these considerations in mind, this study focuses on two key research questions: (1) *how does fertilizer profitability vary across space?* (2) *What factors influence the profitability of fertilizer use*?

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[1] Other factors affecting agricultural productivity include unfavorable weather conditions, declining soil fertility, limited adoption of sustainable land management practices, limited agricultural extension services, market failures, limited access to agricultural credit and (input and output markets), and poor infrastructure (World Bank, 2007; Kilic et al., 2013; MoAFS, 2010).

In answering these questions, the following specific hypotheses will be tested:

H1: Fertilizer profitability does not vary across districts or agro-ecological zones in Malawi;

H2: Complementary agronomic practices, such as the application of organic matter, do not affect the profitability of fertilizer use in Malawi;

H3: *Public goods such as road density and output markets do not affect the profitability of fertilizer use in Malawi.*

Contribution:

This essay contribute to knowledge both in terms of the issues it addresses and in terms of the methods used. To the best of our knowledge issues related to the profitability of fertilizer use in Malawi and how it is could possibly explain the limited utilization of fertilizer have not been studied. Specifically, little is known about where fertilizer use is profitable or unprofitable, or about the role that complementary farm practices and public goods may play in influencing the profitability of fertilizer use in specific locations. From the perspective of methods, the present subsidy builds on the work of Xu et al. (2009) and Sheahan et al. (2013), who analyzed the profitability of fertilizer use in Zambia and Kenya respectively. We explicitly model the determinants of fertilizer profitability using a spatial hierarchical model. To the best of our knowledge, this study will be the first to use a spatial model in the analysis of input profitability. The analysis will take advantage of the geo-referencing and the hierarchical nature of the data (i.e. plots nested within households, and households nested within enumeration areas), which will allow us to fit a spatial hierarchical model (Corrado and Fingleton, 2011). Also, the study will acknowledge the existence of the large scale farm input subsidy program by considering both commercial and subsidized prices of fertilizer in the analyses.

Relevance of the study

Knowing how fertilizer profitability varies across districts or agro-ecological zones will help in the future geographical targeting of FISP. The results of the study will also help the Government of Malawi to formulate other policies that will boost the adoption of fertilizer by farmers, and hence increase agricultural productivity.

Conceptual Framework

In integrating agronomic theory and insights into economic analysis, Guan et al. (2006) dichotomized inputs used in crop production into two categories: growth inputs and facilitating inputs. Growth inputs include inputs such as seed; nutrients such as nitrogen, phosphorus etc. from fertilizer and soil; and water that are directly involved in the biological process of plant growth and development. Facilitating inputs are not directly involved in the growth and development process of plants but influence the response rate of plants to the growth inputs. Examples of the facilitating inputs include labor, capital and pesticides.

Following Guan et al. (2006), the crop production model is represented as:

$$y = G(x).F(z) \quad (1)$$

where *y* is crop yield, *x* is a vector of growth inputs, and *z* is a vector of facilitating inputs. As reflected by different functional forms - *G (.)*, *the growth model* and *F (.), the scaling factor* - the growth and facilitating inputs affect crop yield differently. *G (.)* defines the attainable yield under specific biophysical environment. *F (.)* is defined over the interval [0, 1]. The value of the *F (.)* reaches 1 and *y* reaches the attainable yield when the growth conditions are optimal given the levels of the growth inputs. The scaling factor down scales actual output when conditions are not optimal.

In addition to the growth and facilitating inputs, this study also acknowledges that household characteristics and other factors such as the timing of fertilizer application can also affect crop yield. These additional inputs are considered as part of the facilitating inputs, and are therefore included in *F (.)*.

Empirical model

Following Xu et al. (2009), the crop-growth and the scaling functions are specified for maize production in Malawi using the quadratic and exponential functional forms respectively. The specification of the crop-growth function with the quadratic functional form imposes concavity on the yield response, which is consistent with most observable biological processes. For plot *i* belonging to household *h* at time *t*, the quadratic function for the maize growth function is specified as:

$$G_{ih} = \alpha_1 N_{iht} + \alpha_2 Seed_{iht} + \alpha_3 Organic_{iht} + \alpha_4 N_{iht}^2 + \alpha_5 Seed_{iht}^2 + \alpha_6 Organic_{iht}^2 + \alpha_7 N_{iht} * Seed_{iht} + \alpha_8 N_{iht} * Organic_{iht} + \alpha_9 Seed_{iht} * Organic_{iht} \quad (2)$$

where *N* is the quantity (kg/ha) of nitrogen and phosphorus applied; *Seed* is a dummy variable for the use of hybrid seed (= 1 if hybrid seed is used); and *Organic* is a dummy variable for the use of organic matter (= 1 if organic matter is used). $\alpha_1 - \alpha_9$ are parameters to be estimated.

Fertilizer application in maize production is typically done twice per planting season in Malawi. Basal fertilizer (NPK 23:21:0 + 4S) is applied within a week after planting; and is followed by top dressing, mainly Urea (NPK: 46:0:0) or Calcium Ammonium Nitrate (CAN), 21 days later. Because basal fertilizer is entirely nitrogen and phosphorus, Urea is entirely nitrogen, and CAN is predominantly nitrogen, the study will concentrate on nitrogen and phosphorus (N in the model).

For plot *i* belonging to household *h* at time *t*, the exponential function for the maize scaling function is specified as:

$$S_{ih} = \exp[-(\beta_0 + \beta_1 * Labor + \boldsymbol{Chem} * \beta_2 + \boldsymbol{H} * \beta_3 + \beta_4 * EXT)^2] \quad (3)$$

where $Labor$ is the hours of (hired and family) labor; $\boldsymbol{Chem}$ is a vector of chemicals such as pesticides, weedicides, fungicides etc. used in the production of maize; $\boldsymbol{H}$ is a vector of household variables such as the level of education of household head, number of adults in the household etc.; EXT is a dummy variable for whether not a household received useful agricultural extension service (= 1 if household received extension service). $\beta_0\ to\ \beta_6$ are parameters to be estimated.

Given equation (2) and (3) the overall maize production function is given by the nonlinear function:

$$Y_{ih} = \{(\alpha_1 N_{ih} + \alpha_2 Seed_{ih} + \alpha_3 Organic_{ih} + \alpha_4 N_{ih}^2 + \alpha_5 Seed_{ih}^2 + \alpha_6 N_{ih} * Seed_{ih}) * \exp[-(\beta_0 + \beta_1 * Labor + \boldsymbol{Chem} * \beta_2 + \boldsymbol{H} * \beta_3 + \beta_4 * EXT)^2] + \varepsilon_{iht}\} \quad (4)$$

where Y is maize is yield; f_i is unobserved plot level heterogeneity; ε_{iht} is a random error assumed to be i.i.d and normally distributed.

Method of Estimation

The use of panel data allows for the control of unobserved household heterogeneity such as skills and motivation. The Mundlak-Chamberlain device (MC) (Chamberlain, 1984 and Mundlak, 1978) will be used to estimate equation (4). This model is used in order to test and control for unobserved heterogeneity such as time-constant farmer ability and soil variation and its correlation with observables, while yielding a fixed effects-like interpretation[2]. The model accounts for the possible correlation between unobserved heterogeneity f_i and explanatory variables X_{iht} by assuming the following form:

$$f_h = \tau + \overline{X_h}\gamma + a_i \quad (6)$$

where $\overline{X_h}$ is a vector of the averages of X_{iht} across time periods, γ is a vector of parameters and a_i is i.i.d and normally distributed and independent of ε_{iht} in equation (4). The vector of time averages is added as an additional set of covariates to the

The Maximum Likelihood Estimation (MLE) method is used for the estimation of the parameters in equations (4) and (6). MLE is asymptotically unbiased and efficient under regularity conditions.

Profitability of fertilizer use

In determining where fertilizer is profitable and where it is not profitable, the profitability of fertilizer use is determined for each of the 28 districts and 5 agro-ecological zones of Malawi. The agro-ecological zones include the highlands, the escarpments, the plateau, the lakeshore and upper shire valley, and the lower shire valley. Two measures of profitability - expected marginal value-cost ratio (MVCR) and expected average marginal cost-ratio (AVCR) – have been used in the literature to determine the profitability of fertilizer use (Xu et. al, 2009; Sheahan et al., 2013).

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[2] The Mundlak-chamberlain model allows for the test of the hypothesis of no correlation between unobserved heterogeneity and $\overline{X_h}$ through the joint significance test of γ (in equation 6).

MVCR measures the amount by which farm income will increase from a unit increase in the rate of fertilizer application; and AVCR measures how much income will increase as a result of fertilizer application. The two measures of profitability of fertilizer use are expressed as:

$$E(MVCR_{fijt}) = \frac{E(P_{yt})E(MP_{xijt})}{W_{fijt}} \quad (7)$$

$$E(AVCR_{fijt}) = \frac{E(P_{yt})E(AP_{xijt})}{W_{fijt}} \quad (8)$$

where W_f is the average price of fertilizer in a particular district or agro-ecological zone; and P_y is the average output price of maize in a particular district or agro-ecological zone.

Determinants of profitability of fertilizer use

The determinants of profitability will be identified with a Spatial Hierarchical Model (SHM). SHM is used for two reasons. First, the data for the analysis is hierarchical in nature. The plots are nested within households (because farm households in Malawi and other parts of Africa usually cultivate crops on multiple plots), and the households are in turn nested with communities. Thus the profitability of fertilizer use at the plot level depends not only on plot-level variables but also household-level and community-level variables. The existence of such a hierarchy in the dataset should not be ignored because it has implications for statistical validity – i.e. it affects the coefficient estimates and their standard errors (Goldstein, 1995; Elhorst, 2014; Carrado and Fingleton, 2011). Secondly, SHM is used in order to account for the possible existence of spatial dependence among farmers in term of fertilizer use. Farming, like other human activities, occur within a social system that is characterized by a network of interdependencies among actors, so that farmers (in developing countries especially) adapt their behaviors to the behavior of other farmers in their communities. This is particularly true in the area of adoption and utilization of improved farm inputs. Thus, a farmer's decision regarding fertilizer application - whether or not to apply inorganic fertilizer, the kind and amount of fertilizer to apply, and whether or not to apply basal and/or top dressing fertilizers- is partly influenced by the opinions and behaviors of other farmers. Accordingly, the profitability of fertilizer use at the plot of a particular farmer is likely to depend on unobservable factors that emanate from the farmer's interaction with other farmers. This interaction will be captured with spatial weight matrices.

A three-level model takes the hierarchical structure between plots, households and communities into accounts by modeling the variation at all the three-levels. However, because three-level models are usually difficult to estimate, the intraclass correlation coefficient will be calculated to determine the proportion of the variation in profitability at the plot-level that is attributed to community-level variables. The community level will be dropped from the model if the proportion of the variation coming from the community-level variables is not significant. For now, the three-level model is presented. In the three-level model, a distinction is made between plot-level explanatory variables (variables that vary between plots), household-level explanatory variables (variables that vary only between households) and community-level explanatory variables (variable that vary only between communities). The coefficients of the plot-level variables may vary from one household to another, thus they are treated as random. The coefficients of the household-level variables may vary from one community to another, thus they are also treated also as random. The coefficients of the community-level variables are however the same for all communities and therefore treated as fixed.

For plot *i* belonging to household *h* in community *c*, the mixed random and fixed coefficients SHM is specified as follows:

$$MVCR_{phc} = P_{phc}\beta_h + H_{hc}\delta_c + C_c\gamma + \varepsilon_{phc} \quad (9a)$$

$$\beta_h = \beta + \lambda_h \quad (9b)$$

$$\delta_c = \delta + \alpha_c \quad (9c)$$

$$\varepsilon_{phc} = e_{phc} + \sum_{h \neq k} v_{hc} W_{hk} + u_C \quad (9d)$$

where $C(= 1, \dots N)$ refers to a community; h $(= 1, \dots, h_c$ with h_c the number of households in community C) refers to a household; p (1,…,P_h with P_h the number of plots of household h); $MVCR_{phc}$ is profitability of fertilizer use on plot p of household h in community c. X_{phc} is a vector of plot-level explanatory variables such as fertilizer application rate, time of fertilizer application, soil characteristics. H_{hc} is a vector of household-level explanatory variables such as household size, education of household head, income level of the household etc. C_c is a vector of community-level explanatory variables distance to the nearest output market, road density etc. ε_{pht} is a three-part (e_{phc}, v_{hc} and u_C) heteroskedastic disturbance term with. Respectively, e_{phc}, v_{hc} and u_C represent plot-level, household-level and community-level explanatory variables that could not be accounted for in the model. W_h is a household-level distance weight matrix.

Preliminary Results

Descriptive Statistics

The average plot size is 1.192 acres when measured with GPS, and 1.107 acres when self-reported by farmers; and the average plot-level maize equivalent yield is 648.711 kg/acre and 603.787 for the GPS and self-reported measurements respectively. Average fertilizer and seed application rates are 70.176 kg/acre and 12.381 kg/acre respectively (from GPS measurement). The average fertilizer application rate is quite low given the existence of a large scale farm input subsidy program. Inorganic fertilizer was applied on about 75% of the plots, but organic fertilizer was applied on just about 12.5% of the plots.

The average farm household has a household size of 4.9; and an annual real consumption expenditure of MKW 51464.47. The average household size is quite low given the African context where farmers usually depend mainly on family labor and thus tend to have large families. Only about 23% of the farm households are headed by females. The small proportion of female-headed households is typical of Sub-Sahara African farm households where majority of them are headed by males. The average household received about 71.65kg of subsidized fertilizer.

Empirical Model Results

Only the OLS results of the factors affecting maize yield is presented at this stage. The model was estimated for the three regions of Malawi and for the country as a whole. The next step will be to estimate the maize production function with the non-linear model described above, considering the various districts and agro-ecological zones of the country; and then proceed with the profitability analysis.

The OLS results are presented in table 3. The results of both the pooled and regional datasets show that fertilizer has the expected results on maize production – the level fertilizer variable has a positive and significant effect, while the squared fertilizer variable has as negative and significant effect. The fertilizer effect is strongest in the Southern region, followed by the Central region and the Northern region in that order. This show that the Southern region has highest response rate to fertilizer.

Annual real household expenditure has a positive effect on maize production. This is an indication that, all things being equal, relatively non-poor households are able to obtain higher maize yields than poor households.

Conclusion and policy recommendation

The study aims at assessing the profitability of fertilizer use in Malawi. At this stage, we are only able to provide an OLS estimation of the maize production function. The results indicate that fertilizer yield response rate is highest in the Southern region followed by the Central region and the Northern region in that order; and that non-poor farmers appear to have a relatively higher maize response rate to fertilizer.

The results thus far has implications for policies such as the FISP that are aimed at increasing maize production in order to ensure national food sufficiency. Such policies should consider all the regions of the country, especially the southern region since it has the highest maize response rate to fertilizer. Although policies should not focus on poor farmers alone, because non-poor farmers appear to have higher yields.

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List of Tables

Table 1: Definition of variables

Variable	Definition
Output	Maize equivalent output
Yield_GPS	Kilograms of maize harvested per acre of land (measured by GPS)
Yield_SR	Kilograms of maize harvested per acre of land (self-reported by farmers)
Inorganic	= 1 if inorganic fertilizer was applied on plot
Fertilizer	Kilograms of inorganic fertilizer applied
Organic	= 1 if organic matter was applied on plot; = 0 if otherwise
Chemical	= 1 if chemicals such as pesticides, herbicides etc. were applied; = 0 if otherwise
Seed	Kilograms of seed planted
Hybrid	= 1 if hybrid seed was planted on plot; = 0 otherwise
Labor	Amount of labor (family labor + hired labor) used on plot (in days)
Hired_labor	= 1 if hired labor was used on farm; = 0 if otherwise
Family_labor	Amount of family labor used on plot (in days)
Headage	Age of household head
HHsize	Household size
Irrigation	= 1 if plot was under irrigation; = 0 if otherwise
Female	= 1 if household head is female; = 0 if otherwise
Rural	= 1 if household is located in a rural community; = 0 if otherwise
FISP	= 1 if household received coupon(s) for subsidized inputs; = 0 if otherwise
Subsidy	Kilograms of subsidized fertilizer received by the household
Apply_once	= 1 if inorganic fertilizer was applied only once in the production period ; 0 if otherwise
Apply_twice	= 1 if inorganic fertilizer was applied twice in the production period; 0 if otherwise
Plot_size_GPS	Plot size measured with GPS
Plot_size_SR	Plot size seal-reported by farmer

Table 2: Descriptive Statistics

	Continuous Variables			
	Mean	Maximum	Minimum	Standard Deviation
Output (kg)	543.474	14372.280	0.75	674.204
Plot size (GPS) (acres)	1.192	685.350	0.01	9.361
Plot size (self-reported) (acres)	1.107	12.355	0.01	0.824
Yield (GPS) (kg/acre)	648.711	2989.130	0.349	515.524
Yield (SR) (kg/acre)	603.787	2986.948	0.500	492.045
Age of household head	43.553	102.000	15.00	16.252
Household size	4.902	17.000	1.000	2.255
Hired labor (days)	2.530	128.000	0.000	8.201
Family labor (days)	68.111	596.000	0.000	52.324
Total labor (days)	70.641	596.00	0.000	52.284
Inorganic fertilizer (kg)	59.717	1600.000	0.000	70.910
Seed (kg)	12.381	5005.000	0.0004	60.118
Hybrid seed (kg)	5.422	2000.000	0.000	25.669
Household expenditure (MKW)	51464.47	958056.200	3426.413	46947.530
Subsidy (kg)	71.65	37.45	0.02	600

	Dummy variables	
	Yes	No
Organic	12.547	87.453
Hired_labor	24.261	75.739
Irrigation	0.278	99.722
Female	23.205	76.795
Inorganic	75.383	24.617
Apply_once	20.660	79.340
Apply_twice	17.415	82.585
Rural	92.143	7.857

Table 3: OLS Results of Factors Affecting Maize Yield

	Pooled	**Northern**	**Central**	**Southern**
Fertilizer	1.786*** (0.119)	1.048*** (0.271)	2.143*** (0.179)	2.480*** (0.290)
Seed	-0.443 (0.328)	-0.541 (1.478)	-0.988 (0.891)	0.264 (0.381)
Fertilizer Squared	-0.002*** (0.000)	-0.002** (0.001)	-0.001*** (0.000)	-0.004*** (0.001)
Seed Squared	0.000 (0.000)	-0.002 (0.004)	0.001 (0.001)	-0.000 (0.000)
Fertilizer * Seed	0.008*** (0.003)	0.015 (0.011)	0.003 (0.007)	-0.000 (0.018)
Organic	35.242*** (16.506)	76.745 (47.139)	42.123* (23.928)	-5.637 (26.031)
Chemical	18.409 (64.438)	252.701 (160.722)	-43.015 (80.009)	-49.726 (152.699)
Labor	-0.341** (0.110)	-1.074*** (0.290)	-0.001 (0.170)	-0.726*** (0.167)
Extension	20.296* (10.915)	11.414 (25.297)	-23.771 (17.874)	62.527*** (16.606)
HHsize	10.801*** (2.640)	16.242*** (5.394)	5.862 (4.254)	9.334** (4.270)
Age	-0.606* (0.343)	-0.255 (0.793)	0.707 (0.572)	-1.582*** (0.499)
Female	-54.884*** (13.370)	-31.088 (31.407)	-85.916 (22.577)	-32.929* (19.186)
Expenditure	0.001*** (0.000)	0.001** (0.000)	0.001*** (0.000)	0.002*** (0.000)
Soil_good	100.881*** (18.067)	108.871** (44.222)	127.784*** (27.795)	81.710*** (27.935)
Soil_fair	56.313*** (18.192)	32.871 (44.250)	96.784*** (28.142)	36.922 (28.038)
Constant	410.676*** (27.137)	480.575 (67.573)	412.753*** (42.651)	396.804*** (42.009)
Sample size	8489	1589	3402	3498
R-Squared	7.7	4.4	9.8	8.10
F-statistic	47.14***	4.87***	24.40***	20.46***

*, **, *** *denotes that corresponding coefficients are statistically significant at 10%, 5% and 1% level respectively.*