Session 3

Fertilizer profitability analysis

- Returns to land and labor – explain and give examples.
- Value-cost ratios: use household survey data to present evidence on value cost ratios for different regions/agro-ecological zones, price conditions, spatial factors influencing profitability, and household characteristics associated with differences in the marginal product of fertilizer use on staple food crops. Provide scenarios and ask participants to estimate how farm-level profitability of fertilizer use would change with alternative farming practices, timeliness of fertilizer delivery, weather outcomes, world fertilizer price scenarios, public investments in port, road, and rail infrastructure.
- Estimated impact on overall fertilizer use, and derived impact on maize production.

African Agricultural Markets Program (AAMP)

Shahidur Rashid
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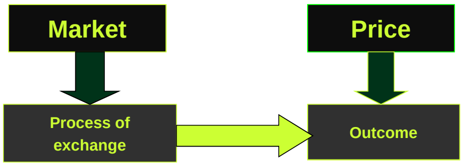
COMMON Market for Eastern and Southern Africa (COMESA), Policy Training Workshop
Livingstone, Zambia

IFPRI

Outline

- Policies
  - What are policies?
  - What justifies them?
- Profitability
  - How do policies affect profitability
  - From Macro to Micro analyses

Markets and prices



Market

Price

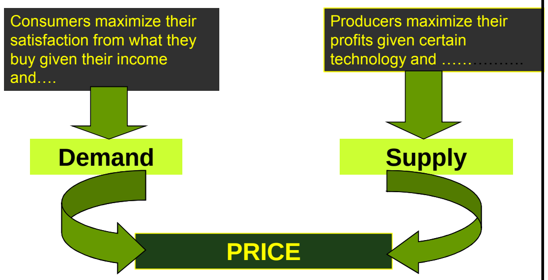
Process of exchange

Outcome

What determine process of exchange?

- Number of traders, producers, and consumers
- Infrastructure, Information, Institutions, coordination, technology
- Law, regulations, contract enforcements

Demand and Supply



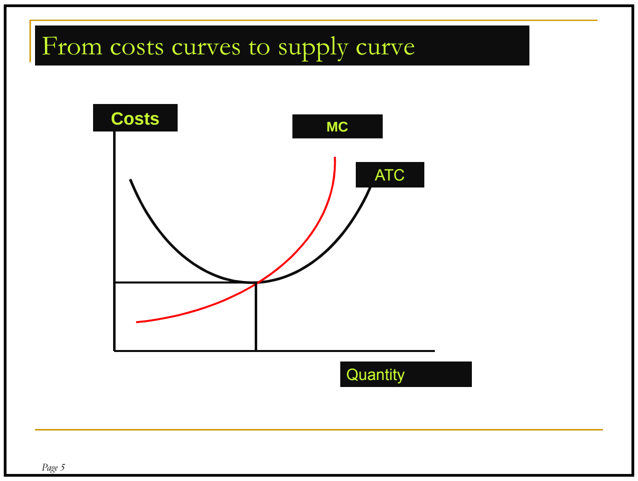
Consumers maximize their satisfaction from what they buy given their income and….

Producers maximize their profits given certain technology and ……………

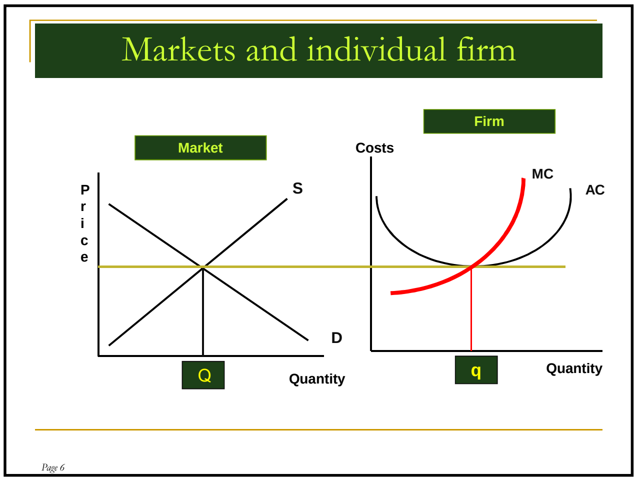
Demand

Supply

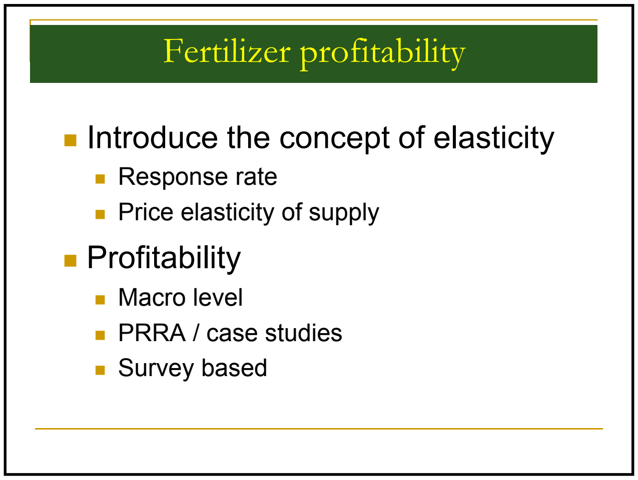
PRICE



From costs curves to supply curve

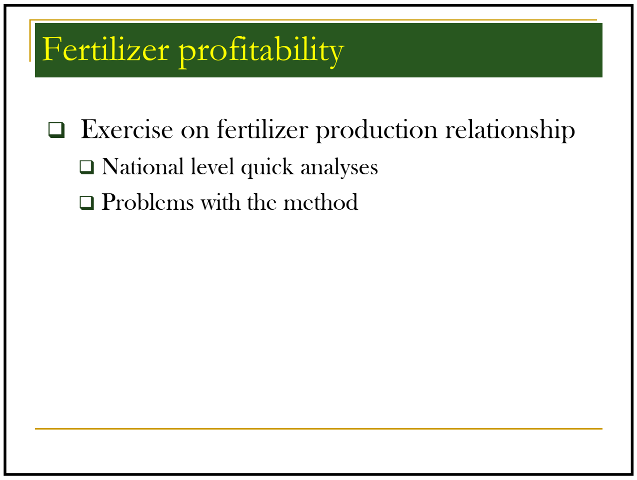


Markets and individual firm



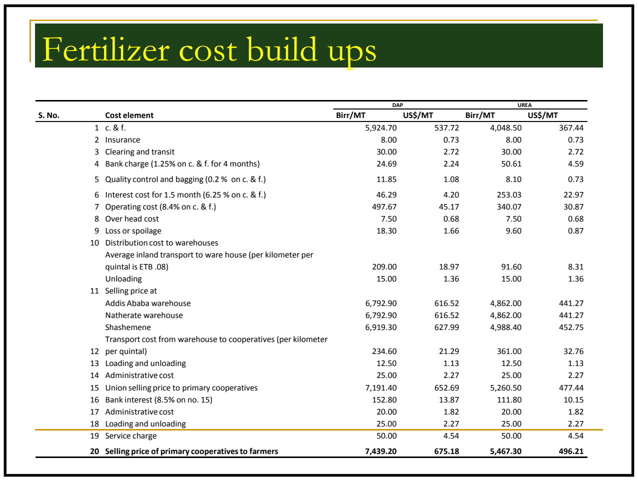
Fertilizer profitability

- Introduce the concept of elasticity
  - Response rate
  - Price elasticity of supply
- Profitability
  - Macro level
  - PRRA / case studies
  - Survey based



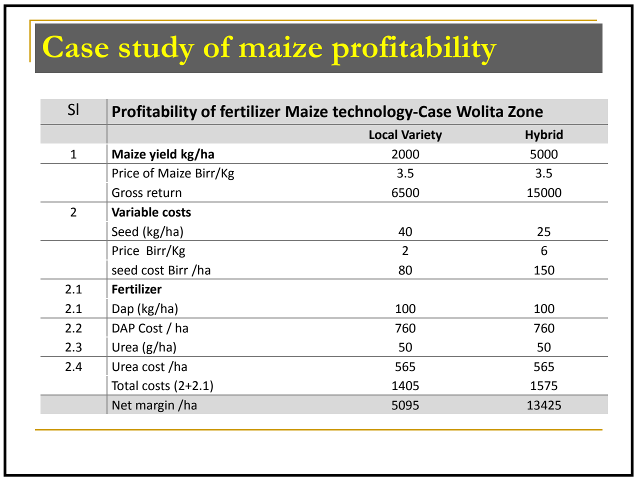
Fertilizer profitability

- ❑ Exercise on fertilizer production relationship
  - ❑ National level quick analyses
  - ❑ Problems with the method



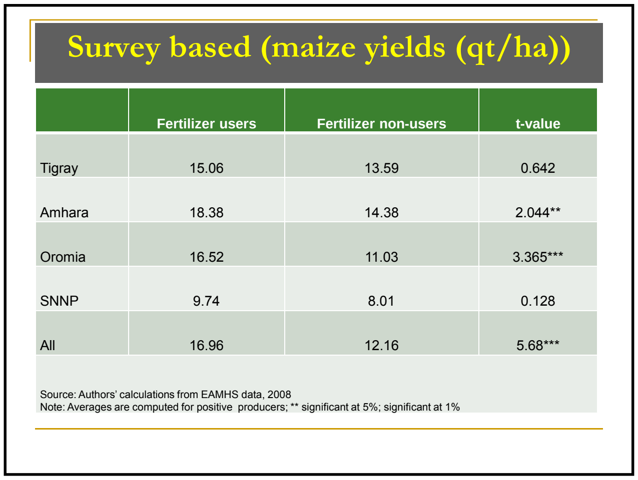
Fertilizer cost build ups

S. No.	Cost element	DAP Birr/MT	DAP US$/MT	UREA Birr/MT	UREA US$/MT
1	c. & f.	5,924.70	537.72	4,048.50	367.44
2	Insurance	8.00	0.73	8.00	0.73
3	Clearing and transit	30.00	2.72	30.00	2.72
4	Bank charge (1.25% on c. & f. for 4 months)	24.69	2.24	50.61	4.59
5	Quality control and bagging (0.2 % on c. & f.)	11.85	1.08	8.10	0.73
6	Interest cost for 1.5 month (6.25 % on c. & f.)	46.29	4.20	253.03	22.97
7	Operating cost (8.4% on c. & f.)	497.67	45.17	340.07	30.87
8	Over head cost	7.50	0.68	7.50	0.68
9	Loss or spoilage	18.30	1.66	9.60	0.87
10	Distribution cost to warehouses				
	Average inland transport to ware house (per kilometer per quintal is ETB .08)	209.00	18.97	91.60	8.31
	Unloading	15.00	1.36	15.00	1.36
11	Selling price at				
	Addis Ababa warehouse	6,792.90	616.52	4,862.00	441.27
	Natherate warehouse	6,792.90	616.52	4,862.00	441.27
	Shashemene	6,919.30	627.99	4,988.40	452.75
12	Transport cost from warehouse to cooperatives (per kilometer per quintal)	234.60	21.29	361.00	32.76
13	Loading and unloading	12.50	1.13	12.50	1.13
14	Administrative cost	25.00	2.27	25.00	2.27
15	Union selling price to primary cooperatives	7,191.40	652.69	5,260.50	477.44
16	Bank interest (8.5% on no. 15)	152.80	13.87	111.80	10.15
17	Administrative cost	20.00	1.82	20.00	1.82
18	Loading and unloading	25.00	2.27	25.00	2.27
19	Service charge	50.00	4.54	50.00	4.54
20	**Selling price of primary cooperatives to farmers**	**7,439.20**	**675.18**	**5,467.30**	**496.21**



Case study of maize profitability

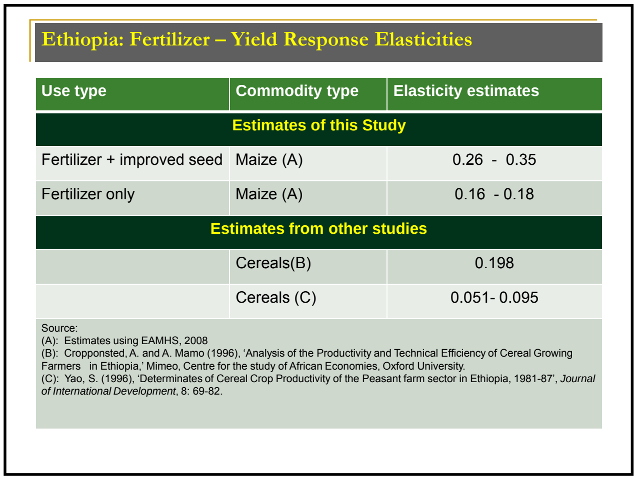
Sl	**Profitability of fertilizer Maize technology-Case Wolita Zone**		
		Local Variety	**Hybrid**
1	**Maize yield kg/ha**	2000	5000
	Price of Maize Birr/Kg	3.5	3.5
	Gross return	6500	15000
2	**Variable costs**		
	Seed (kg/ha)	40	25
	Price Birr/Kg	2	6
	seed cost Birr /ha	80	150
2.1	**Fertilizer**		
2.1	Dap (kg/ha)	100	100
2.2	DAP Cost / ha	760	760
2.3	Urea (g/ha)	50	50
2.4	Urea cost /ha	565	565
	Total costs (2+2.1)	1405	1575
	Net margin /ha	5095	13425



Survey based (maize yields (qt/ha))

	Fertilizer users	Fertilizer non-users	t-value
Tigray	15.06	13.59	0.642
Amhara	18.38	14.38	2.044**
Oromia	16.52	11.03	3.365***
SNNP	9.74	8.01	0.128
All	16.96	12.16	5.68***

Source: Authors' calculations from EAMHS data, 2008
Note: Averages are computed for positive producers; ** significant at 5%; significant at 1%



Ethiopia: Fertilizer – Yield Response Elasticities

Use type	Commodity type	Elasticity estimates
Estimates of this Study		
Fertilizer + improved seed	Maize (A)	0.26 - 0.35
Fertilizer only	Maize (A)	0.16 - 0.18
Estimates from other studies		
	Cereals(B)	0.198
	Cereals (C)	0.051- 0.095

Source:
(A): Estimates using EAMHS, 2008
(B): Croppons ted, A. and A. Mamo (1996), 'Analysis of the Productivity and Technical Efficiency of Cereal Growing Farmers in Ethiopia,' Mimeo, Centre for the study of African Economies, Oxford University.
(C): Yao, S. (1996), 'Determinates of Cereal Crop Productivity of the Peasant farm sector in Ethiopia, 1981-87', *Journal of International Development*, 8: 69-82.

Is fertilizer profitable?

Let’s do some math

- **Our elasticity estimate is=0.26. This means:**
  - 10% increase in fertilizer use →2.6% increase in yield responses
- **Average fertilizer use is 80kg/ha. Using our elasticity estimate:**
  - 10% increase in fertilizer use→8kg/ha additional use of fertilizer
  - Cost of additional fertilizer = 8*4 = 32 Birr
- **Average yield is 1700kg/ha. According to our elasticity estimate:**
  - 2.6% increase in additional output→44.2kg/ha
  - Additional value of extra production → 44.2*2.5 = 110.5 Birr
- **Extra revenue due to fertilizer 110.5 – 32 = 78.5 Birr**

Profitability exercise

Price of fertilizer = 5 Birr / Kg
Production per hectare = 1000 kg
Price of maize = 2.67 Birr / Kg
Response rate = 0.3
Average fertilizer use = 80 kg /ha

Question # 1:
Will it be profitable for a farmer to increase fertilizer use by 10 percent?

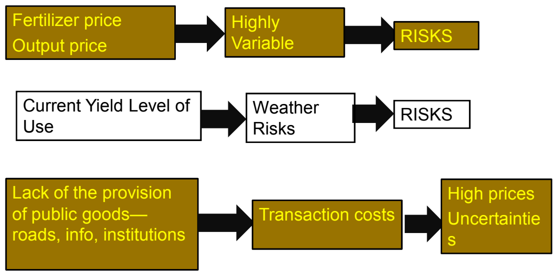
Question # 2:
Now suppose that the country increases fertilizer use by 20 percent that leads to a 6 % increase in supply of maize. If price elasticity of supply is 0.5 (i.e., %Δ in quantity supply ÷ % Δ in price = 0.5), what will happen to maize price? What will happen to profitability?

- Group 1:

20 percent increase in fertilizer
6 percent increase in maize
Country produce 1 million tons of maize
Price elasticity of supply is 0.5
How much will price decline?
How will it effect profitability?

Fertilizer demand and supply

- Key factors behind fertilizer profitability



FOOD SECURITY RESEARCH PROJECT

FACTORS INFLUENCING THE PROFITABILITY OF FERTILIZER USE ON MAIZE IN ZAMBIA

BY

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Executive Summary

Fertilizer use remains very low in most of Africa despite widespread agreement that much higher use rates are required for sustained agricultural productivity growth. This study estimates maize yield response functions in agro-ecological Zone IIA, a relatively high-potential zone of Zambia, to determine the profitability of fertilizer use under a range of small farm conditions found within this zone. The theoretical framework used in this study incorporates agronomic principles of the crop growth process. The model distinguishes different roles of inputs and non-input factors in crop production. We estimate the effects of conventional production inputs as well as household characteristics and government programs on maize yield for households in the dominant acrisols soil type. Results indicate that even within this particular soil type within Zone IIA, the maize-fertilizer response rate in the two specific years varied widely across households. The main factors explaining the variability in maize-fertilizer response rates were the rate of application, the timeliness of fertilizer availability, the use of animal draught power during land preparation, and whether the household incurred the death of an adult member in the past 3 years. These modifying factors, as well as variations in input and output prices due to proximity to roads and markets, substantially affected the profitability of fertilizer use on maize. Fertilizer use on maize tended to be unprofitable at full commercial fertilizer prices for farmers who received fertilizer late and who were located in relatively remote areas.

1. Introduction

Fertilizer use remains very low in most of Africa despite widespread agreement that much higher use rates will be required for sustained agricultural productivity growth. Many studies have examined the causes of continued low use of modern inputs in sub-Saharan African countries (World Bank, 2008; Moser and Barrett, 2006; Crawford et al., 2003). While weak input, credit, and output markets, poor soils, and high production risks have often been identified as the main reasons for low uptake of fertilizer among African farmers, there is a relative dearth of insight about why fertilizer use remains low even in relatively high-potential and accessible areas where fertilizer use is believed to be profitable.

Agricultural production in Zambia is largely rainfed and is based on small-scale family farming systems. Over 80 percent of smallholder farmers nationwide own less than 5 hectares of land. Zambian government agricultural policy has for the past several decades focused on fertilizer subsidies and targeted credit programs to stimulate small farmers' agricultural productivity, enhance food security and ultimately reduce poverty. Improving maize productivity has been a major goal of the government policy. Over 70% of the 900,000 small-scale farmers grow maize as their major staple crop and they are responsible for 65% of the maize production in the country. Maize is the single greatest source of cash income from the sale of agricultural products (Govereh et al., 2003).

In 2002, the Zambian Government launched programs and policies under the framework of its Poverty Reduction Strategy Paper (PRSP) which, in the agricultural sector, includes: the Fertilizer Support Programme (FSP) out-grower schemes, land and infrastructure development, technology development, agriculture extension, and maize marketing in support of small-scale farmers (GRZ, 2004; World Bank, 2002a; 2002b).

Despite government's efforts over the past several decades, overall fertilizer consumption has expanded slowly and mean maize yields remain at the level of 1.2 to 1.8 tons per hectare over the past decade. Maize yields vary greatly among households, but 75 percent of households obtain between 0.7 and 2.5 tons per hectare. Several recent assessments of the implementation and effectiveness of the FSP conclude that FSP has had little impact in terms of increasing maize production and enhancing household incomes and livelihoods (CSPR, 2005; CDFA, 2008; Agricultural Consultative Forum, 2009). Several factors were identified as responsible for reducing the effectiveness of the Programme including late delivery of inputs to farmers, mismanagement by those in charge of distributing inputs, diversion of program inputs, low output prices, poor crop marketing arrangements, and poor transport facilities. These studies underscore the need, among other things, for a better understanding of the factors affecting maize yield response to fertilizer, including the timeliness of fertilizer application, and the profitability of fertilizer use under small farm conditions so as to inform policy process aimed at achieving sustainable increase in maize productivity and smallholder incomes.

Extension messages in Zambia have been based on one nationally recommended application rate of 200 kilograms of basal fertilizer (Compound D, 10-20-10 NPK) and 200 kilograms of top dressing fertilizer (Urea, 46-0-0) per hectare of maize. This one-size-fits-all recommendation ignores heterogeneity in small farm conditions and differing market conditions. As fertilizer remains an expensive input in sub-Saharan Africa, efforts to raise the profitability and effective demand for fertilizer will depend on helping farmers to use the input efficiently, which in turn depends on management practices, use of fertilizer-responsive seeds, and taking into consideration how agroecological and market conditions affect appropriate application rates.

This study examines maize yield response to a range of farm inputs, determines the profitability of fertilizer use by small-scale farmers, and identifies the potential to increase maize productivity and profitability of fertilizer use through public policy tools. The analysis focuses on a relatively high-potential area of Zambia well suited to maize production. An accurate understanding of these issues can be achieved through appropriate specification and estimation of crop production models.

Crop response research has featured various models, in particular, flexible functional forms such as the quadratic and translog, which achieve second-order approximations to arbitrary functions. However, recent crop production studies (see, e.g., Chambers and Lichtenberg, 1994; Guan et al, 2005; Guan et al.; 2006) suggest that the approximation-based models suffer theoretical drawbacks because these models treat inputs symmetrically and implicitly assume different inputs affect crop yield in the same way. To address this issue, asymmetric models have been proposed. In this study we further generalize the asymmetric models proposed in the literature in order to better capture the underlying data generating process in crop responses. The model provides a more robust tool for analyzing crop yield responses.

The article is organized as follows. We describe the yield response modeling framework in section 2. Section 3 describes the data and empirical model. The estimation method is presented in the fourth section, followed by a discussion of the findings in Section 5. We conclude with a summary and implications for policies to promote the profitability of fertilizer use by smallholder farmers in Zambia.

2. Modeling Framework

Recent studies of crop production functions have recognized the relevance of specific agronomic processes in yield determination (e.g. Lichtenberg and Zilberman, 1986; Chambers and Lichtenberg, 1994, 1996). Guan et al. (2006) proposed a conceptual framework that dichotomized inputs used in crop production into *growth inputs* and *facilitating inputs* based on agronomic perspectives that different factors influence yield differently.[1] Growth inputs are defined as those that are directly involved in biological process of crop growth and thus essential for crop growth such as seed type, nutrients, and water. Growth inputs determine attainable yield level in a given biophysical environment, assuming no yield-reducing factors for maximum yield such as weeds, diseases, and pests. These factors cause actual farm yield to be lower than the attainable yield. Facilitating inputs are defined as those that are not directly involved in the basic biological process, but can help create or alter growth conditions under which growth inputs take effect. Guan et al. (2006) included labor, capital, and pesticides in this category. A general crop production model is written as:

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[1] In the agronomic literature, three distinct yield levels are described: potential, attainable, and actual. These levels are determined by different growth conditions: (1) growth defining, (2) growth limiting, and (3) growth reducing factors. Growth defining factors such as weather and species characteristics determine the potential yield, assuming there are no growth limiting and reducing factors. Attainable yield is lower than the potential yield due to growth limiting factors such as water and nutrients. Yield gap between actual yield and attainable yield is caused by the growth reducing factors such as weeds, pests, and diseases. Potential yield is typically not achieved due to growth limiting and growth reducing factors; also, it may not be economically viable to attempt to achieve potential yield (Rabbinge, 1993; Van Ittersum and Rabbinge, 1997; Van de Ven et al., 2003).

(1) $y = G(\boldsymbol{x}) \cdot S(\boldsymbol{z})$

where y is crop yield, $\boldsymbol{x}$ is a vector of growth inputs, and $\boldsymbol{z}$ is a vector of facilitating inputs. Growth inputs and facilitating inputs affect crop output through different mechanisms indicated by crop growth function $G(\cdot)$ and scaling function $S(\cdot)$. Crop-growth function $G(\cdot)$ determines the attainable yield level given the biophysical environment. The scaling function $S(\cdot)$ is defined in the interval [0, 1]. When $S(\cdot)$ reaches 1, i.e., when the growth conditions are optimal for a given level of growth inputs $\boldsymbol{x}$, crop output y attains its maximum value $G(\boldsymbol{x})$. Actual yield is lower than the attainable yield and scaled down by the factor $S(\cdot)$ under non-optimal growth conditions**.**

In this study we define a concept of *yield scaling factors* to generalize the concept of facilitating inputs. The yield scaling factors include not only physical inputs (i.e. facilitating inputs) but also non-input factors that directly affect the efficiency of the crop production process and therefore the actual crop yield. The non-input factors, in conjunction with physical inputs, affect $S(z)$. By accommodating non-input factors, we can obtain more accurate estimates of crop responses to agronomic inputs use, especially crop response to fertilizer that is of particular interest in our study. We further propose to use a quadratic functional form in empirical model specification of crop response to growth inputs, $G(.)$. This specification imposes concavity on the yield response which is consistent with most observable biological relationships. The Mundlak–Chamberlain approach is used in estimation to control for unobserved heterogeneity such as time-constant farmer ability and soil variation and its correlation with observables.

3. Data and Empirical Model

3.1. Data

Household-level data used in this study are from three surveys, the 1999/2000 Post Harvest Survey (PHS), the linked First Supplemental Survey to the 1999/2000 PHS, and the Second Supplemental Survey to the 1999/2000 PHS. All three surveys were conducted by the government Central Statistical Office. A panel data set for two agricultural seasons, 1999/2000 and 2002/2003, is available from these surveys. PHS is a nationally representative survey using a stratified three-stage sampling design. Census Supervisory Areas (CSA) were first selected within each district, next Standard Enumeration Areas (SEA) were sampled from each selected CSA, and in the last stage a sample of households were randomly selected from a listing of households within each sample SEA. The SEA is the most disaggregated geographic unit in the data, which typically includes 2-4 villages of several hundred households. Agro-ecological zone and soil type information is available at the SEA level. Our study area is the primary maize surplus production region, Zone IIA (medium rainfall area) with dominant soil type acrisols or ferrolsols. The parts of Zone IIA with these soil types are considered to be relatively well suited to maize production and responsive to fertilizer application. Households were also separated into two equal groups according to their distance to the nearest district town. We differentiate between these relatively accessible and remote areas in the assessment of fertilizer use profitability. The panel data set consists of 707 farmers in two periods, producing a total of 1,414 observations. The variables used in the analysis are defined in Table 1 and their panel data summary statistics are presented in Table 2.

Table 1. Variable definitions

Variable	Description
YIELD	Maize yield (kg/hectare)
N	Nitrogen application (kg/hectare)
BSLPCT	Percent of basal fertilizer over total fertilizer application
RAIN	Rainfall (mm)
HYBD	1=used hybrid seed
ONTM	1=basal fertilizer available on time
DRTPW	1=used animal or mechanical draught power in land preparation
AREA	Maize planting area (hectare)
EXTNSN	1=received extension service
GVCHNL	1=acquired fertilizer from government channel
ADULT	Number of adults (above age 14) per hectare of maize
AGE	Age of household head
EDUC	Years of schooling of household head
FEMHD	1=female household head
MRTLT	1=adult mortality within past three years
YEAR	1=2002 season

The output specified is maize yield in kilograms (kg) per hectare. Growth inputs consist of fertilizer, seed type, and rainfall. We include nitrogen (the most important nutrient in maize growth) application rate[2] in kg per hectare, as well as the percentage of basal fertilizer in total kilograms fertilizer usage.[3] Seed is specified as a dummy variable indicating whether purchased hybrid seed was used. Rainfall is district-level seasonal rainfall in millimeters. Yield scaling factors modeled as (0,1) variables include whether animal draught power was used during land preparation, whether fertilizer was available at the time of planting, whether fertilizer was acquired from the government fertilizer subsidy program, and whether the household received maize advice from the national extension service. Other factors entering the scaling function include maize planted area, characteristics of household head (age, gender, and education), number of adults above age 14, and whether the household incurred the death of a prime-aged adult between the first and second surveys. A year dummy was included to account for unobserved differences across the two years.

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[2] It is calculated based on the amount of basal fertilizer and top dressing fertilizer used per hectare and the nutrient components in these fertilizers. 100kg of Compound D basal fertilizer contains 10kg nitrogen (*N*), while 100kg of urea top dressing contains 46kg *N*.

[3] Extension messages recommend applying basal and top dressing at a 1:1 ratio.

Table 2. Summary statistics for variables used in the analysis.

	full sample (n=707)				used fertilizer both years (n=203)				Did not use fertilizer either wave (n=315)				Used fertilizer at least one year (n=392)	
		Source of variation (StDev)				Source of variation (StDev)				Source of variation (StDev)				StDev
Variable	Mean	Overall	Between	Within	Mean	Overall	Between	Within	Mean	Overall	Between	Within	Mean	Overall
Yield (kg/ha)	1,779	1,140	874	732	2,198	1,252	980	780	1,573	1,021	759	685	2,082	1,235
Maize area (ha)	1.40	1.50	1.25	0.84	2.04	2.09	1.74	1.16	1.07	0.89	0.71	0.54	1.22	1.90
Nitrogen (kgs/ha)	25.1	42.6	34.7	24.6	62.7	47.8	36.3	31.1					59.0	47.6
Basal-top dress ratio	0.21	0.27	0.23	0.15	0.49	0.17	0.13	0.11					0.49	0.19
Basal on time [0,1]					0.70	0.46	0.33	0.32					0.68	0.47
Fertilizer from gov't channel [0,1]					0.38	0.49	0.36	0.33					0.35	0.48
Use hybrid [0,1]	0.24	0.43	0.35	0.24	0.45	0.50	0.41	0.29	0.10	0.30	0.23	0.19	0.41	0.49
Use power [0,1]	0.50	0.50	0.43	0.26	0.67	0.47	0.41	0.24	0.38	0.48	0.40	0.27	0.63	0.48
Female head of household [0,1]	0.18	0.38	0.35	0.15	0.11	0.31	0.28	0.13	0.22	0.41	0.39	0.14	0.14	0.35
Age (years)	46.0	15.1	13.8	6.0	45.9	13.7	12.8	4.8	45.3	15.9	14.4	6.7	46.1	14.2
Education (years)	4.7	3.9	3.7	1.3	5.7	4.1	3.9	1.3	3.9	3.6	3.4	1.2	5.4	4.0
Adults over 14	3.7	3.0	2.2	2.0	3.6	2.7	2.0	1.8	3.8	3.1	2.2	2.1	3.5	2.6
Mortality	0.11	0.23	0.23	0.00	0.12	0.24	0.24	0.00	0.11	0.23	0.23	0.00	0.11	0.23
Extension advice [0,1]	0.41	0.492	0.34	0.35	0.45	0.50	0.33	0.38	0.36	0.48	0.34	0.34	0.45	0.50
Rain (mm)	936	177	96	149	912	196	91	173	955	159	98	126	914	187

Notes: “overall”= standard deviation over the pooled sample; “between”=standard deviation across time-averaged household sample (sample size is half that of overall sample); “within”=standard deviation within households from their variable means.

3.2. Empirical Model

Under the general framework (1), we specify functional forms for the crop-growth function $G(\cdot)$ and the scaling function $S(\cdot)$ in our empirical application of maize production in Zambia. A quadratic model for the crop-growth function $G(\cdot)$ is specified as:

$$\begin{aligned}(2)\quad G_{it} = {} & \alpha_1 N_{it} + \alpha_2 BSLPCT_{it} + \alpha_3 RAIN_{it} + \alpha_4 HYBD_{it} + \alpha_{11} N_{it}^2 + \alpha_{12} N_{it} \times BSLPCT_{it} + \\ & \alpha_{13} N_{it} \times RAIN_{it} + \alpha_{14} N_{it} \times HYBD_{it} + \alpha_{22} BSLPCT_{it}^2 + \alpha_{23} BSLPCT_{it} \times RAIN_{it} + \\ & \alpha_{24} BSLPCT_{it} \times HYBD_{it} + \alpha_{33} RAIN_{it}^2 + \alpha_{34} RAIN_{it} \times HYBD_{it}\end{aligned}$$

where *N*, *BSLPCT*, *RAIN*, *HYBD* are growth inputs defined in Table 1, and α_1 - α_{34} are parameters to be estimated.

In specifying the scaling function $S(\cdot)$, we extend the traditional production inputs used in the literature to include whether fertilizer is available on time, household characteristics, and government programs. We use an exponential form that does not impose monotonicity on the input-output relationship (Guan et al. 2006):

$$\begin{aligned}(3)\quad S_{it} = \exp[-(&\beta_0 + \beta_1 ONTM_{it} + \beta_2 DRTPW_{it} + \beta_3 MZAR + \beta_4 EXTNSN_{it} + \beta_5 GVCHNL_{it} + \\ & \beta_6 ADULT_{it} + \beta_7 AGE + \beta_8 EDUC + \beta_9 FEMHD + \beta_{10} MRTLT_{it} + \beta_{11} YEAR_t)^2]\end{aligned}$$

where *ONTM*, *DRTPW*, *MZAR, EXTNSN*, *GVCHNL*, *ADULT*, *AGE, EDUC, FEMHD, MRTLT*, and *YEAR* are defined in Table 1, and $\beta_0 - \beta_{11}$ are parameters to be estimated.

With the two functions specified above, the overall maize production function is written as the following nonlinear form:

$$\begin{aligned}(4)\quad YIELD_{it} = (&\alpha_1 N_{it} + \alpha_2 BSLPCT_{it} + \alpha_3 RAIN_{it} + \alpha_4 HYBD_{it} + \alpha_{11} N_{it}^2 + \alpha_{12} N_{it} \times BSLPCT_{it} + \\ & \alpha_{13} N_{it} \times RAIN_{it} + \alpha_{14} N_{it} \times HYBD_{it} + \alpha_{22} BSLPCT_{it}^2 + \alpha_{23} BSLPCT_{it} \times RAIN_{it} + \\ & \alpha_{24} BSLPCT_{it} \times HYBD_{it} + \alpha_{33} RAIN_{it}^2 + \alpha_{34} RAIN_{it} \times HYBD_{it}) \exp[-(\beta_0 + \beta_1 ONTM_{it} + \\ & \beta_2 DRTPW_{it} + \beta_3 MZAR + \beta_4 EXTNSN_{it} + \beta_5 GVCHNL_{it} + \beta_6 ADULT_{it} + \beta_7 AGE + \\ & \beta_8 EDUC + \beta_9 FEMHD + \beta_{10} MRTLT_{it} + \beta_{11} YEAR_t)^2] + f_i + u_{it}\end{aligned}$$

where *YIELD* is maize yield in kilogram per hectare, f_i is unobserved household heterogeneity, and u_{it} is random error assumed to be normally distributed. Taking the expectation of $YIELD_{it}$ in equation (4) conditional on inputs and yield scaling factors (denoted as X_i) and taking partial derivative with respect to N_{it}, we get

$$\begin{aligned}(5)\quad \partial[E(YIELD_{it} \mid X_i)] / \partial N_{it} = {} & (\alpha_1 + 2\alpha_{11} N_{it} + \alpha_{12} BSLPCT_{it} + \alpha_{13} RAIN_{it} + \alpha_{14} HYBD_{it}) \exp[-(\beta_0 + \\ & \beta_1 ONTM_{it} + \beta_2 DRTPW_{it} + \beta_3 MZAR + \beta_4 EXTNSN_{it} + \beta_5 GVCHNL_{it} + \beta_6 ADULT_{it} + \\ & \beta_7 AGE + \beta_8 EDUC + \beta_9 FEMHD + \beta_{10} MRTLT_{it} + \beta_{11} YEAR_t)^2]\end{aligned}$$

It gives the partial effect of N_{it} on the expected $YIELD_{it}$, which is also the marginal product of N_{it}, i.e., the change in expected $YIELD_{it}$ as a result of adding an additional unit of N_{it}, ceteris paribus. As reflected in equation (5), marginal product of nitrogen depends on the nitrogen level as well as the levels of all the other explanatory variables. Partial effects of other continuous variables can be derived similarly by taking the partial derivative of expected $YIELD_{\mathrm{it}}$ in equation (4) with respect to that variable. Partial effect of a dummy variable is the difference between the expected yields when the dummy variable changes from 0 to 1.

4. Estimation Method

Unobserved household heterogeneity such as land quality, farmer skill and motivation can be controlled for through the use of panel data. We estimate production function in equation (4) using the correlated unobserved effects model (Chamberlain, 1984; Mundlak, 1978). The Mundlak–Chamberlain (hereafter M-C) approach explicitly accounts for unobserved heterogeneity and its correlation with observables, while yielding a fixed effects-like interpretation.[4]

Due to the incidental parameters problem,[5] we do not treat the unobserved heterogeneity f_i as additional parameters to estimate.

The M-C approach allows for correlation between unobserved heterogeneity f_i and explanatory variables X_{it} by assuming f_i has the form:

$$(6) \quad f_i = \tau + \bar{X}_i \gamma + a_i$$

where $\bar{X}_i$ is a vector of the averages of X_{it} across time periods, τ is constant, γ is a parameter vector, and a_{i} is i.i.d. and normally distributed, and independent of u_{it} in equation (4). Parameters α_1 - α_{34}, $\beta_0 - \beta_{11}$, τ, and γ are estimated using maximum likelihood estimation method (MLE). Under regularity conditions, MLE is asymptotically unbiased and efficient.

We can determine whether unobserved heterogeneity is correlated with $\bar{X}_i$ by the joint significance test of γ. If the hypothesis H_0: $\gamma=0$ is rejected, there is evidence of unobserved heterogeneity that is correlated with $\bar{X}_i$, thus parameter estimates of the crop production function will be inconsistent if unobserved heterogeneity f_{i} is ignored in production function estimation. A joint significance test of the time-averaged explanatory variables reject the hypothesis H_0: $\gamma=0$ in (6), suggesting that unobserved heterogeneity is correlated with the time-averages $\bar{X}_i$, and indicating that the correlated unobserved M-C approach is superior to the pooled or random effects estimators.

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[4] For linear models, the correlated unobserved effects estimator of coefficients on time-variant regressors are mathematically identical to the fixed effects estimator, which is why we describe them as "fixed-effects like" in the non-linear case.

[5] An incidental parameters problem arises with maximum likelihood estimation of panel data models that treat unobserved effects as additional parameters to estimate, leading to inconsistent estimators when N is large and T is small and fixed (Wooldridge, 2002).

5. Empirical Results

We first examined sample attrition which is necessary because nonrandom attrition can cause the panel sample to be unrepresentative of the population of interest and potentially bias the empirical result. Sample attrition is a common problem in panel survey data. Reasons for sample attrition in developing countries include household migration, dissolution due to head death, household split-off, or refusal to be interviewed (Deaton, 1997). Refusal rates are relatively low in developing countries, which may be related to low opportunity cost of time or cultural attitudes (Maluccio, 2004). 164 of the 871 households interviewed in the first survey round are lost from the second round, leading to a balanced panel of 707 households. Potential attrition bias is tested using the methods suggested in the literature (Becketti et al., 1988; Fitzgerald et al., 1998a, 1998b; Maluccio, 2004). The sample of households in the first survey round is first divided into two sub-samples: attritors and non-attritors. Univariate comparison indicates that unconditional means of most variables are not significantly different between the two subsamples. A formal test for attrition bias was then performed using the sample for the first period. An attrition indicator along with interaction terms of the attrition indicator and explanatory variables were added in crop production function (4). The terms involving attrition indicator are jointly insignificant, suggesting that estimation of the crop production function based on the non-attriting sample will unlikely have attrition bias problem in our particular sample.

5.1 Production Function Estimation Results

Because of the model's nonlinear functional form, the parameter estimates do not provide an straightforward interpretation of the effects of specific inputs or factors. The partial effects of each variable on maize yields were estimated using the delta method and are presented in Table 3 evaluated at the 50th percentile level for continuous variables for households using fertilizer. The partial effects of nitrogen use, timely availability of fertilizer acquisition from government channel, and use of animal or mechanical draught power in land preparation, and had statistically significant yield increasing effects. Use of hybrid seed had a positive impact on yield and was significant at the 10% level, Adult mortality was statistically significant and negatively associated with crop yield. The area planted to maize, age and gender of the household head, and the number of adults in the household were not statistically significant. Farmers receiving advice from extension agents had statistically significantly lower yields.

The impact of timely receipt of fertilizer on yield was large, with a partial effect of 11 percent of average yield at the median rate of nitrogen fertilization; the impact was virtually the same for both waves. The use of animal draft power in land preparation also had a large effect on yield, with a partial effect of nearly 15 percent evaluated at the median of nitrogen use. The impact of hybrid seed use is of similar magnitude, 16.5 percent. The partial effect of a 16 percent increase in yields on farms acquiring fertilizer from the government channel may be due to information diffusion by involved agencies. Another possible explanation is that the government program targeted subsidies to more productive farmers in relatively high-potential areas within the sampled zone. The negative partial effect on yield of farms receiving advice from extension agents was 2.9 percent, suggesting some of the recommended agronomic practices may have a counterproductive effect on yield. Waterlogged soils and flooding were frequent problems during the two waves which may help explain the negative impact of rainfall.

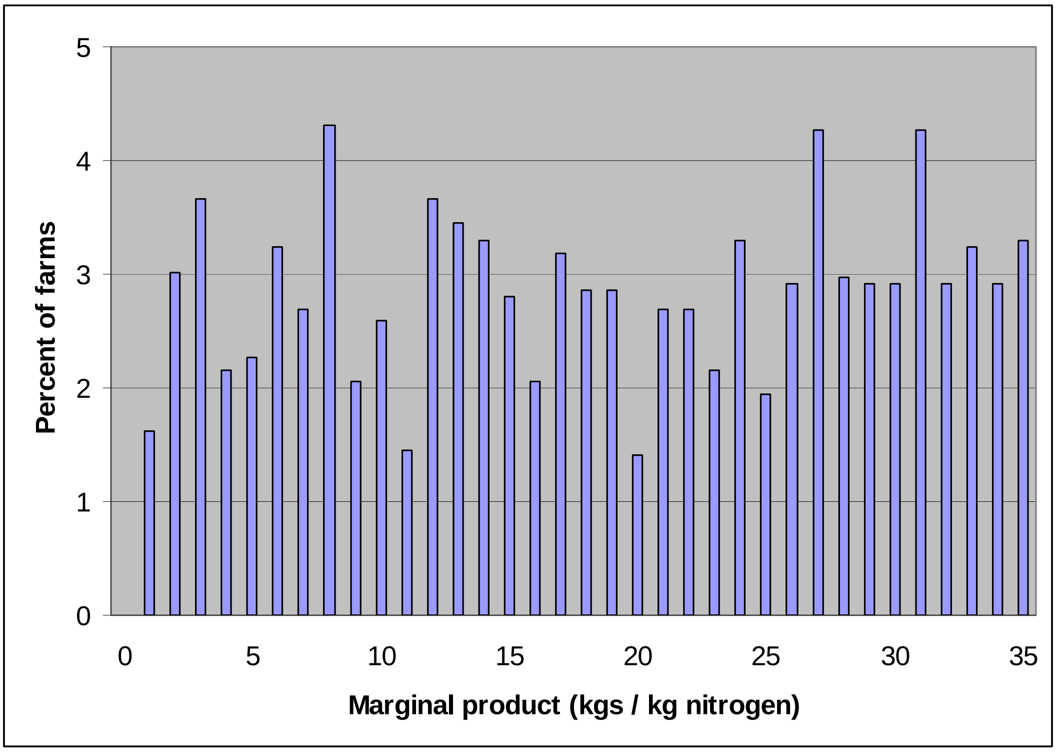
Table 3. Estimates of partial effects

		Period	
Variable		1999/00	2002/03
N	Nitrogen application (kg/hectare)	7.80*	11.70*
		(0.002)	(0.000)
BSLPCT	Percent of basal fertilizer over total fertilizer application	4.61	6.92
		(0.068)	(0.062)
RAIN	Rainfall (mm)	-0.51*	-0.76*
		(0.007)	(0.002)
HYBD	1=used hybrid seed	121.38	184.25
		(0.090)	(0.084)
ONTM	1=basal fertilizer available on time	201.06*	201.96*
		(0.000)	(0.000)
DRTPW	1=used animal or mechanical draught power in land preparation	267.49*	270.34*
		(0.000)	(0.000)
AREA	Maize planting area (hectare)	-40.54	-48.17
		(0.308)	(0.292)
EXTNSN	1=received extension service	-56.90*	-54.06*
		(0.001)	(0.008)
GVCHNL	1=acquired fertilizer from government channel	122.54	183.28*
		(0.065)	(0.000)
ADULT	Number of adults (above age 14) per hectare of maize	27.33	32.47
		(0.280)	(0.276)
AGE	Age of household head	-0.06	-0.08
		(0.904)	(0.904)
EDUC	Years of schooling of household head	1.53	1.81
		(0.522)	(0.517)
FEMHD	1=female household head	-8.03	-9.30
		(0.661)	(0.657)
MRTLT	1=adult mortality within past three years	-275.65*	-268.64*
		(0.000)	(0.000)

Note: Numbers in parentheses are p-values. * indicates the estimate is significantly different from zero at 5% or higher level. Partial effects are evaluated at *HBRD*, *ONTM*, *DRTPW*, *EXTNSN*, *GVCHNL*, *FEMHD*, *MRTLT* equal to zero, and *N*=45.90, *BSLPCT*=50, *RAIN*=892.6, *MZAR*=1.215, *ADULT*=3, *AGE*=44, *EDUC*=6, the 50 percentiles of households with N>0.

The average (AP) and marginal (MP) products of nitrogen application are of particular interest, because they are major determinants of households' incentives to invest in fertilizer. The AP and MP of nitrogen are influenced by the application rate, the other variables entering the growth input function [G(.)], and scaling function [S(.)]. The estimated values of the scaling function range from near zero to near one within the sample; that is, there is substantial variation in the capacity to realize the productivity of the applied fertilizer amongst the households applying fertilizer. The estimated marginal product of N on maize among farmers using nitrogen in at least one wave varied widely within the relatively high-potential zone in which this study was undertaken. The median estimated marginal product of nitrogen was 15.9kgs of maize per kg nitrogen, but as shown in Figure 1, it was under 10kgs maize per kg nitrogen for 25.6% of the sample, between 10 to 20kgs for 29.9% of the sample, between 20 to 30kgs for 27.2%, and over 30kgs maize per kg nitrogen applied for 18.3% of the farms.

Figure 1. Histogram of estimated marginal product of nitrogen for farmers using fertilizer.



The remainder of this section focuses on the main sources of variation in the marginal product of fertilizer application on maize yield. Two of the most important factors were the fertilizer application rate and whether fertilizer was available to farmers on time. Table 4 presents the estimated average and marginal products of N for households applying nitrogen in at least one wave for three rates of application rates and dependent upon whether nitrogen was available in a timely manner (67% of the time for fertilizer received through the government subsidy program and 70% of the time for fertilizer purchased from private stockists). The rates of application are the 25th percentile for those that used fertilizer in at least one wave (28 kgs N per ha), 50th percentile (46 kgs N per ha), and 75th percentile (69 kgs N per ha). Clearly, the nationwide recommended application rate of 200 kgs

Compound D and 200 kgs urea (which amount to approximately 112 kgs of nitrogen) per hectare of maize is well beyond the rates used by the majority of fertilizer users.

The AP and MP of nitrogen fall as the application rate increases. However, the most striking feature is the impact of the timeliness of fertilizer availability. Comparing cases 1 vs 2, cases 3 vs 4, and cases 5 vs. 6 in Table 4 reveal that acquiring fertilizer on time roughly doubles the marginal product of nitrogen. Because over 30 percent of the households reported that fertilizer was delivered late, these findings indicate that efforts to ensure timely distribution can contribute substantially to the productivity gains achievable from fertilizer use. Interviews of private fertilizer distributors reveal that delays in the distribution of government program fertilizer cause uncertainty for private traders who first assess whether subsidized government fertilizer will be distributed in a certain area of operation before determining where to distribute their fertilizer (Govereh et al., 2003). These dynamics give rise to the late acquisition of fertilizer through both public and private channels.

5.2. Profitability of Fertilizer Use

In the absence of data on full production costs such as labor input, value cost ratios have often been employed to assess the profitability of fertilizer use (Crawford and Kelly, 2002). The marginal value-cost ratio (MVCR) divides the value of the marginal product by the price of nitrogen

$$(7) \qquad MVCR = \frac{MPN \times P_{maize}}{P_N}$$

where P_{maize} is the price of maize per kilogram and P_N is the price of nitrogen per kilogram.[6] Similarly, the average value cost ratio (AVCR) measures the average net gain per kg of nitrogen applied. If the response function were known with certainty, the incentive would be to apply nitrogen to the point where the MVCR is 1.0. However, there is clearly substantial uncertainty about the outcome of applying fertilizer as can be seen in Table 4 by comparing the MPN in the first vs. second waves. The marginal products of nitrogen were 2/3 as large in the first wave as in the second. Similarly, the substantial uncertainty associated with whether fertilizer will be available on time exacerbates the problem. Taking both the year and timing of fertilizer availability into account, there is a difference in MPN between the lowest and highest value of 250 percent. Given these kinds of variations as well as other sources of uncertainty, households would be expected to apply nitrogen at rates below the value where, in a probabilistic sense, the expected MVCR is 1.0.

Prices paid for fertilizer and received for maize vary according to the transport and handling costs they face, and according to the survey data, the more remote group faces roughly 20 percent lower maize/N price ratios. Overall maize-N price ratios were more favorable in 2002/03 than in 1999/00. Using a nitrogen-maize price ratio of 8.60 in 1999 and 8.06 in 2002 in the accessible areas, the average MVCR across both waves at the 75th percentile application rate is 1.9 if fertilizer is available on time. The ratio drops to 1.0 if fertilizer is not available on time. The comparable values for the median application rate are 2.2 and 1.2. These ratios would fall to 1.6 and 0.96 in the remote areas.

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[6] P_N was calculated using the prices for basal fertilizer and top dressing fertilizer and their nutrient component information. Let x denote the amount of each fertilizer required for 1kg of nitrogen given the 1:1 application ratio of two types of fertilizers, based on the nutrient component information we have $10\%x + 46\%x = 1$. Solving for x yields $x=1.79$kg, that is, 1kg of nitrogen costs approximately 1.79kg of each type of fertilizer, therefore P_N is 1.79×(basal fertilizer price + top dressing price).

Table 4. Estimates of marginal and average products of nitrogen and estimated value-cost ratios for alternative rates of nitrogen application dependent upon timeliness of fertilizer availability.

	25th percentile	50th percentile	75th percentile	Fertilizer available on time		MP of nitrogen (kg/kg N)		AP of nitrogen (kg/Kgs N)		Average Value-Cost Ratio (AP nitrogen*Pmz/Pnitrogen)			
										Remote area		Accessible area	
Case	28 kgs	46 kgs	69 kgs	no	yes	1999	2002	1999	2002	1999	2002	1999	2002
1	x			x		9.2	13.8	10.1	15	1.02	1.66	1.17	1.86
2	x				x	19.2	23.4	20.9	25.5	2.11	2.81	2.43	3.16
3		x		x		8.2	12.2	9.5	14.2	0.90	1.46	1.04	1.65
4		x			x	16.9	20.6	19.7	24.1	1.86	2.47	2.15	2.78
5			x	x		6.9	10.1	8.9	13.2	0.75	1.21	0.87	1.36
6			x		x	14.1	17.2	18.2	22.3	1.55	2.06	1.79	2.32

Note: Average value products over 2.0 signify that fertilizer use on maize is likely to be profitable.

The AVCR captures the average gain per kg of nitrogen used. An AVCR greater than one would imply fertilizer use is profitable if no additional cost is incurred. This is not likely to be the case due to transaction costs and risks associated with fertilizer use. For these reasons, researchers have suggested that an AVCR of 2.0 or greater is generally required for farmers to use fertilizer in appreciable amounts (Crawford and Kelly, 2002). Our paper adopts this convention and considers AVCR of at least 2 as an indicator that fertilizer use is likely to be profitable.

We differentiate households into two groups according to their degree of remoteness or accessibility to markets, according to their distance to the nearest district town. The relatively remote group face maize-N price ratios roughly 20 percent lower than for the relatively accessible group. The majority of farmers in relatively remote areas have MVCRs less than two. During 1999/2000, only one case out of 6 cases presented in Table 4 had MVCRs above 2; 2 of the 6 cases have MVCRs above 2.0 in the 2002/2003 season. In the more accessible areas, only 2 of the 6 cases shown in Table 4 had MVCR above 2.0 in 1999/00 while half of the cases had MVCRs above 2.0 in 2002/03. Given current management practices, fertilizer use at the standard recommended rates on maize appears to be profitable only for a minority of smallholder farmers in the relatively remote areas. For farmers in the more accessible areas, fertilizer use tends to be profitable if received and applied on time. If fertilizer is not available on time, even farmers in the more accessible areas of this area of relatively high agronomic suitability for maize production are largely unable to use fertilizer profitably.

On the other hand, beneficiaries of the government fertilizer program are more likely to find fertilizer use profitable because they were able to acquire fertilizer at roughly half of the full retail price and this would effectively double the MVCR values.

As a final exercise, we compute the level of nitrogen (N^*) at which the MVCR is equal to 2 for each case. Nitrogen applied at a level lower than N^* has a higher MPN and thereby a higher MVCR for profitable use of fertilizer. The standard extension system recommendation of 4 bags basal plus 4 bags top dressing per hectare of maize contains 116kg of nitrogen per hectare. This N application rate is higher than N^* in all cases for both 1999/00 and 2002/03. The median N^* was found to be in the range of 44 to 71kg of N for cases in which fertilizer was delivered on time. Of course these findings are sensitive to maize/N price ratios observed in the two years of the study. In subsequent years since 2002/03, the maize-to-N price ratio has been more than 10% higher than those observed in 2002/03 in two years, while being more than 10% lower in two years. Hence, the profitability results observed in these two years are likely to remain very close to those prevailing in more recent years. These findings suggest that fertilizer applied on maize can indeed be commercially profitable for farmers in the more accessible areas of Zone IIa as long as the fertilizer is applied on time and application rates are less than the standard 4 by 4 bag recommendation. Recommended application rates are unlikely to be economically viable for farmers in the more remote areas given the more adverse maize-to-fertilizer price ratios observed in these areas in recent years in Zambia. Profitability could of course be restored even in the remote areas if farmers were able to use fertilizer more efficiently, i.e., raise the average and marginal product of fertilizer through management improvements and greater use of complementary techniques and inputs.

6. Conclusions

Using longitudinal household survey data from Zambia, this paper estimates a maize production function using an asymmetric conceptual framework. We generalized the asymmetric framework by categorizing inputs in crop production as growth inputs and yield scaling factors. This framework incorporates agronomic perspectives on the underlying crop growth process and further accommodates the impacts from non-input factors. We control for unobserved heterogeneity using the Mundlak-Chamberlain approach.

The main factors influencing fertilizer use profitability were found to be fertilizer application rates, whether fertilizer was available in a timely manner, whether the household incurred a recent adult death, whether hybrid seed was used, and the maize/fertilizer price ratio facing the household, which is influenced by proximity to roads and markets.

Given current management practices, fertilizer use at the standard recommended rates on maize appears to be profitable only for a minority of smallholder farmers in the relatively remote areas. For farmers in the more accessible areas, fertilizer use tends to be profitable if received and applied on time. If fertilizer is not available on time, even farmers in the more accessible areas of this area of relatively high agronomic suitability for maize production are largely unable to use fertilizer profitably.

Only for beneficiaries of government input programs who purchased fertilizer at a much lower price does fertilizer use appear to be clearly profitable. These findings suggest that many small farmers may lack incentives to purchase commercial fertilizer even for those having the capacity and resources to do so, which may explain why less than 30 percent of smallholder farmers in Zambia acquire fertilizer commercially.

Strategies to make fertilizer use more profitable for farmers will require raising yield response rates and reducing input and output marketing costs. Our study finds that farmers’ ability to acquire fertilizer in a timely manner has a strong positive effect on maize yield response to fertilizer. Subsidized fertilizer under government programs in Zambia has often been distributed late. These programs have also caused uncertainty for private traders who first assess whether subsidized government fertilizer will be circulated in a certain area of operation before determining where to stock fertilizer (Govereh et al., 2003). These dynamics give rise to the late acquisition of fertilizer through both public and private channels. Fertilizer use in any appreciable amount is unlikely to be profitable for a large majority of smallholder farmers until efforts are made to ensure more timely delivery of fertilizer. Moreover, the extension service may consider revising downward their recommended fertilizer application rates taking into consideration relevant factors that will influence profitable use of fertilizer. Lower application rates may be necessary for relatively less efficient farmers to achieve minimum threshold conditions of profitability. However, households in the sample are characterized by great variation in the marginal product of nitrogen even in the same agro-ecological and soil conditions, which most likely reflects differences in management ability, knowledge about appropriate application rates, and whether they are able to acquire fertilizer in a timely manner. Higher fertilizer application rates may become more profitable if there are concomitant improvements in the use of draft power, improved cultivars, timely availability of fertilizer, improved agronomic practices, and investments in physical infrastructure to reduce the costs of acquiring fertilizer and marketing maize.

These findings suggest that improving the efficiency of fertilizer use among smallholder farmers through more effective extension messages and timely fertilizer availability could make fertilizer use profitable even at much higher application rates. We find that if farmers in the bottom half of the distribution ranked by their marginal product of nitrogen were able to achieve the mean marginal product level of 15.9kgs maize per kg N applied, this itself would raise maize production among the entire sample of fertilizer using households by 15.2 percent. The findings of this study indicate that efforts to raise the efficiency of fertilizer use by smallholder farmers could make great strides in raising the profitability of, and hence the effective demand for fertilizer in Zambia.

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Determinants of Adoption and Levels of Demand for Fertiliser for Cereal Growing Farmers in Ethiopia

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ABSTRACT: The current government of Ethiopia has put agriculture at the heart of its policies. There is particular emphasis on promoting adoption of fertiliser, improved seeds and the efficiency of input marketing and distribution. In this paper we use a nationally representative data set for 1994 to analyse what factors influence adoption of as well as intensity of fertiliser use of small-scale farmers. Results show that farmer literacy, access to all-weather roads, access to banking, extension services, and the labour availability play a role in fertiliser adoption. Addressing the first four points would substantially increase the rate of adoption. With regard to the amount of fertiliser used we find that smaller sized farms use this input more intensively. Further we find that previous experience with fertiliser, supply, liquidity, oxen owned by the household, and the ratio of the price of the main crop to the cost of fertiliser are important. Availability of credit and supply constraints are important factors in constraining fertiliser use. Our results suggest that the effect of the subsidy on fertiliser consumption is small and that providing credit would be much more effective in terms of raising adoption of and level of use of fertiliser and thus contributing to increasing agricultural output.

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1. Introduction

Improving the agricultural sector's performance in Ethiopia is of crucial importance for a variety of reasons. For one, there is the relative importance of this sector. Agriculture accounts for 60% of GNP[1] and about 87% of the population live in rural areas and depend, directly or indirectly, on this sector for their livelihoods. Agricultural goods — mainly coffee, hides and skins, and oilseeds — account for 90% of exports and are therefore the main source of foreign exchange and an important source of government revenue.

Past performance of the economy has been dismal. GNP per capita shrunk by about -1.9% over the period 1980-92. Agriculture only grew at the rate of 0.7 and 0.4% over the period 1970-80 and 1980-92 respectively[2]. Moreover, Ethiopia, a country of 51.9 million is categorised as the third poorest; 60% of the population is below the poverty line and 60% of children suffer from chronic malnutrition. Ethiopia has also suffered two large-scale famines (1973-74 and 1983-85) claiming hundreds of thousands of lives. Cereal imports and food aid came to 1045 and 963 thousand metric tons respectively, in 1992.

These figures paint a dire picture and one which indicates that the agricultural sector will play a vital role in achieving food security, combating poverty and promoting overall economic development. It is therefore not hard to see why the present government has put agriculture at the heart of its policies. These policies were developed by the Transitional Government of Ethiopia[3] and focus on promoting the adoption of new technology, hybrid seeds and fertilisers as well as improving the marketing and distribution of agricultural inputs[4]. Cereal growing peasant farmers will inevitably play a leading role if any agricultural policy is to have the desired impact. Individual peasant farming is the dominant sub-sector, accounting for 97% of output. Moreover, cereals account for about 83% of the area used to cultivate major crops. This is distributed as follows: Teff = 26.5% of coverage; Maize = 15.9%; Barley = 12.6%; Sorghum = 12.7%; Wheat= 11%; and Millet = 3.3%; other crops include Neug, Linseed, Fenugreek and Rapeseed (CSA (1995)). Production of cereals came to 6.15 million tons in 94/95. This was down from 6.5 million tons in 80/81. This 5% decline compares with a 40% increase of the population.

In this paper we use a representative data set to assess factors which influence the adoption of fertiliser as well as the level of fertiliser consumption of cereal producing peasant farmers in

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[1] Figures taken from the World Development Report (1995, 1994 and 1993) the Fertiliser Marketing Survey prepared by Kuawab (1995) and the Agricultural Sample Survey prepared by the Central Statistical Authority (CSA) (1995).

[2] This compares to a population growth rate of 2.7% and 2.5% over the periods 1970-80 and 1980-91.

[3] The TGE took power in 1991 by overthrowing the Soviet style "Derg" regime. Elections were held in 1995, but policies regarding agriculture have not changed.

[4] The benefits of using improved seed varieties and the increased use of fertiliser (as promoted for example by Global 2000) and the need to reverse the serious food-deficit situation in Ethiopia was highlighted in a recent article in "The Economist" (November 25th, 1995, p. 49).

Ethiopia. The emphasis on fertiliser is appropriate because: a) much of the land in the high potential cereal zone is already under cultivation so increasing output calls for intensification of production; b) financial limitations make it unlikely that an entire package of improved seeds, improved soil and water conservation and more irrigation can be adopted. It would therefore appear more promising to focus on increasing fertiliser use.

The benefits of increased fertiliser use in Ethiopia have been documented by the ADD/NFIU (1992). Four year trials (1988-91) showed that the yield response to fertiliser was substantial, but varied regionally. For example, increments of 3kg of teff (using local seed types) perkg of fertiliser (at optimal rates of 100kg per hectare (Kuawab, 1995)) were obtained for Shewa, Gojam and Arssi. However, yield increases of 1.8kg were obtained in other regions. For wheat, the national average was 4.3kg of additional wheat per kg of fertiliser (using improved seeds), while for maize this figure was 6.5kg per kg of fertiliser[5]. It would appear that substantially increasing fertiliser consumption in Ethiopia would go a long way to addressing some of the pressing issues, such as the food deficit, faced by the country.

2. The Model

Econometric studies of fertiliser adoption in Africa are rare. Falusi (1974) used a probit model to analyse fertiliser adoption of farmers in Western Nigeria. Green and Ng'ong'ola (1993) applied a logit model to data from Malawi. While the former identified extension services and access to credit to be important, the latter found that the crop grown; the farming system; access to credit; off-farm employment opportunities; and regular labour were the main determinants of fertiliser adoption. In this paper we model fertiliser adoption and fertiliser demand for a representative sample of cereal farmers in Ethiopia. We use a self-selection model which corrects for the selectivity bias (which would occur if one dropped the observations for those farmers not using any fertiliser). More sophisticated techniques have been employed by Coady (1995) who used a double-hurdle approach to model fertiliser adoption[6]. Our possibilities are limited by the fact that some of the data has only been collected for the sub-sample of farmers that use fertiliser (see the discussion in the data section below).

The choice of fertiliser adoption is modelled by the following selection function:

$$(1) \qquad I_i^* = \alpha' x_i + \epsilon_i\ , \quad I_i = 1 \text{ if } I_i^* > 0 \quad \text{and} \quad I_i = 0 \text{ if } I_i^* \leq 0\ .$$

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[5] A majority of the trials were conducted in the high potential areas. The numbers reported are therefore on the optimistic side. Sasakawa Global 2000 reported yield increases of 52.7 and 1.8 tons/ha for maize, wheat and teff for locally available seeds and prevailing agronomic practices.

[6] In an interesting parallel, the supply and use of fertiliser was seen as an important means of adressing the food supply problem (in conjunction with the introduction of high yielding varieties of wheat and rice) in Pakistan. 48% of the total increase in agricultural output in the Sixth Five Year Plan (mid-80s) was expected to come from increased use of fertiliser (Coady (1995)).

Here I_i is the selection variable of which we only observe the sign; x is a vector of factors that affect adoption; ϵ is a random disturbance term distributed with mean 0 and variance 1; the subscripts denote the *i*th farmer. The regression equation for the demand for fertiliser is given by:

$$(2) \qquad y_i = \beta' z_i + \xi_i \quad ,$$

where y is the amount of fertiliser purchased per hectare (in natural logarithms); z is a vector of factors affecting the level of purchases made (not necessarily the same factors that affect adoption); ξ is a random disturbance with mean 0 and variance σ^2; the subscripts are as above. We observe y_i and z_i only if $I_i = 1$ and hence we have a problem of truncation[7]. If we apply least squares to equation (2) for the full sample we generate inconsistent estimates. The same is true if we use only the sub-sample of farmers that use fertiliser. The most popular estimation technique, that generates consistent estimates, is to use Heckman's (1976) two-step procedure: 1) to estimate the probit stage (equation (1)) and then, using the estimated α, to compute:

$$(3) \qquad \lambda_i = \frac{\phi\,(\hat{\alpha}' z_i)}{\Phi\,(\hat{\alpha}' z_i)}$$

where ϕ and Φ are the density and the cumulative distribution functions of a standard normal variable, respectively. Equation (3) is the Mills-ratio, without which equation (2) will suffer from omitted variable bias.

3. The Data

The data are obtained from a fertiliser marketing survey undertaken as part of the Development of Competitive Markets Programme, funded by the United States Agency for International Development (USAID)[8]. The survey, conducted in 1994, covered four regions and seventeen zones. These are:

Region	Zone
Amhara	East Gojam, West Gojam, North Shewa, South Gonder.
Oromia	Arssi, East Shewa, East Wolega, Jimma, West Shewa, North West Shewa.
Southern	Guraghe, Hadiya, Kembata, North Omo, Sidama.
Tigray	South Tigray, West Tigray.

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[7] Some of the variables contained in z are observed over the whole sample, but most are not.

[8] The survey was conducted by Kuawab for USAID. We are grateful to Kuawab and USAID for making this data set available to us.

The number of households interviewed were 6240. After some cleaning of the data we were left with 4942 households[9]. These were distributed among the regions as follows: Amhara = 1337; Oromia = 2167; Southern = 1139; Tigray = 299. We aggregated the zonal groups into 7 geographical groups (the name by which we will refer to them) that we used for dummies in the analysis. The explanatory variables used in this study are described below.

Variables available over the entire sample (numbers in parentheses are cases in this category — out of a total of 4942 observations):

AGE:	The age of the head of the household. We expected age to be a proxy for experience and thus be positively correlated with adoption and level of demand for fertiliser.
SEX:	1 if household is male, 0 otherwise. Because female headed households often tend to be poorer and more subsistence oriented we expect a male headed households to be more likely to use and apply more fertiliser. An additional argument is that female headed households are likely to have a lower endowment of labour (4570 farmers are male).
EDUCA:	1 if head of household is literate, 0 otherwise. The ability to read and write would imply greater access to information and thus we anticipated a positive coefficient in the two equations (1695 farmers are literate).
TOTVAL:	We use the natural logarithm of the total value (in Ethiopian Birr) of sale of crops in 1993[10] (adding 1 for the zero values) as a measure of the households liquidity. Liquidity is expected to be an important constraint for farmers wishing to use fertiliser, as well as to the amount they wish to use.
ADULT:	The number of adults, in natural logarithms, is a proxy for labour availability, and should positively influence adoption and the level of fertiliser.
DEPD:	The number of dependents in the household.
DUOX:	1 if household has 2 or more oxen, 0 otherwise. 2 oxen are required to plough a field. Households with less than 2 oxen face the uncertainty of being able to hire in at the right time (or at all). We expect a significant difference between these two groups for the choice of adopting fertiliser (2517 farmers have 2 or more oxen).
OXEN:	The number of oxen (in natural logarithms) are expected to play a role in determining the amount of fertiliser used. In particular having two or more oxen is expected to be positively correlated with fertiliser adoption. Farmers with none or only one oxen face the additional risk of obtaining oxen at the right time and may therefore be discouraged from buying fertiliser.
CULTLAND:	Land area cultivated by the household, in hectares.
EXTEN:	1 if extension services are strong, 0 otherwise. Good extension services are expected to be positively correlated with fertiliser adoption (1579 farmers had good extension services).
ACCESS:	1 if farmer has access to all-weather road, 0 otherwise. Farmers with access to all-weather roads are expected to be more likely to adopt fertiliser as well as using more of it (4051 farmers had access to all-weather roads). We note that of the surveyed farmers, 88% used pack animals to transport fertiliser.
BANK:	1 if farmer has access to bank (within 30km), 0 otherwise. This variable captures the farmers access to credit in 1994 (although of course not all farmers with access to banking received credit) as well as in the past. The argument is that credit to purchase fertiliser in the past will still have a positive impact on fertiliser adoption in the present. This is borne out by our finding that experience with fertiliser is an important variable in the decision of how much fertiliser to use (2788 farmers had access to a bank).
PCRA:	The price of output to cost of fertiliser ratio. We note here that fertiliser prices in Ethiopia have always been under state control and have remained pan-territorial to date. The Price of output

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[9] Details available from the authors. Essentially the cleaning entailed dropping missing values and eliminating some extreme observations.

[10] It is therefore a predetermined variable and hence we treat it as exogenous.

is the price obtained for 100kg of the main crop (in that area) in several market towns for each particular zone. We had output price information for 65 market towns (between 2 and 5 for each zone) for the main crop[11]. The output price is divided by 178, the subsidised price of fertiliser (per 100kg.).

DU0:	Dummy for western and southern Tigray (299 farmers). This group serves as the reference group in the econometric analysis.
DU1:	Dummy for Arssi and Guraghe, Hadiya and Kembata (1035 farmers). Dummies for the geographical areas are introduced to capture some of the geographic variations, such as altitude, rainfall and erosion (particularly bad in Tigray and South Gonder). We note that grain production is largely rain-fed so these dummies are expected to be very important.
DU2:	Dummy for East and West Shoa, East Welega and Jimma (1424 farmers).
DU3:	Dummy for Gojam (811 farmers).
DU4:	Dummy for North Shewa (124 farmers).
DU5:	Dummy for Sidama and North Omo (511 farmers).
DU6:	Dummy for South Gonder (402 farmers).
DU7:	Dummy for North West Shewa (336 farmers).

Variables available only for households who purchased some fertiliser (3060 cases in this category):

SPKNOW:	1 if the farmer reported to know the specific use of fertiliser, 0 otherwise (2693 farmers know about the specific use of fertiliser - out of 3060).
SUPPLY:	1 if the farmer perceived supply of fertiliser to be a problem (i.e. a shortage), 0 otherwise (1255 farmers have a supply problem).
CREDIT:	1 if fertiliser is bought on credit, 0 if fertiliser is bought on a cash basis (1928 farmers bought fertiliser on credit).
EXYIELD:	1 if the farmer reported to have obtained the expected yield in the previous season, 0 otherwise. We expect this variable to act as a proxy for an uncertain environment and hence we anticipate a positive coefficient (1867 farmers got the yield they expected).
EXPER:	The number of years (in natural logarithms) that the farmer has been using fertiliser.
DISTANCE:	Distance (in natural logarithms) that the farmer travels to buy fertiliser, in minutes.

We added a one to the variables which had some zero observations and which we wanted to use in natural logarithms. Some preliminary work (not reported here) suggested that this yielded better results than using the variables without the transformations. It also makes for an easier interpretation of the coefficients. Some descriptive statistics of the variables are given in tables 1 and 2.

Before turning to the econometric results we present some of the national findings of the survey which are interesting in themselves. The four regions dominate fertiliser consumption. 99% of the 165,000 metric tons of fertiliser distributed to small-scale farmers by The Agricultural Inputs Supply Corporation (AISCO, the principal fertiliser distribution agency) in 1994 went to these four regions.

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[11] As some prices were missing we only had 53 observations available. We used average prices (per zone) for missing observations.

In table 3 we give the rate of application of DAP[12] (Di-ammonium phosphate) for the four regions. While the recommended rate of application is 100kg/hectare it is only in Tigray and in the Southern Peoples Regions that a substantial number of farmers operate at this level. Over the whole sample, about 28% use 100kg/ha or more and 47% of farmers apply 50kg/ha or less. What is noteworthy is that there is a high degree of variation between regions and that there is quite a range of fertiliser application rates within regions. The average DAP application rates for all regions were: 51kg/ha in 1994, 38kg/ha in 1993 and 35kg/ha in 92.

Table 4 shows the distribution of DAP application by crop. While Teff has the lowest yield, it also commands the highest prices, which is generally held to explain why relatively more fertiliser is apportioned to this crop. Table 5 relates market participation to fertiliser application. It is interesting to note that a large proportion of farmers using fertiliser produces only for themselves. 51.1% produce in part for the market as well as for additional income. Table 6 gives a ranking of why farmers prefer one supplier over another and brings out the importance of credit and fertiliser cost.

4. The Results

4.1 Factors Affecting the Adoption of Fertiliser

The results of the probit estimates are given in table 7. As heteroscedasticity is a serious problem which generates inconsistent estimates in probit models (Yatchew and Grilliches, 1985) we chose to test for a violation of this assumption. We found that the hypothesis of homoscedasticity could be rejected using an LM test[13] and therefore used a model correcting for multiplicative heteroscedasticity[14]. After correcting for heteroscedasticity we find that all the parameters increase quite markedly in magnitude (DUOX increases from 0.3021 to 0.3788 as a typical example). What these results show is that it is important to check for heteroscedasticity and correct for it if necessary. The conclusions we draw below will obviously be different (stronger) from the model with heteroscedasticity.

The variables SEX and AGE are not found to be significant. With regard to AGE, we note that the absence of a well developed labour market (as in Ethiopia) implies that the attributes of the household's own labour are of increased significance. If this variable captures the age

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[12] DAP has 88.6 of the market share.

[13] This test was based on assuming that CULTLAND, AGE, TOTVAL, ADULT, and OXEN might be related to the variance. The Chi-square statistic was 38.27 and since the critical value is given by 11.07 at the 0.95 level we can reject the null hypothesis of homoscedasticity at the 5% level.

[14] We included CULTLAND, AGE, ADULT, and OXEN as possible sources of heteroscedasticity. We found that ADULT and CULTLAND (both 5%) and AGE (10%) were statistically significant. OXEN did not come out significant and neither did DUOX (although we kept the latter in the specification as the t-ratio was greater than 1). TOTVAL was not used as it was found to be insignificant in a trial run.

structure of the household then age may capture not only experience but also strength of the household labour, and these two effects will work in opposite directions[15].

In table 11 we present the marginal effects for the different variables for each geographical dummy in the probit function (excluding AGE and SEX). For the dummy variables these marginal effects give us the percentage increase in the probability of adopting fertiliser due to a change in status (of say EDUCA) of the farmer (i.e. from a 0 to a 1). For example, for Tigray (DU0) a literate farmer is 18% more likely to be using fertiliser than an illiterate one. There is clearly a lot of variation in the marginal effects over the different regions.

The strongest effects are for ACCESS and EDUCA. Except for DU1 we find that in all cases a literate farmer having access to all-weather roads is much more likely to be adopting fertiliser. The fact that all effects are much weaker for DU1 is a reflection of the relatively much higher levels of adoption which already exist in that area. Also BANK and DUOX have an important impact. Clearly farmers with only one or zero oxen find this a constraint and are less likely to be using fertiliser. Less important but still large is the role of EXTEN and the family size which we take as a proxy for the labour availability. TOTVAL, ADULT and DEPD are evaluated at their mean values. Results in table 12 show that a targeted policy of addressing literacy, oxen ownership, extension services, access to all-weather roads and access to banking (credit) could have a very substantial impact on fertiliser adoption rates. We note that the earlier studies on fertiliser adoption in African countries mentioned in section 2 also found extension services and credit availability (among others) to be important factors.

Table 8 gives the frequencies of actual and predicted outcomes. We find that for farmers that do not use fertiliser our model would predict a lot of these to be using fertiliser. Obviously there are factors at work which we have not been able to model satisfactorily: credit constraints and shortage of supply/late delivery being the two most serious factors[16]. In table 10 we give the predicted and actual frequencies of adopting fertiliser for the eight geographical areas. The model performs reasonably well in most of the cases. Discrepancies are in some part due to the fact that we evaluated the predictions at the overall mean levels. However, in the main, the results serve to underline the heterogeneous nature of agriculture in Ethiopia.

4.2 Factors Affecting the Level of Fertiliser Consumption

Table 9 gives the parameter estimates of the demand for fertiliser equation[17]. We find that CULTLAND, EXPER, SUPPLY, TOTVAL, OXEN, and PCRA are the most important

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[15] Croppenstedt and Mamo (1996) found a negative and statistically significant relationship between the average age of the household members engaged in agriculture and farm productivity of 271 cereal farmers from three regions in Ethiopia. The data are from the Ethiopian Rural Household Survey: First Round - 1994.

[16] Statement made on basis of rankings of fertiliser consumption problems in the four regions as produced in Kuawab (1995).

[17] Correcting for heteroscedasticity in the first stage does not alter the estimates, but does affect their standard errors. The effect is generally quite small.

factors determining the levels of per hectare fertiliser consumption. Of these, the first two contribute 27% and 8% to R^2 respectively. The amount of fertiliser per hectare falls with increasing farm size showing that smaller farmers use this input more intensively. This is a surprising result as access to complementary inputs would be expected to be easier for farmers with larger holdings. The significance of SUPPLY underlines the fact that supply shortages play an important role in limiting the use (and probably adoption) of fertiliser.

Other findings which are perhaps also surprising are the negative coefficients on AGE and SEX. Again we point to the age - strength of household labour relationship as a possible explanation. The negative coefficient on SEX shows that women led households use more fertiliser per hectare *ceteris paribus*. EDUCA is dropped from the final specification as it was very insignificant and results improved when omitting this variable. We conclude that literacy, while important for adoption, does not play a role in determining the level of fertiliser use.

Of interest is the finding that experience is very important in determining the quantity of fertiliser per hectare used. A farmer who adopts fertiliser is likely to increase use substantially (by about 23%) in the second year[18]. The effect wears down as the farmer continues to use fertiliser, but the very strong and positive relationship is very promising indeed. While it does not follow directly, the strong and positive effect of EXPER might suggest that farmers that have tried fertiliser are very likely to continue using it.

The positive coefficient on PCRA shows that farmers are conscious of prices when making input decisions. We can deduce the impact of the subsidy on fertiliser use from our results, using the mean PCRA figure. If the subsidy were removed the cost per 100kg of fertiliser would rise from 178 to 252.25 Birr (1994 prices). This would constitute a drop in the PCRA (at the mean) of 30% and would result in a decreased fertiliser per hectare use of about 9%[19]. Output elasticities with respect to fertiliser are reported to lie within 0.051 and 0.095 for Teff, Wheat, Maize, Barley and Sorghum by Yao (1996)[20]. This implies that the effect on output of a removal of the subsidy would be very small.

As a simple example we calculate that for 100 farmers the subsidy is 8734 Birr (using the mean values in our study for area cultivated and fertiliser consumption). If this subsidy were to be taken away, and assuming that yield of cereals is 1.1 tons (CSA 1995) per hectare, then the loss in output is about 1.9 tons of cereals (for this sample of "average" farmers)[21]. The subsidy

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[18] Based on the coefficient on EXPER and a farmer who has one year of experience, initially.

[19] Admittedly one should also consider the impact the subsidy removal would have on fertiliser adoption.

[20] Results by Croppenstedt and Mamo (1996) based on micro-level data suggest an output response coefficient of 0.1980, i.e. much higher those reported by Yao (1996).

[21] 1.1*1.73 (average area) = 1.90 tons of cereals per farmer. 1.90*100 = 190 tons of cereals is output for our 100 "average" farmers. If the removal of the subsidy causes a 9% decline in fertiliser consumption and the output elasticity of cereals with regard to fertiliser is 10% then the resulting drop in output would be roughly 1% of 190 tons. Using a response coefficient of 0.198 for the calculations we obtain a drop in output of 3.42 tons.

would pay for credit for about 20 farmers to buy the average amount of fertiliser, i.e. to introduce 20 farmers to fertiliser (less than that due to other costs). If the credit covered the recommended rate of fertiliser application then the resulting gain in output would be around 10 tons[22]. The resulting gain in output would therefore be substantially greater than the loss (also when we use the larger fertiliser response coefficient of 0.1980). Assuming that loans are recoverable[23] (a big assumption given the history of unrecovered loans in Ethiopia) these gains would be cumulative.

Given this perspective one should consider carefully whether money spent on subsidies would not be better allocated to factors that increase adoption rates (one has to keep in mind that credit may not be the only obstacle). We make this statement with the result for EXPER in mind, as it suggests to us that the response of farmers to fertiliser, once they have tried it, is very positive. We do not attempt to calculate the possible costs of increasing literacy rates, of making more oxen available, of providing better extension services, or even of giving farmers access to a bank within a reasonable distance. Nevertheless, the results of this study show that the marginal effects of each of these variables individually is going to have a significant impact on the number of farmers using fertiliser. A longer term strategy would focus on specific issues determined as important in this study (such as farmer literacy) and would thus promote fertiliser adoption and output growth on a more substantial level.

5. Conclusion

In this study we analysed the factors that determine the adoption and the level of fertiliser consumption in Ethiopia in 1994. Fertiliser consumption increased substantially in 1994, relative to 1991 but the average rate of application and the number of farmers using fertiliser is still low. It is also clear that the experience varies markedly from zone to zone. While application rates are low in Tigray and North West Shewa, they are quite high in Arssi, Guraghe, Kembata and Hadiya. Hence one conclusion is that policies need to be designed with regional/zonal variations in mind. An across the board strategy is likely to be less effective than a carefully targeted one.

Important factors influencing fertiliser adoption are: literacy of the farmer; access to all-weather roads; the number of oxen owned by the household; access to banking; and labour availability. If the first four points and extension services were addressed jointly the impact on fertiliser adoption is likely to be substantial. This is particularly so for areas where adoption rates are presently low. The effect of oxen and banking show that credit is going to play an important role in increasing adoption rates in the future.

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[22] 100 (recommended rate of fertiliser application) * 1.73 = 173. Then 173*2.52 (price of DAP per kg) = 436 Birr which is the cost of fertiliser per "average" farmer. 8734/436 = 20. Assuming that the gain in output due to 1kg of fertiliser is approximately 3kg, so the increase in output would be about 173*3 = 519kg per farmer and 10380kg for 20 farmers.

[23] Even if the loans were not recoverable, it is possible that the strategy of giving the money away — in an effort to introduce farmers to fertiliser — would be superior to a fertiliser price subsidy.

With regard to the level of fertiliser use, our findings show that experience with fertiliser is a very important factor in terms of increased levels of fertiliser consumption. This ought to be a very encouraging result for policy makers aiming to implement programmes designed to increase adoption rates. Supply problems point to marketing and distribution bottlenecks, which are already a priority for the government. Also important in explaining levels of fertiliser demand are oxen ownership, liquidity, access to banking and credit. Clearly all this helps to underline the pivotal role of credit the absence of which either directly or indirectly constrains farmers. Indirectly because credit may also serve to purchase assets such as oxen which is of importance for adoption and levels of consumption.

We find that the ratio of the price of the main crop to cost of fertiliser is a significant variable and suggests that farmers are indeed price sensitive. Using our results we show that the effect of the subsidy on the level of fertiliser use and crop production is very limited. A policy that would switch funds from a subsidy to one of providing credit for fertiliser would generate substantially greater benefits in the short run, and particularly in the long run, and switch the focus to enhancing adoption rates.

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Table 1

Descriptive Statistics of the Variables Used in the Probit Stage

Variables	Range	Mean	Standard Deviation
DUPU*	0-1	0.62	-
AGE (years)	17-97	43.89	13.25
SEX	0-1	0.93	-
EDUCA	0-1	0.34	-
TOTVAL (Birr)	0-4000	176.59	376.46
ADULT	4.04	1-21	1.99
DEPD	0-8	2.11	1.44
DUOX	0-1	0.51	-
OXEN	0-25	1.69	1.64
EXTEN	0-1	0.32	-
ACCESS	0-1	0.92	-
BANK	0-1	0.56	-
CULTLAND (hectare)	0.02-12.50	1.73	1.27

*DUPU = 1 if farmer purchased some Fertiliser, 0 otherwise.

Table 2

Descriptive Statistics of the Variables Used in the Fertiliser Demand Equation

Variables	Range	Mean	Standard Deviation
FERTILISER (kg/hectare)	2.00-300.00	68.22	43.83
AGE (years)	17-97	43.62	12.99
SEX	0-1	0.93	-
TOTVAL (Birr)	0-4000	224.65	419.59
CULTLAND (hectare)	0.10-10.00	1.73	1.20
OXEN	0-25	1.66	1.57
ADULT	1-21	4.23	2.03
DEPD	0-8	2.23	1.48
SPKNOW	0-1	0.88	-
EXTEN	0-1	0.34	-
ACCESS	0-1	0.90	-
SUPPLY	0-1	0.41	-
PCRA	0.449-1.404	0.803	0.267
BANK	0-1	0.65	-
CREDIT	0-1	0.63	-
EXYIELD	0-1	0.61	-
EXPER (years)	1-45	9.62	7.00
DISTANCE (minutes)	0-720	142.97	123.35

Table 3

Rate of Application of Fertiliser (DAP) for the Four Regions (% of farmers)

Dap Rate: kg/ha	**Tigray**	**Amhara**	**Ormo**	**Souther Peoples**	**National**
Up to 10	2.6	2.1	2.7	0.4	1.8
11-25	11.8	22.4	15.8	3.8	13.4
26-50	35.8	39.1	35.1	20.5	31.4
51-99	6.6	23.2	24.8	30.1	25.6
100	42.1	7.9	13.1	27.0	17.1
101-150	1.4	3.8	5.5	10.5	6.5
151-200	-	1.3	2.7	6.3	3.5
201-300	-	0.2	0.3	1.4	0.7

*Source: Kuawab (1995)

Table 4

Distribution of Fertiliser Application by Crop

Crop	Land covered by	Dap application to
Teff	33.28	39.91
Maize	17.52	16.23
Sorghum	3.93	2.12
Wheat	14.35	17.58
Barley	14.95	15.25
Millet	3.73	2.52
Others	12.23	6.39

Source: Central Statistics Authority (CSA, 1995).

Table 5

Market Participation and Fertiliser Adoption

Reasons	National percentage
Produce for the market	2.0
Produce for self	44.0
Produce for self and market	41.3
Produce for additional income	9.8
Other	2.9

*Source: Kuawab (1995)

Table 6

Rankings of Reasons for Preferring One Supplier Over Another

Reasons	**Ranking**
Sells on credit	1
Charges lower prices	2
Does not cheat	3
Is efficient and delivers on time	4
Deliver near to farm	5
Other	6

*Source: Kuawab (1995)

Table 7

Probit Coefficient Estimates of the Fertiliser Adoption Equation

Variable	Coefficient	T-ratio's (Absolute values)
CONSTANT	-2.7059	4.925***
LN(AGE)	0.090	0.920
SEX	0.0917	0.920
EDUCA	0.4925	6.610***
LN(TOTVAL)	0.0700	5.484***
LN(ADULT)	0.3068	4.254***
LN(DEPD)	0.1747	3.246***
DUOX	0.3788	5.089***
EXTEN	0.2197	3.410***
ACCESS	0.5488	5.435***
BANK	0.3734	5.453***
DU1	1.9918	7.867***
DU2	1.1678	6.452***
DU3	0.5697	3.711***
DU4	1.0029	4.592***
DU5	1.3298	6.512 ***
DU6	-0.2142	1.405
DU7	-0.1874	1.099

***, * and ** indicates statistical significance at the 1, 5 and 10% levels respectively.

Log-likelihood: -2534
Restricted Log-likelihood: -3284
$X^2(21)$: 1499
PSEUDO-R^2=70
COUNT R^2=74

Table 8

Frequencies of Actual and Predicted Outcomes

		Predicted	
		0	1
Actual	0	981	901
	1	369	2691

Table 9

Coefficient Estimates of the Fertiliser Demand Equation

Variables	Coefficient	T-ratio's (Absolute values)
CONSTANT	3.4813	15.907***
LN(AGE)	-0.1727	4.996***
SEX	-0.0860	2.228**
LN(TOTVAL)	0.0285	7.096***
LN(CULTLAND)	-0.5788	33.367***
LN(OXEN)	0.1486	6.468***
LN(ADULT)	0.0452	1.982**
LN(DEPD)	0.0383	1.938*
SPKNOW	0.1435	4.799***
EXTEN	0.0851	3.634***
ACCESS	0.1291	3.397***
SUPPLY	-0.2027	9.942**
PCRA	0.2942	5.898***
BANK	0.0801	3.320***
CREDIT	0.0627	2.791***
EXYIELD	0.0318	1.575
LN(EXPER)	0.2324	16.428***
LN(DISTANCE)	-0.0129	1.218
DU1	0.3035	2.860***
DU2	0.1677	1.891*
DU3	0.4044	4.841***
DU4	0.3904	3.801***
DU5	0.2393	2.375**
DU6	0.3711	4.343***
DU7	0.3143	3.122***
λ	-0.1579	2.125**

***, ** and * denotes statistical significance at the 1, 5 and 10% levels, respectively.
Adjusted $R^2 = 43$

Table 10

Predicted and Actual Frequencies of Fertiliser Adoption

	DU0	DU1	DU2	DU3	DU4	DU5	DU6	DU7
Actual	0.28	0.88	0.70	0.62	0.65	0.65	0.25	0.17
Predicted	0.31	0.94	0.76	0.54	0.70	0.80	0.25	0.25

Table 11

Marginal Effects for Variables in the Probit Model

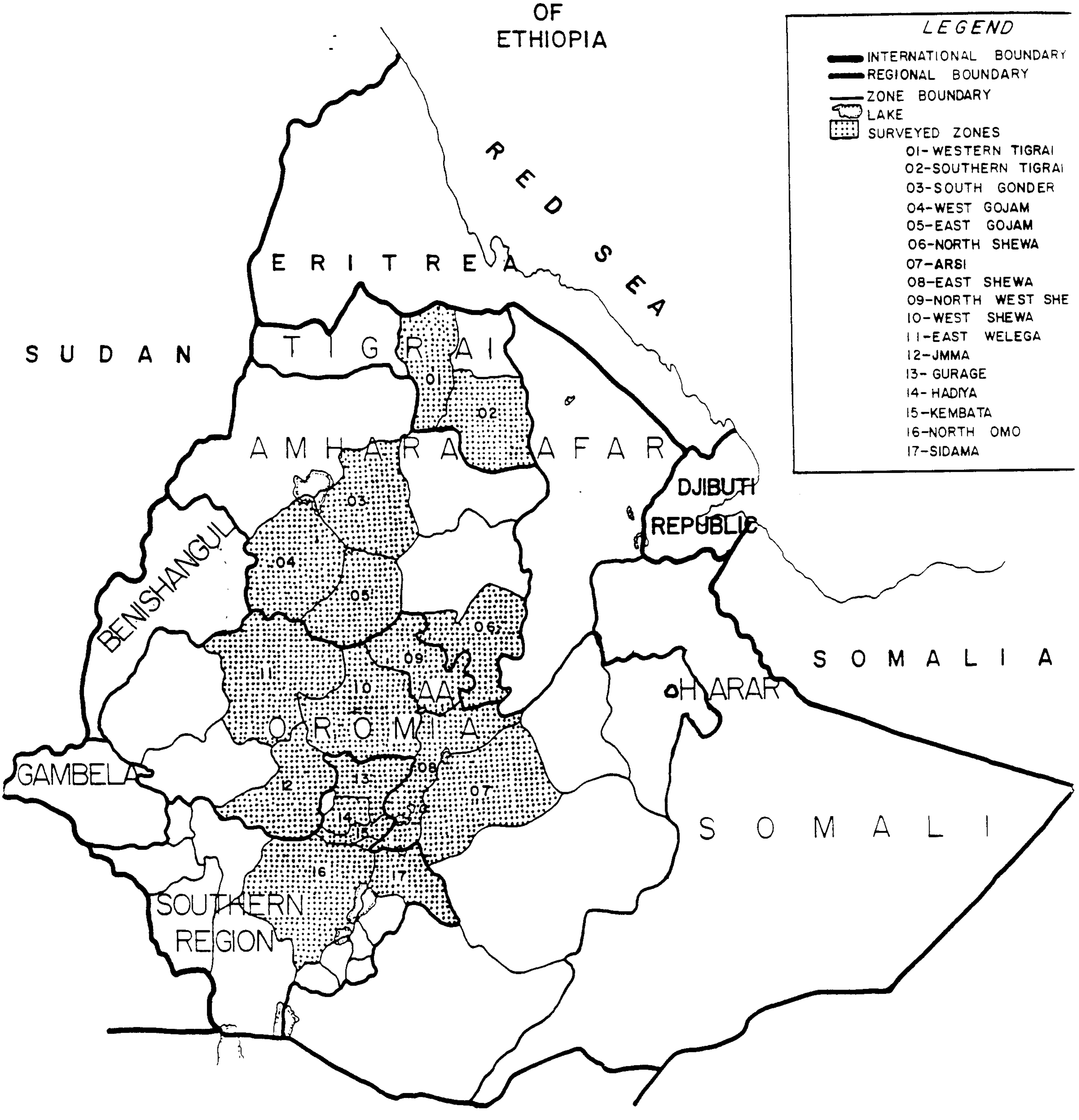
Variables	DU0	DU1	DU2	DU3	DU4	DU5	DU6	DU7
EDUCA	0.18	0.06	0.15	0.19	0.16	0.13	0.16	0.16
DUOX	0.13	0.05	0.12	0.15	0.13	0.11	0.12	0.12
EXTEN	0.08	0.03	0.07	0.09	0.08	0.06	0.07	0.07
ACCESS	0.18	0.09	0.19	.022	0.20	0.17	0.15	0.15
BANK	0.13	0.05	0.12	0.15	0.13	0.11	0.12	0.12
TOTVAL	0.03	0.01	0.02	0.03	0.02	0.02	0.02	0.02
ADULT	0.11	0.04	0.10	0.12	0.11	0.09	0.10	0.10
DEPD	0.06	0.02	0.06	0.07	0.06	0.05	0.06	0.06

Table 12

Joint Marginal Effect for EDUCA, DUOX, EXTEN, ACCESS, BANK

DU0	DU1	DU2	DU3	DU4	DU5	DU6	DU7
0.61	0.33	0.60	0.69	0.64	0.56	0.55	0.56

FERTILIZER MARKETING-SURVEYED ZONES AND REGIONS OF ETHIOPIA



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MARKET ANALYSIS NOTE #3

Grain Market Research Project
Ministry of Economic Development and Cooperation
January 1997

THE DEREGULATION OF FERTILIZER PRICES: IMPACTS AND POLICY IMPLICATION[1]

This note assesses how the recent deregulation of fertilizer prices will affect the profitability of fertilizer use on various crops throughout Ethiopia. The note also identifies other policy measures that can increase the cost-effective use of fertilizer to promote productivity growth throughout the food system. Results are based mainly on the derivation of value-cost ratios (VCRs) for the use of DAP fertilizer on selected crops in 51 cereal production areas of Ethiopia. The VCR is an indicator of profitability of fertilizer use (measuring the value of additional crop ouput relative to the cost of a given application of fertilizer). The factors that affect the VCR are the agronomic response of crop yields to the application of fertilizer, the cost of fertilizer to the farmer, and the price of the crop to which fertilizer is applied.

Increasing crop yields is the only realistic option for improving food availability in Ethiopia.[2] At present, cereal yields are among the lowest in the world. Yields of teff, wheat, and maize average 8, 12, and 16 quintals per hectare, respectively. However, it has been shown through national and donor extension programs that cereal yields on peasants' farms can be increased two- to three-fold using on-shelf technology.[3] Increased use of fertilizer and improved seed types are critically important in achieving this production growth. Hence, the focus of this study on identifying the factors affecting the profitability of fertilizer use.

The main findings of the report are as follows:

- ***Payoffs to Increased Fertilizer Use:*** Using national average figures, the payoffs to society of increased fertilizer use appear to be very high. Data in Table 1 demonstrates that about 10 million quintals (12% of total cereal output)in 1995/96 was attributable to the use of fertilizers. This is roughly 46% of the total cereal marketed in 1995/96. This volume of cereal output, valued at average 1996 producer prices, is about 1.18 billion birr. The full unsubsidized cost of the fertilizer used on cereals in the 1995/96 meher season was 0.56 billion birr.[4] Hence, even at relatively low yields and fertilizer response rates, the use of fertilizer on cereal crops in Ethiopia contributed over 0.60 billion birr ($94 million) to agricultural GDP. This is about 3.5% of average agricultural GDP during 1993/94 - 1994/95.

- ***Profitability of fertilizer use by crop, by region, and by type of household:*** The major factor determining fertilizer use is the agronomic response of crop yield to fertilizer application. The average response rate varies greatly by crop and region, as shown in Column B of Table 2. For example, the incremental response rate of wheat can be as high as 10 quintals per quintal of DAP

Table 1. Incremental yield obtained as a result of fertilizer use in 1995/96 compared to not using fertilizer at all

Crop	(A) %of total fertilizer use in 1995/96 (2,416,490Qt) applied to each crop (%)	(B) Fertilizer used on each crop (1995/96) (quintals)	(C) Incremental Yield by using 100kg DAP (Qt/Ha)	(D)=(B)*(C) Incremental yld as a result of fertilizer use (quintals)
Teff	46.3	1,118,835	3.87	4,329,891
Wheat	21.7	524,378	4.86	2,548,479
Maize	10.7	258,564	7.03	1,817,708
Barley	7.5	181,237	5.10	924,307
Millet	2.9	70,078	3.68	257,888
Sorghum	1.8	43,014	3.40	146,246
Total	90.0	2,196,106		10,024,519

Note: Total fertilizer supply for the 95/96 crop year = 406,565 tons. The amount unutilized in 1995/96 crop year = 164,916 tons (54330 tons for AISCO, 91689 tons for Amalgamate Eth. Ltd. and 18897 ton for Ambassel Trading Co.). Therefore, the amount utilized in 1995/96 = 241,649 tons. The total marketed quantity of cereals in 1995/96 = 21.65 Million quintals (i.e., 26.2 % of the total cereal produced). The total quantity of cereals produced in the 1995/96 meher season = 82.7 Million quintals.

A = percentage proportion of fertilizer applied on each crop obtained from CSA Agricultural Sample Survey Statistical Bulletin # 152.

B = Incremental yield as a result of using 100 kg of DAP/ha obtained from KUAWAB/DSA" Fertilizer Marketing Survey; USAID/Ethiopia, October 1995.

C = The incremental yield resulting from use of fertilizer.

fertilizer applied in some areas of Arssi. By contrast, the average response rate of teff is rarely over 5 quintals per quintal of DAP in any of the regions examined. In general, yield response to fertilizer application is highest for wheat and maize, and lowest for teff. However, this is offset to some extent by the high value of teff relative to wheat and maize.

- ***Importance of crop value rather than just crop prices in determining fertilizer use:*** The VCR highlights that the profitability of fertilizer use depends on the additional *value* of crop output generated from its application, not just the price of the crop. Crop value is related not only to the output price, but also the additional amount produced from fertilizer application. While it is commonly felt that incentives to use cash inputs on grain crops may be depressed by low grain prices, low prices do not necessarily mean that producers are worse off. If low grain prices occur as a result of favorable production, and farmers are able to produce more (for own consumption or for sale) than ordinarily, then farmers' may have greater incentives to use fertilizer in low price/good harvest conditions and may also be in a better position to finance input purchases in the next season.

The value of crop output also affects the economics of fertilizer use by rural households that sell little or no cereals. For these net grain-purchasing households, which account for almost half of Ethiopia's rural population, the response rate of fertilizer and the acquisition price of cereal crops influence whether the household should spend its scarce money on buying fertilizer to produce more grain that would otherwise need to be purchased. The ability of net cereal-buying farm households to afford fertilizer is negatively affected as grain prices rise. The higher the price of grain, the more of their scarce income must be spent on procuring grain for household consumption, leaving less money to purchase inputs for the next crop. These households are generally adversely affected by higher prices of staple food.

- ***Implications of Deregulating Fertilizer Prices:*** Until January 1997, fertilizer prices were subsidized by 20% to 39% depending on the location. The total cost of distributing fertilizer to production regions averaged 257 birr per quintal according to Government records, while the selling price in 1995/96 was 200 birr per quintal. In addition, a pan-territorial pricing policy on fertilizer tended to reduce the price even further in the more remote areas (relative to market conditions) and offset the general price subsidy somewhat in the areas where transport costs were relatively low. The implications of deregulating fertilizer prices for 1997 are assessed for 51 location and crop combinations (Table 2). The landed import cost of DAP at Assab are added to transport costs to each wholesale distribution location (using private freight rates obtained from Ministry of Transport and Communications). A further transport cost of 37.5 birr per ton is added to account for transport costs from these wholesale locations to the retail points. To these costs are added 1996 average CIF, bank charges, handling costs, inspection expenses, etc. to obtain the deregulated fertilizer price referred to as Scenario 1 in Table 2.

Scenario 1 represents a situation in which deregulation is accompanied by no cost savings in fertilizer distribution. This gave an average weighted price of DAP fertilizer of 261.15 birr per quintal (column c, Table 2).[5]

Under Scenario 1, the removal of fertilizer price subsidies and pan-territorial pricing would result in a 21 to 39 percent increase in the price that farmers pay for fertilizer, compared to subsidized 1996 prices. Farmers in areas with very high transport costs such as Gondar, Harar and Mekelle are likely to pay at least 35% more in nominal terms than they did in 1996.[6] Under this scenario, the VCR of DAP fertilizer use is above 2.0 (the generally accepted break-even point for fertilizer profitability) in only 20 of 51 crop/location combinations presented in Table 2. By contrast, using subsidized 1996 fertilizer prices, the VCR exceeded 2.0 in 41 of 51 cases. Based on Scenario 1 deregulated fertilizer prices, the VCR estimates exceeded 2.0 in 5 of 13 cases for maize, 12 of 25 cases for teff, and 6 of 8 cases for wheat. These results indicate that, other factors held constant, the demand for fertilizer will decline in some areas following the removal of subsidy in 1997.

The cost to the Government of the fertilizer subsidy in 1995/96 was approximately 149 million birr (US$24 million). If the elimination of the subsidy results in a 20% reduction in fertilizer use, the value of the output foregone would be approximately 170 million (based on information in Table 1). If the elimination of the subsidy resulted in only a 10% reduction in fertilizer use, then the value of the output foregone would only be approximately 91 million. On-going analysis is attempting to estimate the expected demand for fertilizer at unsubsidized price levels.

Table 2. Profitability of Fertilizer Use, Various Regions, with and without subsidy

Region	(A) Most fertilized. crop in the area	(B) Avr. incremental yield (qt per qt DAP applied)	(C) average producer price, January-June 1996 (Birr per qt)	(D)=(B)*(C) incremental value of one qt DAP applied (birr)	(E) subsidized price DAP (birr/qt)	(F) unsubsidized price DAP (birr/qt)	(G)=(D)/(E) VCR with subsidy	(H)=(D)/(F) VCR without subsidy
S. Tigray								
Ambalagie	Mixed Wheat	2.68	215	576.2	2000	2568.7	2.88	2.24
Chercher	Mixed Teff	3.5	224	784	2000	2568.7	3.92	3.05
W. Tigray								
Lilay Keraro	Mixed Teff	3.1	224	694.4	2000	2568.7	3.47	2.70
E.Gojjam								
Guzamen	Red Teff	4.09	110	449.9	2000	2568.7	2.25	1.75
Mechakel	Red Teff	0.91	110	100.1	2000	2568.7	0.50	0.39
Shebel Bernta	Red Teff	4.37	110	480.7	2000	2568.7	2.40	1.87
N. Shoa								
Kaya Gabriel	Mixed Wheat	3.42	141	482.22	2000	2568.7	2.41	1.88
S.Gondar								
Dera	Millet	5.05	125	631.25	2000	2568.7	3.16	2.46
Iste	Red Teff	3.39	147	498.33	2000	2568.7	2.49	1.94
Kemkem	Red Teff	3.2	147	470.4	2000	2568.7	2.35	1.83
Simada	Red Teff	2	147	294	2000	2568.7	1.47	1.14
W. Gojjam								
Bahir Dar	Millet	3.83	80	306.4	2000	2568.7	1.53	1.19
Dembecha	Mixed Teff	3.14	114	357.96	2000	2568.7	1.79	1.39
Jabi Tahnan	maize	5.95	70	416.5	2000	2568.7	2.08	1.62
Quarit	Mixed Teff	2.3	132	303.6	2000	2568.7	1.52	1.18
Yilma & Densa	barley	3.6	115	414	2000	2568.7	2.07	1.61
Arsi								
Bale Gesgar	Mixed wheat	10.72	101	1082.72	2000	2568.7	5.41	4.22
Diksis	Mixed Wheat	5.81	106	615.86	2000	2568.7	3.08	2.40
Hitosa	Mixed wheat	10.25	106	1086.5	2000	2568.7	5.43	4.23
Limu Bilbilo	Mixed wheat	3.79	106	401.74	2000	2568.7	2.01	1.56
Tena	Mixed wheat	5.45	106	577.7	2000	2568.7	2.89	2.25
E. Shoa								
Ad'a	Mixed Teff	4.32	202	872.64	2000	2568.7	4.36	3.40
Dugda	Red Teff	3.8	153	581.4	2000	2568.7	2.91	2.26
Liben Zequala	Mixed Teff	4.12	202	832.24	2000	2568.7	4.16	3.24
Shashemene	maize	7.85	66	518.1	2000	2568.7	2.59	2.02
E. Wollega								
Gida Kiramu	Mixed Teff	1.45	152	220.4	2000	2568.7	1.10	0.86
Jima Rarie	Mixed Teff	4.03	152	612.56	2000	2568.7	3.06	2.38
Sibu Sire	Maize	6.87	56	824	2000	2568.7	4.12	3.21
Jimma								
Dedo	Maize	3.21	52	166.92	2000	2568.7	0.83	0.65
Limu Kosa	Maize	6.51	52	338.52	2000	2568.7	1.69	1.32
Mana	Maize	7.97	52	414.44	2000	2568.7	2.07	1.61
Seka Chokorssa	Mixed Teff	3.85	145	558.25	2000	2568.7	2.79	2.17
N.W. Shoa								
Kuyu	Mixed Teff	5.35	155	829.25	2000	2568.7	4.15	3.23
Sululta	Mixed Teff	4.86	155	753.3	2000	2568.7	3.77	2.93
W. Shewa								
Ambo Zuria	Mixed Teff	2.86	155	443.3	2000	2568.7	2.22	1.73
Cheliya	Mixed Teff	2.7	155	418.5	2000	2568.7	2.09	1.63
Dendi	Mixed Teff	2.97	155	460.35	2000	2568.7	2.30	1.79

Welmera	Mixed Teff	1.94	155	300.7	2000	2568.7	1.50	1.17
Wenchi	Mixed Teff	3.64	155	564.2	2000	2568.7	2.82	2.20
S. People								
Guraghe								
Dalocha	Maize	11.54	64	738.56	2000	2568.7	3.69	2.88
Gumera	Barley	9.33	77	718.41	2000	2568.7	3.59	2.80
Izha & Welene	Barley	7.33	77	564.41	2000	2568.7	2.82	2.20
Hadiya								
Lemo	Mixed Wheat	6.89	105	723.45	2000	2568.7	3.62	2.82
Soro (Timbaro)	Mixed Teff	5.7	139	792.3	2000	2568.7	3.96	3.08
Kembata								
Alaba	Maize	7.67	64	490.88	2000	2568.7	2.45	1.91
Kacha Bira	Mixed Teff	5.56	139	772.84	2000	2568.7	3.86	3.01
North Omo								
Damote Gale	Maize	5.81	64	371.84	2000	2568.7	1.86	1.45
Kindo Koyisha	Maize	9.93	64	635.52	2000	2568.7	3.18	2.47
Sidama								
Aleta Wondo	Maize	7.15	66	471.9	2000	2568.7	2.36	1.84
Dale	Maize	9.32	66	615.12	2000	2568.7	3.08	2.39
shebedino	Maize	6.95	66	458.7	2000	2568.7	2.29	1.79

Notes: 1. Output prices are average prices for January - June 1996 obtained from Grain Market Research Project MIS Unit; Incremental yield from fertilizer use from KUAWAB/DSA Fertilizer Marketing Survey, 1995; 1996 fertilizer price from National Fertilizer Industry Agency (NFIA).

- However, there appear to be important opportunities to reduce the cost of fertilizer delivery to the farm gate. These are discussed in detail in the main report. Scenario 2 assumes that increased competition and private sector initiatives will reduce input delivery costs by about $35 per ton or 22.2 birr per quintal, according to the following (figures in US$ per ton): adjusting the month of purchase ($10); more competitive bidding ($2); economies of scale in purchase ($5); bulk purchase instead of bag purchase ($4); use of chartered vessels ($5); use of larger vessels ($4); improving port and clearing services ($2); more competitive wholesale, retail, and transport services ($3). However, the gains through advance purchase imply extra costs in the form of interest and storage. These costs are estimated at 3.43 birr per quintal. Hence, the net savings are estimated at 18.80 birr per quintal (22.23-3.43) under Scenario 2.

  Assuming that such cost reductions in fertilizer distribution can occur, the average weighted price of DAP fertilizer for 1997 would then be estimated at 242 birr per quintal, an 8% cost reduction compared to the unsubsidized price in Scenario 1. In this case (Scenario 2), the VCR for fertilizer use exceeds 2.0 in 28 of 51 cases. After accounting for the increased crop output that would result from increased use of fertilizer estimated under Scenario 2, the gain to the economy (due to an assumed 8% cost reduction in input marketing) would be roughly 313 million birr each year (US$49 million).

- A major conclusion from the results of Scenario 2 is that even with assumed cost savings of 8% in fertilizer distribution to the farm gate, this is expected to improve the profitability of fertilizer use only moderately. The expected profitability of fertilizer use is estimated to remain below that obtained in 1996 largely because of the extent to which fertilizer was subsidized under the former system. It thus follows that unless the deregulation is accompanied by other measures such as improvement in the performance of the grain market and/or improvement in the agronomic efficiency of fertilizer use in the long run, the decline in profitability reduce fertilizer demand in some areas.

- ***Implications of Increasing the Agronomic Response of Fertilizer Use:*** The output response to fertilizer application is low in many areas because of inappropriate cultivation practices, sub-optimal nutrient use and lack of complementary inputs such as improved seed, chemicals, and animal traction.. Also, fertilizer has for the most part been applied without improved seeds and chemicals; hence yields are low. As mentioned above, the Government's agricultural extension efforts in recent years have shown the potential for substantially raising cereal yields on peasant' farms with on-shelf technology.[7] Under the assumption of a 20% increase in yield response to fertilizer use, the VCR for fertilizer use exceeds 2.0 in 35 of 51 cases (holding other factors constant at levels in Scenario 1) and in 40 of 51 cases under Scenario 2. The mean VCR estimates, under the assumption of a 20% increase in yield response, increases 18.2 percent (from 2.14 under existing response rates, to 2.53 with a 20% improvement in response rates). There is also the potential for greater use of fertilizer on high-valued crops such as cotton, coffee, and oilseeds which could further contribute to productivity growth in Ethiopian agriculture.

- However, the profitability of the National Agricultural Extension Program technology package needs to be clarified. While average yields under the program are two- to three-fold higher than non-participating farms, these advantages could be potentially offset by additional labor demands, timing of labor for improved cultivation practices, and additional cash input costs. If solid research shows that the NAEP-type technology package provides peasant farmers with higher returns to land and labor than existing technical practices in most regions, then this would indicate the high payoffs to diffusion of this new technical package through sustainable coordination of credit, input, and output markets to meet the needs of smallholder farmers.

- ***Importance of Grain Market Performance in Influencing Fertilizer Use***: Data presented in this note emphasize that efforts to reduce grain marketing costs should be viewed as a critical component in the overall strategy to stimulate fertilizer demand and crop productivity in Ethiopia. Improving the efficiency and reducing costs in the grain marketing system represent one important means for conferring higher output prices to farmers. Evidence indicates that grain market liberalization, initiated in Ethiopia in 1990, has raised output prices for Ethiopian farmers in major surplus-producing areas (Asfaw and Jayne 1997; Dercon 1995). For example, Asfaw and Jayne estimate that grain market liberalization has raised equilibrium maize prices in Shashemene and Bako, two important maize producing areas, by 29 birr/quintal and 21 birr/quintal, respectively. Moreover, in January 1997, some regional governments announced their intention to eliminate or reduce taxation of grain movement at regional grain checkpoints. These taxes had increased grain marketing costs between 4 to 15 birr per quintal on major grain trading routes in 1996 (i.e., about 20% to 33% of observed price spreads between major wholesale markets in the country). Under the assumption that the elimination of these taxes and further efficiency gains in grain marketing were capable of increasing cereal output prices by 10 birr per quintal, the VCR of fertilizer use (holding other factors constant at Scenario 1 values) rises above 2.0 in 32 of 51 cases. The average VCR rises to 2.69, given the unsubsidized fertilizer price specified in Scenario 1 and largely offsets the adverse effect of fertilizer subsidy elimination on fertilizer profitability.

  A major conclusion of this report is that the performance of the grain marketing system in Ethiopia strongly influences the profitability of fertilizer use by farmers. This conclusion underscores the importance of viewing productivity growth from a "systems perspective," in which the profitability of investments made at one level of the system (e.g., farm production) are liable to depend on the kinds of investments (or lack thereof) made at other stages of the agricultural system.

- ***Synergistic Effects of Improved Output Markets, Input Delivery Systems and Agronomic Response to Fertilizer:*** If higher producer prices (as above) were accompanied by lower input costs (Scenario 2) and 20% higher agronomic response rates, the VCR for fertilizer use would exceed 2.0 in 42 of 51 cases. This emphasizes that substantial increases in fertilizer profitability can be accelerated most rapidly through concerted efforts at increasing agronomic response rates, improved crop marketing and efficient procurement and distribution of fertilizer.

A major unknown in the immediate future is how the deregulation of fertilizer prices will affect the demand for fertilizer in the coming years. The results above indicate that the answer to this question will depend largely on what other steps are taken to improve the functioning of input delivery systems, output markets, credit provision, and to improve crop management practices.

Notes

1. This Note is a synthesis of a Working Paper by the Grain Market Research Project: Mulat Demeke, Ali Said, and T.S. Jayne, 1997. "Relationships Between Fertilizer Use and Grain Sector Performance," Working Paper #5, Grain Market Research Project, Ministry of Economic Development and Cooperation, Addis Ababa. Readers interested in details as to method, model specification, and results are referred to this paper.

2. Food production growth can conceivably occur through expansion of cropped area, but much of the highland regions suitable for cropping are already fully utilized given the carrying capacity of the land.

3. Over 300,000 peasant farmers took part in the Government's New Agricultural Extension Program (NAEP) in 1995/96, patterned after the Sasakawa Global-2000 Program. The centerpiece of these programs are farmers' half-hectare extension plots, utilizing improved seeds, improved management practices, and fertilizer types and rates as recommended by the Ministry of Agriculture. Results from the SG-2000 Program have shown that yields for maize, wheat and teff can be increased to 55, 31 and 18 quintals per hectare respectively.

4. A full accounting of costs associated with this fertilizer use would include the additional labor and other complementary input costs incurred from the fertilizer use.

5.The difference between this derived cost of 261 birr per quintal and the Government estimate of 256 birr per qunital is due to the more realistic provision for transport costs in estimating the deregulated price.

6. With general price inflation at roughly 4%, the real annual price increase of DAP in 1997 in these areas is likely to reach roughly 33%.

7. Even in the case of fertilizer, only one type, DAP, is used by the vast majority of farmers. According to the new recommendation, DAP and urea should be applied in equal proportion in order to the greatest yield response.

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The Grain Market Research Project (formerly known as Food Security Research Project) is a joint collaboration between the Ministry of Economic Development and Cooperation, USAID/Ethiopia, and Michigan State University. Please direct all inquiries to the In-Country Coordinator, Grain Market Research Project, Ministry of Economic Development and Cooperation, P.O. Box 1037, Addis Ababa, Ethiopia; Tel. 12-89-73; Fax 55-01-18; Internet: GMRP@TELECOM.NET.ET

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Does Fertilizer Use Respond to Rainfall Variability? Panel Data Evidence from Ethiopia

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Abstract

In this paper we use farmers' actual experiences with changes in rainfall levels and their responses to these changes to assess if patterns of fertilizer use are responsive to changes in rainfall patterns. Using plot and farm level panel data from the central Highlands of Ethiopia matched with corresponding village level rainfall data; results show that both the current year's decision to adopt and the intensity of fertilizer adoption is positively associated with higher rainfall levels experienced in the previous year. Furthermore, we find a concave relationship between previous season rainfall levels and fertilizer adoption, indicating that too much rainfall discourages adoption. Abundant rainfall in the previous year could depict relaxed liquidity constraints and increased affordability of fertilizer, which makes rainfall availability critical in severely credit constrained environments. In light of similar existing literature, the major contribution of the study is its use of plot level panel data, which permits us to investigate the importance of plot characteristics in fertilizer adoption decisions.

Key words: Fertiliser adoption; Rainfall; Highlands of Ethiopia; Panel data

JEL Classification: O12; O33; Q12; Q16; Q54.

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1. Introduction

Agriculture is inherently risky. Agroclimatic situations condition the performance of agricultural activities and determine the type of crops grown and animals reared (Downing, 1996; Watson et al., 1996; Reilly 1995; Smit et al. 1996; Risbey et al. 1999) and increased inter-annual climate variability accompanying mean climate changes has been argued to have a greater effect on crop yields than mean climate changes alone (Mearns et al., 1995).

However, in addition to conditioning production outcomes, uncertainty associated with climate variability may also affect investment decisions with upfront cost and uncertain outcomes. The use of productivity-enhancing external inputs is one such investment. In settings where financial and insurance markets are imperfect, households cannot freely borrow to finance external input use nor can they trade away the risk of crop failure in the insurance market. As Paxson (1992) finds, rainfall is positively correlated to income and rainfall variability -being one aspect of climate variability- negatively affects households' propensity to save. Hence, the decision to apply external inputs like fertilizer tends to be associated with climate variability.

A number of studies have documented the limiting role of resource and credit constraints on the use of modern agricultural inputs like fertilizer. In their study of the constraints with regards to use of inorganic and organic fertilizers by smallholder farmers in South Africa, Odhiambo and Magandini (2008) find that inability to access credit significantly limits fertilizer use. Similarly, in Madagascar, adoption of a high yielding rice variety-fertilizer package is shown to be hampered by liquidity constraints (Moser and Barrett, 2005).

In addition to financial constraints which impose ex-ante barriers to fertilizer use, missing formal insurance markets in developing countries imply that farmers face serious constraints in coping with production risks (Murdoch, 1995; Dercon, 2002). Indeed, covariate shocks due to climate change and variability e.g. droughts have long-lasting negative effects on households' welfare (Dercon, 2004). This implies that households have to rely on their limited resources to cope with such risks by reducing their vulnerability to such risks. Such risk avoidance strategies have been attributed to limited fertiliser use in developing countries (Lamb, 2003). This paper contributes to the limited empirical literature that assesses empirically the role of rainfall on farmers' factor demands. It does this by assessing the possible links between rainfall patterns and corresponding farmers' decisions to use fertilizer. As noted earlier, higher rainfall levels are expected to result in increased harvests which in turn are expected to ease the liquidity constraints facing households. Relaxation of liquidity constraints could then mean that households are more likely to adopt fertilizers.

The analysis is based on three rounds of representative plot- and farm-level data from the Ethiopian Highlands. By focusing on plot-level analysis, our paper builds on Dercon and Christiaensen (2007) whose analysis was based only on farm-level analysis. We employ random effects estimators which allow us to treat each plot observation within a given household as a variable unit thereby controlling for intra-group correlation due to unobserved cluster effects in addition to unobserved effects. Our results confirm both at plot- and farm-level, that fertilizer adoption by farmers is positively associated with rainfall levels in the previous year, supporting the hypothesis that rainfall encourages fertilizer adoption by relaxing liquidity constraints. This is also in line with Seo and Mendelsohn (2008) and Bezabih et al. (2008) who find that the riskiness of crop portfolio over time is influenced by the rainfall patterns, as higher rainfall leads to higher harvests, increases liquidity and enhances risk bearing capacity.

The strength of the analysis therefore is that it is not based on implicit production risk. It deals with actual farmers' experiences with changes in rainfall levels, and their responses to these changes relative to other factors which influence their decision to apply fertilisers. Inclusion of such adaptive responses is critical to a valid assessment of the impacts of climate change and variability, given that such responses result in less or more adverse effects than if they are excluded.

The rest of the paper is organized as follows: section 2 presents the conceptual framework underlying the analysis while in section 3 we present the econometric framework that forms the basis of the empirical approach used in the paper. The data used in the analysis is discussed in section 4 together with a background on fertilizer use in Ethiopia. Section 5 presents and discusses the results of the econometric estimation and section 6 concludes the paper with policy implications.

2. The conceptual Framework

Rural farming households in developing countries operate under uncertain production environments with imperfect credit and insurance markets implying that liquidity constraints are a huge limiting factor in technology adoption decisions such as fertilizer adoption decisions. The rationale behind our conceptual framework is that fertilizer is a risky input and is liquidity dependent. It argues that rainfall and in particular, lagged average rainfall, determines the level of output in the lag year and thus gives an indication of the degree of liquidity constraints faced by the household in the current year. Since fertilizer use is determined both by the level of liquidity constraints and the degree of uncertainty in the production environment, it responds directly to the lagged average rainfall. The conceptual framework we pursue is an adaptation of an agricultural household model by Shively (1997), which uses an expected utility maximization framework to represent investment decisions made under uncertainty.

Consider an agricultural household, which is assumed to maximize its expected returns from farming, i.e.:

$$\text{Max } E\left[\sum_{t=0}^{T}\beta^{t}\pi_{t}(d(\pi_{t-1}))\right], \tag{1}$$

subject to the farm income defined as:

$$\pi_t = A\left[f(d(\pi_{t-1}), x(\pi_{t-1}), \varsigma) - c(d(\pi_{t-1}), x(\pi_{t-1}))\right] + wL + I, \tag{2}$$

and a household-specific safety-first constraint:

$$\Pr(\pi_t < \bar{I}) \leq \alpha \;\; \forall t. \tag{3}$$

In equation (1), β is a per-period discount factor; π_t per-period net farm income, and $d = \{0,1\}$ denotes the decision to adopt fertilizer. The net farm income in the previous period is denoted by (π_{t-1}) and this is expected to be an indicator of the disposable income available to the household to spend on farm inputs. In equation (2), A denotes plot sized: $f(d(\pi_{t-1}), x(\pi_{t-1}), \varsigma)$ is a stochastic production function that depends on the decision to adopt fertilizers (θ), other inputs (x), and a stochastic shock (ς); and $c(d(\pi_{t-1}), x(\pi_{t-1}))$ is a cost function for inputs. Non crop incomes of the agricultural household are captured in equation (2) and are combination of nonwage income (I) and labor (L) supplied at the wage rate (w). $\bar{I}$ is a threshold or critical level of income and α denotes a maximum allowable probability of falling below the threshold in equation (3).

The agricultural household should evaluate expected returns in terms of a probability distribution for minimum income and that is why the safety-first constraint is introduced in the household’s problem. According to Shively (1997) this distribution will depend on the income-earning capacity of the household. Although restrictions could be used to specify a closed form for the conditional probability distribution of returns, a more general approach is to re-express the safety-first constraint as:

$$\pi_t(D(\pi_{t-1})) + F^{-1}(\alpha)\sigma_\pi \geq \bar{I} \ \forall t \qquad (3')$$

where $F^{-1}(\alpha)\sigma_\pi$ is the inverse of the distribution function of returns and σ_π is a measure of spread (Boussard, 1979 cited in Shively, 1997).

The first order conditions for maximizing equation (1) subject to the constraints equations (2) and (3') leads to an optimum where in each period

$$\frac{\partial f}{\partial D} = \frac{\partial c}{\partial D} + \frac{\lambda}{(A-\lambda)}\frac{\partial F^{-1}}{\partial D} \qquad (4)$$

where λ is the Langragean multiplier associated with relaxing the safety constraint. Equation 4 above shows the marginal benefit-marginal cost condition for adoption that explicitly accounts for the cost of adoption in terms of its impact on the safety-first constraint in each period. If this constraint is binding, (i.e., if $\lambda > 0$), adoption decision will not be based solely on a comparison of net benefit flows between techniques, but will also depend on farm size, non-farm income, and the impact of adoption on the probability of income shortfall. Inverting equation (4) results in a demand function for fertilizer use of the form:

$$D = \phi(A, \pi_{t-1}, c, E\left\{F^{-1}(\alpha)\sigma_\pi \mid A, w, L, I\right\}). \qquad (5)$$

In this paper we draw on the established link between rainfall and the household's farm income and the ability to save (Paxson, 1992; Hoddinott, 2006) to posit that rainfall variability impacts the safety-first constraint in equation (3') through the crop income in the previous period π_{t-1}, which is intuitively expected to affect the affordability of fertilizer use by households. Thus the equation the reduced form demand function for fertilizer use becomes:

$$D = \phi(A, W_{t-1}, c, E\left\{F^{-1}(\alpha)\sigma_\pi \mid A, w, L, I\right\}), \qquad (5')$$

where W_{t-1} denotes the rainfall levels in period $(t-1)$. According to equation (5'), the decision regarding fertilizer use will depend on rainfall levels in the pervious period, plot size, the cost of inputs, and the shape of the expected probability distribution associated with the safety-first constraint. The probability distribution is conditioned on the income-earning capacity of the household. Furthermore, by influencing technology performance or adoption cost, farm or plot-specific attributes such as land quality or slope, socioeconomic characteristics may also influence adoption decisions. Including the safety-first constraint in the adoption problem underscores the point that when technology adoption is costly, it has the potential to push a low-income household below its disaster level. As a result, one might expect that adoption decisions will be influenced by the productive capacity of the household. We can thus use equation (5’) as a basis for the reduced-form empirical model to be investigated in the following section.

3. The econometric framework and estimation strategy

In this section we set up an econometric framework for analyzing the link between fertilizer adoption decisions and rainfall patterns. First, we specify the relationships between whether or not to adopt fertilizer and determinants of fertilizer adoption, to investigate the existence of a significant impact of rainfall patterns on the decision to use fertilizer. We then investigate if the quantity of fertilizer applied on a given plot is attributable to changes in rainfall patterns by studying the relationships between plot level fertilizer use, and yearly average rainfall.

The premise behind our hypothesis and the specification of the empirical model is that fertilizer is a risky input and is liquidity dependent. Our key decision variable -lagged average rainfall -by determining the level of output in the lag year- gives an indication of the degree of liquidity constraints faced by the household in the current year. Since fertilizer use is determined both by the level of liquidity constraints and the degree of uncertainty in the production environment, it responds directly to the lagged average rainfall. The advantage of using lagged rainfall here is that it is exogenous to current choices and as such provides a good proxy for income and consequently the ability of the household to afford fertilizer adoption.

Following the conceptual framework outlined in the preceding section as well as previous technology adoption literature (e.g. Dercon and Christiaensen, 2007), our empirical investigation is based on the following specifications of household *h*’s fertilizer adoption decisions:

$$d_{pt} = g(Z_{pt}, W_{p(t-1)}, \varepsilon_{pt}), \tag{6}$$

where d_{pt} is the decision by household h to fertilize plot p at time t; $W_{p(t-1)}$ is the average yearly precipitation at time $(t-1)$ and Z_{pt} is a vector of other factors derived from economic theory and earlier work on fertilizer adoption. These include characteristics such as plot-specific attributes which may influence adoption decisions by influencing technology performance or adoption costs. When market imperfections are important, inclusion of household characteristics and resource endowments in explaining investment decision is important (Pender and Kerr, 1998; Holden et al., 2001), in addition to other determinants of investment decision. Accordingly we include variables to capture the “natural capital” of the plot (biophysical characteristics such as soil fertility, slope and soil type); the household’s endowments of physical capital (land, livestock); the human capital (education, age, and gender of household head, number of female and male adults in the household); and random factors are captured by ε_{pt}.

As the next section describes, not all surveyed plots (and households) were fertilized. Given our conceptual framework which considers the decision to adopt fertilizer as a binary decision, our econometric strategy is to estimate two models: the first model estimates the decision to adopt (a binary decision) and the second model is a censored regression model which is used to correct for the fact that not all surveyed parcels were fertilized. This allows for the possibility that the decision to adopt fertilizer and the intensity of adoption are determined by different factors. We chose this over selection models such as the Heckman model due to lack of strong theoretical arguments to guide the selection of exclusion variables that determine the decision to adopt fertilizer but not the intensity of adoption

Thus given a latent variable K^*_{pt}, that is observed only when fertilizer application takes place, the decision by household h to adopt fertilizer use on plot p at time t is such that:

$$\begin{array}{l} K^*_{pt} = \beta_0 + \beta_1 Z_{pt} + \beta_2 W_{p(t-1)} + \beta_3 W^2_{p(t-1)} + \varepsilon_{pt} \\ d_{pt} = 1 \text{ if } K^*_{pt} > 0 \\ \quad = 0 \text{ otherwise} \end{array} , \qquad (7)$$

where d_{pt} is a dummy that denotes the decision by household h to adopt fertilizer on plot p at time t. Thus the decision to adopt fertilizer is modelled as a binary choice model. The parameters to be estimated are $\beta_0, \beta_1, \beta_2$ and β_3. It is assumed throughout the paper that the error term, ε, is such that (Z,ε) and $(W,\varepsilon) \sim i.i.d$ and $N(0,\sigma^2)$. We include a quadratic term of lagged rainfall levels to allow for the possibility that there is a threshold level of rainfall above which the marginal benefit associated with fertilizer application declines.

To use the random effects estimator we decompose the error term into two components such that

$$\varepsilon_{pt} = \varphi_p + \mu_{pt}, \tag{8}$$

where we also assume that $\mu_{pt} \sim i.i.d$ and $N(0,\sigma^2)$. φ_p is assumed to be independent random draws from a normal distribution, where we assume $\varphi_p \sim N(0,\sigma^2)$, as before. This treatment lends itself to a random effects estimator whereby we treat each plot observation within a given household as a variable unit. This means that in addition to controlling for unobserved effects we are also control for intra-household correlation due to unobserved cluster effects (Wooldridge, 2002) such as features of microclimates. Thus in accordance with the foregoing discussion, our estimation of the decision to adopt fertilizer on a given plot, applies the panel-data random effects estimator model with the dependent variable being observed across three time periods, and the weather variable is observed with lagged time.

Given that not all plots were fertilized, estimating the intensity of fertilizer requires the use of econometric models that correct for this censoring of the dependent variable, since the use of Ordinary Least Squares (OLS) on the whole sample will give inconsistent estimates (Wooldridge, 2002). Accordingly a censored regression model is used. Specifically we estimate a random effects Tobit model on the intensity of fertilizer use. A censored regression model is such that:

$$\begin{aligned}
&K^*_{pt} = \beta_0 + \beta_1 Z_{pt} + \beta_2 W_{p(t-1)} + \beta_3 W^2{}_{p(t-1)} + \varepsilon_{pt} \\
&K_{pt} = K^*_{pt} \text{ if } K^*_{pt} > 0 \\
&\quad = 0 \text{ otherwise} \\
&\Rightarrow K_{pt} = \max(0,\ \beta_0 + \beta_1 Z_{pt} + \beta_2 W_{p(t-1)} + \beta_3 W^2{}_{p(t-1)} + \varepsilon_{pt})
\end{aligned}, \tag{9}$$

where K_{pt} is the observed intensity of fertilizer application i.e. the amount of fertilizer used per hectare, in kilograms. Assuming the error term is independently, identically and normally distributed with zero mean and constant variance leads to a Tobit model, originally developed by Tobin (1958). Decomposing the error term according to equation (8) makes it possible for us to estimate a random effects Tobit model thus allowing us to control for intra-group correlation due to unobserved cluster effects in addition to unobserved effects.

4. The data and fertilizer use in Ethiopia

The data

To estimate the models we use plot-level panel data from the Highlands of Ethiopia. The dataset contains rich information on plot and farm characteristics, cropping patterns, the traditional and modern inputs used in each period, as well as socioeconomic characteristics of a total of 1500 rural households. The data were collected from rural households in two districts of the Amhara National Regional State by the Environmental Economic Policy Forum for Ethiopia and Addis Ababa University, Department of Economics. The regional state comprises part of the northern and central Highlands of Ethiopia. The data collection was done in three waves which covered the years 2002, 2004 and 2007. Given little intra- and inter-village migration, not much attrition is experienced in forming the panel. In the few cases where respondents are missing in the succeeding waves of the survey, the households were dropped out of the sample. We match this data set with longitudinal annual rainfall data collected from local stations by the Ethiopian Metrology Authority. Monthly rainfall data was collected from four meteorological stations close to the twelve study sites. These monthly figures are then used to compute the annual figures, which we use in this analysis.

Summary statistics of all the variables used in the ensuing analysis are presented in Table 1 below. Our variable of interest is *Lagged rainfall* which increases productivity in the previous year, thereby easing liquidity constraints faced by households in adoption decisions. Though difficult to verify given data limitations, *Lagged rainfall* could be correlated with the levels of rainfall households anticipate in the current year which could intuitively influence their fertilizer adoption decisions, with higher anticipated rainfall levels encouraging adoption of fertilizer since use of fertilizers in dry years will burns seeds and thus increase the risk of low harvests. The average *Lagged rainfall* over the period of analysis is around 1205mm while the intensity of plot-level fertilizer use is 156kg and 65kg at farm-level. The mean plot size is approximately 0.22ha while the mean farm-size is 1.04ha. Around 87% of the households are male-headed. The number of times the household has experienced land changes by the government; *Frequency of land change*, is considered an indicator of tenure security.

Table 1: Definition of variables and descriptive statistics

Variable	Description	Mean	Std. Error
Fertilizer Use			
Plot-level adoption	Whether any fertilizer was applied on the plot (1=yes, 0=no)	0.20	0.40
Plot-level intensity	Fertilizer application per hectare, in kilograms	155.82	7369.8
Farm-level adoption	Whether any fertilizer was applied on the farm (1=yes, 0=no)	0.40	0.49
Farm-level intensity	Fertilizer application per hectare, in kilograms	65.14	759.0
Rainfall			
Lagged rainfall	Lagged rainfall levels/1000, in mm	1.205	0.223
Socioeconomic characteristics			
Gender	Gender of household head (1=male, 0=female)	0.87	0.34
Age	Age of household head	48.73	15.34
Education	Level of education of household head	1.92	0.96
Formal farmer training	Household head received some formal farmer training (1=yes, 0=no)	0.17	0.37
Male adults	Number of male adults in the household	3.03	1.65
Female adults	Number of female adults in the household	2.79	1.40
Oxen	Number of oxen owned and used by the household	2.12	27.53
Frequency of land change	Frequency of land change	0.71	1.06
Plot and farm characteristics			
Plot distance	Distance from homestead to the plot, in minutes	14.53	21.46
Plot size	Size of the plot, in hectares	0.23	0.24
Average distance	Average distance from homestead to each plot, in minutes	1. 49	16.86
Farm size	Size of the farm, in hectares	1.04	0.90
Fertile	Proportion of plot that is perceived as fertile	0.41	0.37
Moderately fertile	Proportion of plot that is perceived as moderately fertile	0.39	0.35
Flat slope	Proportion of plot that is of flat slope	0.67	0.33
Moderate slope	Proportion of plot that is of moderate slope	0.28	0.31

Source: Authors' own calculation.

Inorganic fertilizer use in Ethiopia

According to FAO (1995) fertilizer was first introduced to Ethiopia in 1967 following four years of trial carried out by the Imperial Government with the assistance of FAO. Fertilizer adoption by the peasant sector, which was 14,000 metric tons in the year 1974/75, reached about 50,000 metric tons in 1979/80 and 200,000 metric tons in 1993/1994. About 80 percent of the fertilizer used is for cereals and 45 to 50 percent of it is applied on the major staple, teff where as the remaining on wheat, barley, maize and sorghum. Only about one-third of the farmers in highlands apply fertilizer and their rate of application is much lower than 50kg/ha on average (FAO, 1995). Demeke et al. (1998) documented that it is recommended to use 200 kg (100kg Urea and 100 kg Di-Ammonium phosphate (DAP)) per ha for all cereal crops in most areas of Ethiopia. The current intensity of fertilizer use is therefore quite lower than recommended. Table 2 gives a year-by-year breakdown of fertilizer adoption and intensity of use in the sample we analyze.

Table 2: Fertilizer use in the Highlands of Ethiopia, 2002-2007

Year	Farmers using fertilizer (%)		Application rate per ha (kg)	
	Plot-Level	Farm-Level	Plot-level	Farm-Level
2002	23.68	53.05	42.092	35.123
2004	18.46	36.65	51.3889	69.269
2007	17.45	30.57	348.7999	89.769

Source: Authors' own calculation.

Table 2 indicates that approximately 53 percent of the farmers in the sample areas applied fertilizer on their farms in the year 2002. This figure declined to about 37 and 31 percent in the years 2004 and 2007. Consistent with all the previous studies, table 2 also shows that intensity of fertilizer use is still very low in the Highlands of Ethiopia. In the year 2000, an average of about 35 kg fertilizer was applied per ha and this figure increased to 69 and 89 kg per ha in the years 2004 and 2007. Although the number of farmers adopting fertilizer is declining, intensity among farmers choosing to use fertilizer has been improving. However, the intensity of fertilizer use is still lower than the recommended rate of 200 kg per ha. Dercon and Christiaensen (2007) also documented that both adoption rates and intensity of fertilizer use are relatively low; with only 22 percent of all households in the sample using fertilizer in each period and only about 30 kg per ha being used, far below the recommended application rate of 200 kg per ha. Thus the main objective of the study is to examine factors explaining this low adoption rates and subsequent intensity of adoption, with a focus on how rainfall impacts adoption decisions.

With the exception of Dercon and Christiaensen (2007), studies examining factors determining fertilizer adoption decisions of farmers in rural Ethiopia have tended to ignore risk factors associated with rainfall variability, probably due to data unavailability. Accordingly the main contribution of this paper lies in employing plot-level panel data collected from about 1,500 rural households in the Highlands of Ethiopia to investigate whether households, faced with imperfect insurance and credit markets, use risk avoidance as a strategy to cope with threats to harvests (which is directly related to income) due to climate change and variability. The main improvement to Dercon and Christiaensen (2007) is our use of both plot- and farm level data whereas their analysis is based only on farm-level data. This way we are able to investigate the significance of plot characteristics in fertilizer adoption decisions.

5. Empirical results and discussion

Table 3 below presents the random effects Probit results for the decision to adopt fertilizer and random effects Tobit results for the intensity of adoption, both at plot-level. The coefficient rho basically represents the proportion of the observed total variance of the error term due to random effects. Thus the test for the null hypothesis that rho=0 is rejected justifying the use of a random effects estimator. This demonstrates the importance of intra-household correlation due to unobserved cluster effects in fertilizer adoption decisions.

We also estimate both the random effects Probit and Tobit at farm-level. However, since this analysis focuses mainly on plot-level analysis we report the results from the farm-level analysis in Table A1 in the appendix. The results have similar implications to plot-level results presented and discussed here.

Table 3: Random Effects Probit and Tobit on Plot-Level Fertilizer Adoption

	Random Effects Probit		Random EffectsTobit	
Variable	Coeff.	Std. Error	Coeff.	Std. Error
Rainfall				
Lagged rainfall	9.739***	2.576	45.390***	12.155
Lagged rainfall squared	-0.004***	0.001	-0.018***	0.005
Socioeconomic characteristics				
Gender	0.476***	0.167	2.374***	0.792
Age	-0.012***	0.004	-0.060***	0.017
Education	0.017	0.053	0.020	0.253
Formal farmer training	-0.183	0.119	-0.913	0.565
Male adults	0.002	0.033	0.009	0.158
Female adults	-0.089**	0.036	-0.458***	0.174
Oxen	0.203***	0.054	0.969***	0.252
Farm size	0.124**	0.061	0.633**	0.260
Frequency of land change	-0.112	0.084	-0.491	0.390
Plot characteristics				
Plot distance	0.000	0.002	0.003	0.008
Plot size	0.283*	0.145		
Fertile	-0.579***	0.165	-2.800***	0.773
Moderately fertile	-0.580***	0.161	-2.809***	0.752
Flat slope	-1.129***	0.239	-5.810***	1.127
Moderate slope	-0.613**	0.253	-3.379***	1.182
Constant	-6.141***	1.590	-27.237***	7.472
Rho	0.472	0.037	0.458	0.034
LR test of Rho=0: p-value	0.000			
Wald chi2	126.73		120.28	
Log-likelihood	-1494.508		-3147.713	
Observations	3648		3646	
Number of household id	914		914	

*Note: * significant at 10%; ** significant at 5%; *** significant at 1%*

Climate variability and fertilizer adoption

The primary objective of this paper has been to analyze the link between rainfall levels and farmers' fertilizer adoption decisions, our hypothesis being that higher previous season rainfall levels will lead to increased fertilizer adoption. This is because abundant rainfall in the previous year translates into good harvests which could in turn relax liquidity constraints and consequently lead to increased probability of applying fertilizer as well as the intensity of fertilizer application. Our results suggest that both the decision to adopt fertilizer and the intensity of adoption in a given year is positively affected by previous year's rainfall levels, in line with *a priori* hypothesis. Furthermore we find a concave relationship between previous season rainfall levels and fertilizer adoption. This suggests for a threshold level of rainfall after which the marginal impact of rainfall on fertilizer use starts to decline. This result is also confirmed at farm-level (see Table A1 in the appendix) indicating that even at the farm level both the decision to adopt fertilizers and the intensity of adoption in a given year is positively affected by previous year's rainfall levels.

This result demonstrates the poverty implication of climate variability and change. Climate variability and change, via its direct impact on crop income, is expected to worsen poverty levels by lowering incomes of better off farmers while those who are already poor will remain trapped in poverty as adverse weather patterns will negatively impact on their income prospects. The link between rainfall levels and crop or farm income is well established (Hoddinott, 2006). Furthermore, rainfall variability negatively affects households' propensity to save (Paxson, 1992). Moreover, existing literature has established that poverty, being an indicator of vulnerability due to its direct association with income or access to resources, significantly constraints households in coping with impacts of extreme weather changes (Adger, 1999). This informs policies that seek to mitigate or adapt to climate variability and change to explicitly factor in the impact of poverty on the ability to cope with such changes. A plausible policy is to provide credit and insurance in as far as its provision might ease the constraints households face when they try to invest in farm inputs. One possibility is to develop index-based crop insurance schemes whereby indemnity payments are made when an agreed upon condition, in this case when recorded rainfall at a particular station falls below a certain threshold. The advantage with such insurance schemes is that they are based on conditions that are independent from both farmers and insurers' influence thereby minimizing moral hazard and adverse selection problems. Such mechanisms might ease the households' vulnerability to crop failure which might constraint the ability to invest in farm inputs.

Another possible explanation to our finding is that anticipated weather changes are informed by current weather patterns i.e. anticipation about next year's rainfall patterns are influenced by current year rainfall patterns[5]. Thus given the anticipated rainfall patterns, households use opportunities within their means to shield themselves against

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[5] Anecdotal evidence shows that farmers anticipate bad weather once in four years. The survey years and the rainfall observation years all correspond to the 'good weather' years according to this anecdotal evidence. Hence, farmers in the study area may have expectations that current rainfall is close to previous rainfall in pattern.

crop failure; in this case they either abandon or reduce fertilizer use given that they anticipate lower rainfall levels, in line with Fufa and Hassan (2006). Higher anticipated rainfall levels signal reduced anticipated risk of fertilizer use, since applying fertilizers under dry conditions could simple burn seeds and increase the probability of crop failure. In this way reducing fertilizer application can serve as a relevant strategy in coping with production risks associated with climate variability, with the expectation being that higher rainfall levels will be associated with increased adoption of fertilizers and vice versa. This is also supported by findings by Smit et al. (1996) and Hucq et al. (2000) who find evidence that farmer alter the intensity of input use to reduce the risks associated with climate change.

Other correlates of fertilizer adoption

Existence of gender differences in technology adoption is confirmed, with male-headed households being more likely to adopt fertilisers. This lends support to the contention that women are generally discriminated against in terms of access to productive inputs (Dey, 1981; Doss, 1999). Given the demonstrated contribution of fertilisers to raising agricultural yields and land productivity in sub-Saharan Africa (Mwangi, 1997) and particularly in Ethiopia where the population growth rate and land degradation places a challenge on agriculture (Fufa and Hassan, 2006), such discrimination with regards to productivity-enhancing farm inputs can result in gender differentials in farm productivity (Udry et al., 1995) and subsequently poverty. This is further supported by the fact that female labor, proxied by the number of female adults in the household, is associated with lower probability and intensity of adoption. The negative impact of female labor might also be reflecting households' preference for female labor-saving technologies particularly where there are alternative opportunities for female labor.

The probability of fertilizer adoption and intensity of adoption decreases with age, consistent with Fufa and Hassan (2006) and Chianu and Tsujii (2004). This suggests that older household heads might have a shorter planning horizon and thus less likely to adopt soil conservation practices than younger household heads. Furthermore research has found evidence than younger farmers are more likely to adopt technologies and given that they have more energy, they are more likely to invest in productivity-enhancing technologies (Alavalapati et al., 1995).

The suggested positive impact of oxen ownership on both the decision to adopt as well as the intensity of adoption suggests that wealthier households have an advantage in adoption of fertiliser. The number of oxen owned by a household can be taken as a proxy for household wealth (Clay, et al., 1998). Wealthier households are better placed to purchase fertilisers as well as to amass additional resources that can be used for on-farm investments. Poverty has been found to be a major constraint in African agriculture (World Bank, 2007). The significance of oxen in determining use of farm inputs such as inorganic fertilisers combined with the finding that fertiliser enhances productivity in Africa (Mwangi, 1997) confirms this. This suggests that policies aimed at alleviating poverty will help alleviate constraints to access and use of farm inputs needed to improve agricultural productivity.

With regards to plot characteristics, the positive impact of plot size could be suggesting that it might not be economically efficient for farmers with small farm holdings to apply fertilisers due to economies of scale effects at plot-level, for example, packaging of fertilisers. Similarly the positive impact of farm size (Table A1 in the appendix) suggests that larger farmers benefit from either economies of scale or preferential access to inputs and credit (Polson and Spencer, 1991) and/or might be able and willing to bear more risks than small farmers. It could also be the case that farm size is capturing the wealth status of the household in which case this is in line with concerns we raised earlier regarding the constraints poverty imposes on fertiliser adoption.

Farmers have been found to have fairly good indigenous knowledge of the challenges facing their farming systems and their assessment of soil quality impacts greatly on their soil fertility management strategies (Edwards, 1987 cited in Adesina, 1996). Given that the primary goal of fertilizer use is to enhance soil fertility by supplying the nutrients necessary for improved crop yields (Mwangi, 1997), it is intuitive that perceived soil fertility is associated with reduced adoption and subsequent intensity of adoption. Gentle or flat slopes are associated with less erosion compared to moderate slopes (Ovuka and Ekbom, 1999) implying that they experience less nutrient loss and thus farmers might not see the need to apply fertilizers on them. Thus intuitively we find that the likelihood of adoption as well as adoption levels decline in the proportion of the plot that is both flat and moderately sloped i.e. the flatter the plot, the less likely the adoption.

6. Conclusions and policy implications

This paper investigates how farmers' adoption of fertiliser is influenced by changes in precipitation, using plot and farm level panel data from the central Highlands of Ethiopia matched with corresponding village level rainfall data. The analysis is an addition to the limited empirical literature that assesses empirically the risk factors associated with rainfall variability and how this impacts investments in productive farm inputs such as fertilizer. Our main hypothesis is that higher anticipated rainfall levels will lead to higher fertilizer adoption. This is based on the argument that higher anticipated rainfall is also to result in increased harvest levels which in turn are expected to ease the liquidity constraints faced by households. The major contribution of the analysis lies in its use of plot level panel data that highlights the importance of not only household-level but also plot level characteristics. In addition, the strength of the analysis is that it is based on actual weather changes and explicitly examines farmers' responses to these, which conventionally is assumed in climate assessment studies.

The results indicate that in a world of credit and insurance market imperfections, previous year rainfall levels relaxes constraints due to such imperfections by increasing households disposable income. Thus our results suggest for possible poverty traps on poor farmers in the face of uninsured risks due to climate change and variability, given that rainfall variability is one aspect of climate change and variability. Given the link we establish between rainfall and fertiliser adoption patterns, climate change and variability, via its direct impact on crop income, is expected to worsen poverty levels by lowering incomes of better off farmers while those who are already poor will remain trapped in poverty as adverse weather patterns will negatively impact on their income prospects. This is evidence that there may be a market for weather-based derivatives in low-income agriculture and that the next step would be to establish the value of such insurance and the proper mechanism design. Provision of such insurance might ease the constraints households face when they try to invest in farm inputs. Furthermore, such mechanisms need to be accompanied by policies that seek to eliminate possible discrimination against female household heads in terms of access to productive inputs such as fertilisers. The significance of wealth indicators imply that polices aimed at poverty alleviation will help ease constraints farmers face in technology adoption.

The analysis is important in informing future studies that attempt to assess the link between weather related uncertainty and agricultural investment in credit constrained settings. The fact that we find evidence that households depend on good weather to make necessary productivity enhancing investments underlies the enormous importance attached to weather not only in determining current productivity but also future investments.

The analysis in this paper is based on average rainfall (abundance) and the impact of its variability on fertilizer use over years. Equally (even more) important measure in the Ethiopian context is the timing and variability of rainfall in a given year, which not only affects productivity, but also conditions fertilizer adoption decisions. Enhancing fertilizer use by Ethiopian farmers would require policy measures that provide insurance against losses associated with such variability. In addition, given the near-total dependence of the Ethiopian economy on such risk-prone, small-holder agriculture, short-term insurance measures might not be sustainable; and structural measures that reduce dependency on agriculture, particularly crop production, such livestock as off-farm employment options are worth exploring and investing in.

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Appendices

Table A1: Random Effects Probit and Tobit on Farm-Level Fertiliser Adoption

	Random Effects Probit		Random Effects Tobit	
Variable	Coeff.	Std. Error	Coeff.	Std. Error
Rainfall				
Lagged rainfall	21.742***	3.686	49.840***	8.412
Lagged rainfall squared	-0.008***	0.001	-0.019***	0.003
Socioeconomic characteristics				
Gender	0.736***	0.213	2.224***	0.522
Age	-0.018***	0.005	-0.047***	0.011
Education	-0.001	0.070	0.004	0.172
Formal farmer training	-0.076	0.157	-0.195	0.382
Male adults	0.005	0.041	0.031	0.105
Female adults	-0.105**	0.045	-0.266**	0.113
Oxen	0.261***	0.078	0.804***	0.181
Frequency of land change	-0.249**	0.126	-0.496*	0.290
Farm characteristics				
Average distance	-0.002	0.003	-0.001	0.009
Farm size	0.456***	0.081		
Fertile	-0.972***	0.230	-2.356***	0.533
Moderately fertile	-0.940***	0.219	-2.191***	0.519
Flat slope	-1.520***	0.346	-3.836***	0.786
Moderate slope	-0.796**	0.352	-2.014**	0.821
Constant	-12.443***	2.256	-27.076***	5.183
Rho	0.489	0.089	0.527	0.063
LR test of Rho=0: p-value	0.000			
Wald chi2	108.66		157.03	
Log-likelihood	-641.076		-1601.627	
Observations	1220		1215	
Number of household id	936		932	

*Note: * significant at 10%; ** significant at 5%; *** significant at 1%*