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Production technologies in Ethiopian agriculture

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Abstract

This article examines the characteristics of and choice among two production technologies in Ethiopian agriculture, one with fertilizer and the other without, using 1989–90 farm-level data. For northwest and central Ethiopia, fertilizer usage determinants are estimated simultaneously with technology-specific production functions. For southern Ethiopia, where fertilizer is rarely used, a single production function is estimated. Three conclusions emerge. First, fertilizer use is not significantly affected by a farm's stocks of capital or land. This is consistent with the fact that fertilizer allocation decisions under the deposed Mengistu regime were politicized to the point where farmers had little control over use. Second, fertilizer is associated with a smaller factor share for cattle and a larger share for land, meaning that those who control land may gain relative to the individual farmers who own cattle as the country develops agriculturally. Third, farms without fertilizer in northwest and central Ethiopia tend to be too small, a problem due to population pressures on the land and communal methods of land allocation. This suggests that land allocation institutions should adjust by distributing land to a smaller but more economically viable number of farmers.

1. Introduction

In the last decade, perhaps no other country in the world has had food problems as severe as Ethiopia. Hundreds of thousands of people died in each of two major famines, 1984–85 and 1990–91. Drought, along with a civil war in the northern part of the country that disrupted agricultural production and food aid shipments, have widely been blamed for the famines. However, misguided government policies also contributed by preventing agriculture from escaping the vagaries of the weather. The civil war culminated in the 1991 overthrow of the Marxist regime of President Mengistu that had ruled the country since 1974.

At present, Ethiopia is one of the poorest countries in the world, with a per-capita income

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of about \$120. [1] Agriculture is the mainstay of the economy, employing more than 80% of the work force and accounting for more than 40% of GDP. Although the country is large, less than 20% of the land is presently cultivated. Over 90% of agriculture, as measured by either land or output, is traditional and subsistence in nature. It is characterized by simple hand implements (hoes, sickles), ox-drawn wooden plows, unimproved seed varieties, small and often fragmented land holdings, and a high dependence on seasonal rainfall. Farm labor is almost exclusively unskilled family labor. Major food crops include cereals (accounting for about one-third of agricultural output), pulses, and oilseeds. The main cash crop is coffee, accounting for over 60% of agricultural output, as well as about 60% of Ethiopia's foreign exchange earnings. Agriculture as a whole accounts for nearly 90% of total exports. However, it also accounts for approximately 40% of imports.

Ethiopian agriculture can be divided into three agroclimatic regions: North, Central, and South. Within each region, though, is a complex geography containing important local differences in climate and soil. The North falls within the cool highlands, where rainfall is moderate and seasonal, soils are average to fairly good, land is highly fragmented and overgrazed, population pressures on the land are strong, and staple crops predominate. The Central also falls within the cool highlands, but rainfall is greater than in the North, soils are better, population pressures are not as severe, and cash crops are somewhat more important. The South falls within the temperate highlands, where rainfall is good, the soil is quite fertile, population growth is not a major problem, and farmers produce significant amounts of both staples and cash crops.

The problem is not that Ethiopia is poorly endowed with agricultural resources. Ethiopian land is generally considered to be among the most fertile in Africa, and it has been estimated that over 70% of the land is suitable for agriculture. Instead, the problem is that new techniques have not been permitted to make any inroads into Ethiopian agriculture. The only new technique that has been used to any significant degree is fertilizer, and even there the adoption rate among peasant farms is less than 15%. Less than 10% of peasant farms use high-yielding seed varieties (HYVs), fewer than 5% use herbicides, and less than 1% use pesticides. Of the farms that use fertilizer, the vast majority are located in the North and Central. Under the former Marxist regime, the bulk of modern inputs went to socialist enterprises (state farms and producer cooperatives), despite the fact that they accounted for only about 4% of total crop production and 5% of land area.

In 1975, the Mengistu regime embarked on land reform, establishing public ownership of all rural land and abolishing share tenancy. Every farm family was given use rights of up to 10 hectares of land, with the land to be distributed by officers of local peasant associations (PAs). Land reform had little effect in the Central and North, where land has always been communally distributed under a kinship system. Under this system, any male who claims ancestry from a particular village is entitled to part of that village's land. The government tried to get rid of the kinship system, but failed. In the South, where share tenancy and large estates had been common, land reform had much larger effects. However, it often failed to have the intended effects because of incompetence and corruption on the part of PA officers.

In 1976, the former regime established the Agricultural Marketing Corporation (AMC), while sharply curtailing the activities of private traders. AMC sets quotas for staple crops to be delivered to the government at fixed prices, often significantly below prices prevailing on local parallel markets and in neighboring countries, encouraging widespread smuggling. AMC prices have also tended to lag behind agricultural input prices, especially fertilizer. During 1987–88, AMC purchased about 30–40% of the country's marketed surplus of grain. The regime also established the Agricultural Input Marketing Corporation (AIMCO). AIMCO has monopoly power over the distribution of fertilizers and agricultural chemicals, which it sells at a fixed price. Over half of all fertilizer has gone to the large state farms, with small peasant farms receiving the remainder. Credit is channeled to PAs from AMC and the government's Agricultural Industrial Development Bank (AIDB). However, peasant farms have only received about 15% of AIDB credit, with the rest going to state farms.

2. Objectives

Significant productivity improvements in Ethiopian agriculture, and thus the economic wellbeing of the country's 42 million peasants, hinge in large measure on new techniques. Thus the objective of this article is to examine the characteristics of, and choices among, production technologies in Ethiopian agriculture. This subject has received little empirical attention in the literature, notwithstanding Ethiopia's tremendous food problems. There are few published, empirical studies of production, except for Robinson and Yamazaki (1986); supply response, except for Weaver and Shire (1988); or technology adoption, except for Aklilu (1980) and Kebede et al. (1990).

In studying production technologies, the dominant approach in economics has been to identify technology with a production function and technological change with shifts in the production function (see, e.g., Chambers, 1988; or Antle and Capalbo, 1988). Typically, the shifts are factor-augmenting, so that doubling the productivity of an input has the same effect on output as doubling the quantity of that input. [2] In this framework, the production function changes over time, but at any given point in time there is only one production function.

However, as Mundlak (1988a,b) observes, this framework cannot come to grips with the fact that many different agricultural production functions can and do coexist at the same point in time. In general, there may be as many production functions as there are farms, or even more if a farm uses different techniques on its different plots of land. One would expect a farm's choice among production technologies to depend on state variables such as soil and other natural resources, climate, relative input prices (to the extent that inputs are used in different proportions in different production functions), and endowments of fixed or quasi-fixed inputs, including publicly supplied inputs such as infrastructure. If access to new technologies is constrained by the government, as it has been for peasant farms in Ethiopia, then the farm's choice also depends on political-economic variables that influence government allocation decisions. In any case, what is observed in empirical work is not 'the' production function but rather the envelope of implemented technologies. Following Hayami and Ruttan (1985), this envelope is well-known as the meta-production function.

From an econometric point of view, identifying production technologies is impossible unless (1) there are fewer production technologies than there are observations, and one can assign each observation to a specific technology; or (2) the meta-production function varies systematically with the technologies used, which in turn vary systematically with the state variables listed above. The preferred option is (1), since it permits one to clearly distinguish the production function associated with each technology. However, when working with aggregate data, in which inputs and outputs are not differentiated by techniques, (2) is the only realistic option, and it is the one employed by Hayami–Ruttan (1985) and Mundlak (1988a,b).

Production technologies in Ethiopia vary considerably within the North, Central and South regions on the basis of many characteristics. However, one critical characteristic in the North and Central is fertilizer. As the figures above imply, fertilizer is the only modern input currently being used on peasant farms to any significant degree. As is well known, the use of fertilizer is associated with a variety of changes in production practices. Fertilizer is mainly a substitute for land rather than other inputs such as labor or capital (Hayami and Ruttan, 1985). As such, it increases land productivity both absolutely and relative to the productivity of labor or capital. Fertilizer is a complement to other inputs such as high-yielding varieties and water (whether provided by rainfall or irrigation). As a result, these inputs often tend to be adopted as part of a single package rather than individually (Hayami and Ruttan, 1985). Fertilizer may also be a complement to labor, since weeding requirements typically increase significantly when fertilizer is used. In addition, fertilizer may be a complement to management skills, since improved husbandry practices are often critical to realizing higher yields (Norman, 1985). For example, optimal crop rotations and intercropping patterns often change significantly when fertilizer is used (Mokwunye and Vlek, 1985; Kang, 1986).

This study uses farm-level data from a 1989–90 survey in Ethiopia to estimate production functions for the Northwest, Central and South regions. [3] The potential importance of fertilizer suggests that approach (1) above can be feasibly implemented within the Ethiopian context, with there being two technologies that depend on fertilizer use. Accordingly, in the Northeast and Central, separate production functions are estimated for farms that use fertilizer and for those that do not. In the South, where hardly any peasant farms use fertilizer, a single production function is estimated. Of course, a farm's decision regarding the technology to employ is not given, but instead is a function of the state variables listed above (soils, climate, input prices, political-economic characteristics). Therefore, the decision whether or not to use fertilizer is treated as endogenous. A switching regression model (Maddala, 1983) is constructed in which farms are selected into one of the two technologies based on a choice function for fertilizer usage.

3. Modelling technology choice

Following Hayami–Ruttan (1985) and Mundlak (1988a,b), consider a farmer choosing between two technologies, labeled traditional (0) and modern (1). Compared to the traditional technology, the modern technology is assumed for expositional purposes to be more intensive in the use of capital. However, any input could be chosen to illustrate the line of reasoning here. The unit isoquants for the two technologies ($Y_0 = 1$, $Y_1 = 1$) are shown in Fig. 1. The choice between technologies depends on the ratio (p) of the price of other inputs to the rental rate on capital. When p is low, the traditional technology

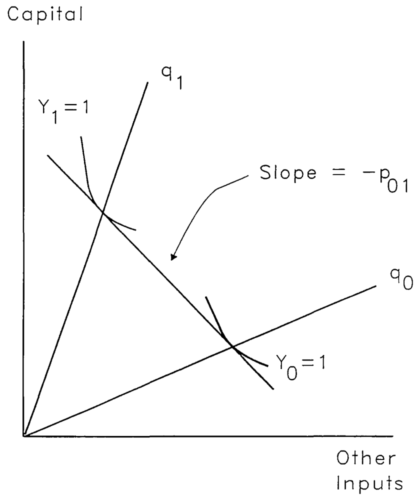

Fig. 1. Choice of technologies.

is used because it has a lower cost of production. Conversely, when p is relatively high, the capital-intensive modern technology is used. Under some weak assumptions about the behavior of the isoquants, there exists a value p_{01} at which the cost of production for the two technologies is the same. At p_{01}, the farm is indifferent as to the choice of technology, and so could use either or both.

Associated with p_{01} are two ratios (q) of capital/other inputs for the two technologies, q_0 and q_1. If we observe a low input ratio ($q < q_0$), then we should also observe that only the traditional technology is used. On the other hand, if we observe a high input ratio ($q > q_1$), we should also observe that only the modern technology is used. Medium values ($q_0 \leq q \leq q_1$) would be consistent with the use of either or both technologies. This relationship between technologies and input ratios is important in a country such as Ethiopia, where factor markets in agriculture are limited. In this context, prices for many inputs are typically unobservable shadow prices, so that testable predictions about technology choice must revolve around observable input quantities.

To empirically implement this model, suppose that the tth farm has some unobservable indicator h_t^* of its propensity to adopt the modern technology. This indicator depends on a vector $\boldsymbol{x}_t$

of input quantities, a vector z_t of other state variables, a parameter vector $\boldsymbol{\beta}$ common to all farms, and a normally distributed random error ϵ_t with zero mean and unit variance: [4]

$$h_t^* = f(\boldsymbol{x}_t, \boldsymbol{z}_t, \boldsymbol{\beta}) + \epsilon_t \quad (1)$$

In contrast to the model above, assume that the farm cannot use both technologies. Since the farm is indifferent between technologies in the case where both are used, this assumption should not cause too much of a problem. The observed counterpart to h_t^* is then h_t, which is zero if the farm uses the traditional technology and one if the farm uses the modern technology. The decision rule is:

$$h_t = \begin{cases} 0 & h_t^* \leq 0 \\ 1 & h_t^* > 0 \end{cases} \quad (2)$$

There are two production functions available to each farm, depending on whether the traditional or modern technology is employed. Assume that output for the ith production function, y_{it} $(i = 0, 1)$, depends on inputs $\boldsymbol{x}_t$, other state variables $\boldsymbol{z}_t$, a parameter vector θ_i that is technology-specific but common to all farms, and a normally distributed random error e_{it} with zero mean and finite variance:

$$y_{it} = g(\boldsymbol{x}_t, \boldsymbol{z}_t, \theta_i, e_{it}) \quad (3)$$

The output that we actually observe, y_t, depends on the technology used:

$$y_t = \begin{cases} y_{0t} & h_t^* \leq 0 \\ y_{1t} & h_t^* > 0 \end{cases} \quad (4)$$

In short, we have what Maddala (1983) refers to as a switching regression model with endogenous switching. The switching is endogenous in the sense that the error term ϵ_t in the switching equation may be correlated with either or both of the error terms e_{0t} and e_{1t} in the production functions. If these correlations are absent, the model becomes one with exogenous switching. In this case, it can be shown that maximum likelihood estimation of the model as a whole is equivalent to single-equation estimation of the fertilizer model (1)-(2) and the two production functions in (3). Thus, estimating the whole model constitutes an implicit test of an alternative model with separate, unrelated production functions with and without fertilizer.

In fitting the model to the data, we distinguish between 'traditional' and 'modern' technologies on the basis of fertilizer use. As noted above, this is the only new agricultural technique that has been used to any real degree in Ethiopia. We assume that e_{0t}, e_{1t} and ϵ_t have a trivariate normal distribution with correlation coefficients of γ_i between e_{it} and ϵ_t $(i = 0, 1)$, and γ_{01} between e_{0t} and e_{1t}. While the γ_i can be estimated, γ_{01} cannot. The reason is that no one is observed using both production functions, so that there is no information on which to base an estimate of γ_{01}. [5]

In estimating the model, we also assume that the fertilizer use equation (1) is linear in the parameters. In addition, we assume that the production functions (3) are CES:

$$\log(y_{it}) = \alpha_{i0} + \sum_j \alpha_{ij} z_{jt} + [\rho_i \sigma_i / (\sigma_i - 1)] \times \log\left[\sum_k a_{ik} x_{kt}^{(\sigma_i - 1)/\sigma_i}\right] + e_{it} \quad (5)$$

where σ_i is the Allen elasticity of substitution, ρ_i is the returns-to-scale parameter, and the a_{ik} are distributive shares satisfying $\Sigma_k a_{ik} = 1$. The CES is more general than the Cobb-Douglas while at the same time does not impose too many demands on the data. Attempts to estimate more complex functional forms proved unsatisfactory, since most parameter estimates were not statistically significant. Flexible functional forms (such as the translog) are commonly estimated in the literature using factor demand equations derived from the cost function. However, since the cost function depends on input prices, this procedure presumes that markets exist for inputs, which as explained below is not the case for labor and land in Ethiopia.

4. Data and variables

The data for this study come from surveys of three regions in Ethiopia, the Northwest, Central

Table 1
Summary statistics

Variable (per farm)	Mean (Standard deviation)				
	Northwest		Central		South
	No fertilizer	Fertilizer	No fertilizer	Fertilizer	No fertilizer
Output (Birr)	500 (413)	776 (754)	686 (495)	704 (466)	685 (2326)
Equipment (number)	7.9 (2.8)	9.9 (3.8)	10.0 (3.8)	11.2 (4.3)	3.7 (2.0)
Cattle (number)	3.2 (2.3)	4.4 (3.9)	3.4 (1.9)	4.7 (2.2)	3.6 (3.6)
Land (ha)	1.8 (1.5)	2.4 (2.0)	1.8 (0.9)	2.3 (1.0)	1.8 (2.7)
Rainfall dummies					
Heavy	0.74 (0.44)	0.82 (0.38)	0.05 (0.23)	0.12 (0.33)	0.14 (0.35)
Light	0.11 (0.31)	0.05 (0.23)	0.04 (0.20)	0.03 (0.16)	0.01 (0.11)
Soil dummies					
Fair	0.34 (0.47)	0.37 (0.48)	0.77 (0.42)	0.72 (0.45)	0.43 (0.50)
Poor	0.34 (0.48)	0.24 (0.43)	0.17 (0.38)	0.25 (0.44)	0.09 (0.28)
Sample size	194	337	447	396	481

The official exchange rate during 1989–90 was 2.07 Birr per U.S. dollar, while the parallel market rate was around 6–7.

and South. The surveys in the Northwest and South were conducted in April–May 1989, while the one in the Central was conducted in March 1990. At that time, the country was divided into 14 administrative regions, with two in the Northwest, two in the Northeast, two in the Central, and eight in the South. [6] Within each administrative region, there were several districts, and then within the districts villages. Households were selected according to the following procedure. Within each administrative region a district was randomly selected. Within each district, a village was chosen on the basis of stratified random sampling with probability proportional to size. Within each chosen village, all households willing to respond were interviewed. This yielded sample sizes of 801 for the Northwest, 1012 for the Central, and 865 for the South.

The analyses below are based on subsamples that are smaller than the original samples, mainly owing to the removal of observations with missing values. We also removed observations in which output, equipment, cattle, or land was zero. [7] This reduced the samples to 531 in the Northwest, 843 in the Central, and 481 in the South. The total population of Ethiopia during 1989–90 was about 49 million, of whom about 42–43 million lived in rural areas. Assuming a mean rural household size of five, there were about 8.5 million rural households at the time of the survey. Our three subsamples, which contain 1855 rural households, thus constitute approximately 0.02% of the total.

Summary statistics for the subsamples are shown in Tables 1 and 2. All outputs and inputs are on a per-farm basis. About 63% of the farms in the Northwest used fertilizer, compared with about 47% in the Central. None of the farms in the South in our sample used fertilizer. For the sample as a whole, about 40% of the farms used fertilizer, a figure significantly greater than for the country as whole, where it is no more than 15% (Pickett, 1991).

Agricultural output is measured as the gross

Table 2
Differences between farms with and without fertilizer

Variable	Difference (Absolute z-score)	
	Northwest	Central
Output (Birr)	277 (5.5) *	18 (0.5)
Equipment (number)	2.0 (7.0) *	1.2 (4.1) *
Cattle (number)	1.2 (4.6) *	1.3 (9.1) *
Land (ha)	0.6 (4.0) *	0.5 (7.4) *
Rainfall dummies		
Heavy	0.09 (2.3) *	0.07 (3.4) *
Light	−0.05 (2.1) *	−0.01 (1.0)
Soil dummies		
Fair	0.03 (0.8)	−0.04 (1.5)
Poor	−0.10 (2.3) *	0.08 (2.8) *

An * denotes significance at the 10% level.

value of crop production during the previous year, with non-marketed production valued at prices received for marketed surplus. Three inputs are included in the production functions: equipment, as measured by the number of implements; the number of cattle owned (data were not available on the number of draft animals); and the amount of land cultivated. [8] The logs of the inputs are included in the fertilizer usage equation.

Labor is excluded because respondents were not asked about the amount of time they devoted to agricultural production. We tried using family size as proxy (with different weighting schemes for various age/sex groups), but it was not statistically significant in the production functions. One would expect labor time to be correlated with the included inputs, so that their estimated coefficients must be interpreted with this in mind. Were accurate labor data available, the estimates of the distributive shares of the other inputs would fall (for inputs positively correlated with labor) or rise (for inputs negatively correlated with labor). We observed this in preliminary regressions using family size. We also observed that estimates of substitution and scale elasticities were fairly robust to the inclusion or exclusion of family size.

Four state variables are included in the production functions and the fertilizer use equation. Two are dummies for whether the household head thought the rains during the previous year were 'heavy' or 'light', with the control category being 'normal'. The other two are dummies for whether the head thinks the farm's soil is 'fair' or 'poor', with the control category being 'good'. In interpreting the results below, it is important to bear in mind the subjective nature of these variables. We also tried human capital variables (head's education, log of head's age, and the squared log of age), but they did not come close to statistical significance in the single-equation models. The switching regression models could not even be estimated with these variables; the Hessian was not negative definite at the apparent maximum of the log likelihood function. This may have been due to collinearity caused by including the human capital variables in the fertilizer use equation as well as both production functions.

One may ask why output and input prices are not included as state variables in the fertilizer use equation. First, factor markets in agriculture are limited, so that prices for many inputs are unobservable shadow prices. There was never much of a market for land, and the 1975 land reform eliminated it entirely. In addition, the land reform's prohibition on share tenancy was written so as to eliminate markets for hired labor.

Second, as noted above, much of the country's marketed surplus is procured by AMC at uniform prices, while fertilizer is distributed by AIMCO at a uniform price. Third, even the limited amount of spatial price variability that does exist in the country is missing from the data set because of heavy sampling from a small number of villages. An absence of spatial variability makes it impossible to include prices in a cross-section analysis.

It may be noted that fertilizer is not included as a factor of production for the farms that use it. The reason for this is econometric. Because of the potential simultaneity between fertilizer use and output, the predicted level of fertilizer use has to be used in the production function instead of the actual level. This raises an identification problem since the same variables are used in the fertilizer equation as in the production functions. To overcome this, we tried including the human capital variables in the fertilizer equation but not the production functions. [9] Unfortunately, the switching regression models still could not be estimated; once again, the Hessian was not negative definite at the apparent maximum of the log likelihood function. The estimated coefficients for the production function with fertilizer must therefore be interpreted as reflecting the 'average' impact of fertilizer use.

For the regressions below, output and the inputs are standardized by dividing by their respective sample means. The soil and rainfall dummy variables are standardized by subtracting by their respective sample means. This facilitates comparison of the production functions with and without fertilizer. At the sample means, assuming that all other relevant variables are accounted for, the effect of fertilizer on output is measured by the difference between the two production function intercepts. Of course, this must be qualified by

Table 3
Maximum likelihood results

Variable	Northwest			Central			South
	Output without fertilizer	Output with fertilizer	Fertilizer use	Output without fertilizer	Output with fertilizer	Fertilizer use	Output without fertilizer
Intercept	0.75 *	−0.28	0.52 *	0.52 *	0.35 *	0.03	−0.63 *
	(4.0)	(1.6)	(7.9)	(8.8)	(6.1)	(0.7)	(9.5)
Equipment	0.52 *	0.33 *	0.61 *	0.30 *	0.61 *	−0.05	0.38 *
	(6.5)	(4.2)	(4.0)	(5.3)	(6.1)	(0.3)	(3.7)
Cattle	0.15 *	0.03	0.26 *	0.15 *	−0.28 *	0.48 *	0.27 *
	(2.3)	(0.7)	(2.9)	(3.6)	(2.9)	(5.8)	(2.8)
Land	0.33 *	0.64 *	0.12 *	0.55 *	0.67 *	0.39 *	0.35 *
	(5.3)	(7.8)	(1.8)	(10.8)	(7.5)	(4.2)	(3.9)
Rainfall							
Heavy	−0.16	−0.13	0.15	0.26 *	−0.19 *	0.19	0.02
	(0.9)	(1.0)	(0.9)	(1.8)	(1.7)	(1.2)	(0.1)
Light	−0.73 *	−0.19	−0.25	−0.14	−0.40 *	0.03	0.33
	(2.6)	(0.9)	(1.0)	(0.8)	(2.1)	(0.1)	(0.7)
Soil							
Fair	0.05	0.08	−0.01	−0.02	−0.31	-0.02	−0.03
	(0.3)	(0.9)	(0.1)	(0.2)	(1.6)	(0.1)	(0.3)
Poor	0.09	0.22 *	−0.19	−0.25	−0.70 *	0.32	−0.44 *
	(0.5)	(2.1)	(1.3)	(1.5)	(3.4)	(1.4)	(2.4)
Substitution,	1.74 *	∞		0.84 *	3.33		0.61 *
σ	(2.3)			(3.7)	(1.5)		(3.3)
Scale,	1.59 *	1.13 *		1.51 *	0.80 *		0.80 *
ρ	(7.9)	(6.7)		(14.6)	(7.1)		(7.1)
Correlation,	0.88 *	0.21		0.91 *	−0.89 *		
γ	(16.4)	(0.5)		(34.8)	(27.8)		
Predicted vs. actual r^2	0.24	0.40	0.10	0.41	0.36	0.10	0.11

Absolute values of asymptotic t-ratios are in parentheses. An * denotes significance at the 10% level.

the omission of labor and other potentially important variables.

5. Results

Maximum likelihood estimates of the switching regression models for the Northwest and Central are shown in Table 3. Also shown are maximum likelihood estimates of a CES production function for the South. Differences between estimated coefficients for the production functions with and without fertilizer are shown in Table 4. The switching model for the Northwest is estimated under the assumption that the elasticity of substitution for the production function with fertilizer is infinite ($\sigma_1 = \infty$). The reason is that neither the switching model nor even a single-equation production function for farms using fertilizer could be estimated without a restriction on σ_1. In both cases, σ_1 became arbitrarily large as the number of iterations increased, suggesting $\sigma_1 = \infty$ as a reasonable restriction. While some may view this as implausible (and one would not expect this to hold over a wide range of input levels), this is what the data tell us. In any case, the results do not justify imposing some other, simple functional form on the data, such as the Cobb–Douglas. Relative to the apparent maximum likelihood estimate of infinity, a likelihood ratio test rejects the restriction that $\sigma_1 = 1$.

The results reveal that farms with more resources do enjoy advantages in access to fertilizer. The estimated coefficients on cattle and

Table 4
Impacts of fertilizer use

Parameter	Difference (Absolute t-ratio) between production functions with and without fertilizer	
	Northwest	Central
Intercept	−1.04 (4.1) *	−0.17 (1.8) *
Distributive parameters		
Equipment	−0.19 (1.7) *	0.31 (2.4) *
Cattle	−0.12 (1.5)	−0.43 (3.8) *
Land	0.31 (3.0) *	0.12 (1.0)
Elasticity of substitution	∞	2.50 (1.1)
Returns to scale	−0.46 (1.8) *	−0.71 (4.2) *

An * denotes significance at the 10% level.

land are positive and statistically significant in both the Northwest and Central, while the estimate for equipment is positive and significant as well in the Northwest. However, the magnitudes of the effects are quite modest. In the Northwest, at the sample means, the predicted probability of fertilizer use is about 0.65. Other things equal, the addition of one implement (which represents an 11% increase over the sample mean for implements) only raises the probability of fertilizer use by 0.02. Adding one cattle (a 25% increase over the sample mean) only raises the probability of use by 0.03. Adding one hectare of land (a substantial 47% increase over the sample mean) raises the probability of use by a mere 0.02. In the Central, the predicted probability of fertilizer use at the sample means is about 0.47. Adding one implement (a 9% increase) has virtually no effect on the probability of use, while adding one cattle (a 25% increase) raises the probability of use by only 0.05. Adding one hectare of land raises the probability of use by 0.07, but one hectare is a 49% increase over the sample mean for land.

The conclusion is that accumulation of capital (equipment, cattle) and land encourages the adoption of fertilizer, but not to a significant degree. Fertilizer use must be explained by other variables, perhaps the political-economic considerations mentioned briefly above. Fertilizer allocation decisions under the Mengistu regime were highly politicized. As noted above, state farms received over half of all fertilizer; even among peasant farms, political considerations often took priority. What is interesting is that the results indicate that farmers with more capital or land were not politically favored. This is especially true for cattle, a principal measure of wealth and thus social status in rural Ethiopia. It may be noted that Kebede et al. (1990) also had a very hard time explaining fertilizer adoption. Aklilu (1980) had more success, but his study concerned farmers participating in a government program that in effect removed political constraints to fertilizer adoption, leaving only the economic constraints.

Consider now the characteristics of the production functions with and without fertilizer. The distributive shares are of interest because they indicate the distribution of income among factors on farms with and without fertilizer. It can readily be shown that, at the sample means, the distributive share for each input is equal to its share of total cost. [10] The effect of fertilizer use on equipment's distributive share is unclear. The difference between farms with and without fertilizer is negative and statistically significant in the Northwest, but is positive and significant in the Central.

The impacts of fertilizer use on shares for cattle and land are clearer. The difference in cattle's share with and without fertilizer is negative in both the Northwest and Central, with it statistically significant as well in the Central. The difference in land's share with and without fertilizer is positive in both regions, with it statistically significant as well in the Northwest. At first glance, this would appear to contradict the hypothesis that fertilizer is mainly a substitute for land. However, to the extent that fertilizer increases output, it also increases the derived demand for all factors of production, including land. Since the supply of land is probably inelastic relative to the supply of other inputs, the result should be a relatively large increase in the (shadow) price of land. If the increase in the price of land is large enough, land's share will rise. [11]

The estimated share for cattle is actually negative and statistically significant for farms with fertilizer in the Central. This may be related to the omission of labor from the production function. Cattle is the major store of wealth in rural Ethiopia. Cattle provide draft power, transportation, manure for fuel, and milk. To a lesser extent, they provide meat and a form of insurance against crop failure. An increase in the number of cattle may have a significant income effect on the demand for leisure, causing farm labor to decline by so much that output decreases. As noted above, however, we found in preliminary work that estimates of substitution and scale elasticities were fairly robust to the inclusion or exclusion of a crude labor measure, family size.

Since cattle are the major store of wealth, the cattle variable is likely to be positively correlated with household credit availability and, in turn, usage of purchased inputs not included in our production function. However, as indicated above, this effect is very small for fertilizer. Since other modern inputs (HYVs, herbicides, etc.) are used to an ever lesser extent than fertilizer, our results should not be biased much by the exclusion of these inputs.

With the exception of farms in the Central that use fertilizer, estimates of the other substitution elasticities are all statistically significant (at the 10% level). However, the estimates of σ in the Northwest and Central for farms without fertilizer are not statistically different from one. The elasticity of substitution might be greater for farms with fertilizer than for farms without it, but this difference is presumed for the Northwest and not statistically significant in the Central. Only in the South is σ statistically different from both zero and one. The low σ for the South (about 0.6) could be explained by the large share of acreage devoted to perennials such as coffee and ensete. [12] Given sufficient time, substitution possibilities between land and non-land inputs may (or may not) be large, but in any given year the possibilities are limited by acreage planted with perennials in previous years.

A null hypothesis of constant returns to scale ($\rho = 1$) can be rejected at the 10% level for farms in the Central that use fertilizer and in the South. In each case, $\rho \approx 0.8$. Constant returns to scale can also be rejected for farms in the Northwest and Central without fertilizer. However, for these farms, ρ is substantially greater than one (about 1.5–1.6) and statistically greater than the corresponding ρ for farms using fertilizer. Given that farms in the Northwest and Central using fertilizer exhibit diminishing or constant returns to scale, there is no strong reason to believe that increasing returns are an inherent feature of the production process. Instead, the results may suggest that farms without fertilizer are too small to be in the region of input values where constant or diminishing returns prevail. It may be noted that the differences in Table 2 in equipment, cattle and land between farms with and without fertilizer are all positive and statistically significant.

On the other hand, there is a long literature on how the exclusion of inputs such as management skills conditions may cause scale economies to be overestimated (Kislev and Peterson, 1994; Hoch, 1976). Excluding inputs will cause total inputs to be underestimated on all farms, large and small. However, if management is a complement to other inputs, then total inputs (included and excluded) will be underestimated to an even greater extent on large farms than small farms. This will lead to the false impression that large farms are relatively more efficient. The problem with this argument in the present context is that it should be even more applicable to farms with fertilizer than ones without it, since those using fertilizer tend to be larger. And yet there is no evidence of scale economies on farms with fertilizer.

Why would scale economies ever exist as more than a transitory phenomenon? If there were free markets in inputs, especially land, one would expect some farms to exploit scale economies by buying out their neighbors and expanding to the point where constant returns prevail. Under the land reforms of the deposed Marxist regime, however, this was not permitted. The age-old kinship system of land allocation has also contributed to small farm sizes by dividing up each village's land among an ever-increasing number of male village descendants.

As noted above, the impact of fertilizer on output at the sample means is measured by the difference in intercepts for the production functions with and without fertilizer, assuming there are no omitted, confounding variables. As Table 4 indicates, the difference is actually negative and statistically significant in both the Northwest and Central. However, this may reflect omitted agro-climatic factors that are negatively correlated with output when fertilizer is used but positively correlated with fertilizer use. It may also reflect omitted factors positively associated with both fertilizer use and output without fertilizer. In the Central, the correlation coefficient between the error terms in the fertilizer equation and the production function with fertilizer (γ_1) is negative (-0.89) and statistically significant. At the same time, γ_0 is positive and statistically significant in both the Northwest (0.88) and Central (0.91).

In this regard, one should remember the subjective nature of the soil and rainfall variables. These variables are generally not statistically significant in either the production functions or the fertilizer equations. There is one anomaly: Poor soils appear to increase production with fertilizer in the Northwest. Perhaps people in the Northwest, who are mostly Orthodox Christians with little political clout, lied about soil quality in hopes of getting better land. People in the Central and South, who are closer to Addis Ababa and better connected politically, may have felt less of a need to lie about soil quality. In any event, this variable is statistically significant and does seem to be measuring something, if not soil quality.

6. Conclusions

The objective of this article was to examine the characteristics of, and choices among, production technologies in Ethiopian agriculture. We considered the choice made by farmers among two techniques in northwest and central Ethiopia, one with fertilizer and the other without, and estimated production functions for each technique. In southern Ethiopia, where fertilizer is rarely used, we estimated a common production function for all farms. This study is unique in its use of recent, farm-level data from Ethiopia, a country that has suffered more from famine and malnutrition than perhaps any other in the last decade.

Three conclusions emerge from this study. First, the use of fertilizer in northwest and central Ethiopia does not depend on farm resources (capital and land) to any significant degree. This is consistent with the fact that fertilizer allocation decisions were largely taken out of the hands of farmers and made subject to political considerations under the Mengistu regime. The implication is that freer markets in fertilizer should be a priority for the new government. Second, fertilizer is associated with a smaller factor share for cattle and a larger share for land. This means that those who control land (PA officers and other village leaders) may gain relative to the individual farmers who own cattle as the country develops agriculturally. Pickett (1991) argues that distributive issues are unimportant in a country such as Ethiopia, where the 'pie' is so small that concerns about its division pale in comparison to the need to make it bigger. This is undoubtedly true, but experience in many poor countries has shown that distributive issues do matter politically.

Third, a large proportion of farms in northwest and central Ethiopia (those not using fertilizer) are too small. This is evidenced by the fact that their levels of land and other inputs are so low that they are still in the region of increasing returns to scale. The root of the problem may be intense population pressures on the land. In this regard, it should be noted that Ethiopia's population was relatively small until the 1950s and 1960s, when successful malaria and smallpox eradication programs led to a large decline in mortality. Thus, it remains to be seen whether land distribution institutions in Ethiopia will eventually adjust to the changed environment by allocating land to a smaller but more economically viable number of farmers.

7. Notes

[1] This section draws heavily on Belete et al. (1991), Cohen and Isaksson (1988), Dejene (1987),

Franzel et al. (1989), Gryseels and Anderson (1983), McCann (1988), Nelson and Kaplan (1981), Pickett (1991) and Webb et al. (1992).

[2] T.W. Schultz (1964, p. 132), in an important but often forgotten critique, stated: "But what is all too seldom recognized... is that the term 'technological change' is merely a bit of shorthand for an array of (new) factors of production that have been omitted in the specification of factors... A technology is always embodied in particular factors and, therefore, in order to introduce a new technology it is necessary to employ a set of factors of production that differs from the set formerly employed."

[3] The civil war at the time of the survey precluded any work in the Northeast part of the country.

[4] The unit variance assumption is made because $f(\boldsymbol{x}_t, z_t, \boldsymbol{\beta})$ in Eq. (1) can be estimated only up to a scale factor.

[5] Of course, a farm may use fertilizer on some plots and no fertilizer on others. However, within the context of our study, where we have farm-level data rather than plot-level data, our statement is correct.

[6] The country was later redivided into 29 administrative regions.

[7] Removing households with no output or land makes sense, since they are not really farm households. However, removing ones with no equipment or cattle deserves some justification. Ideally, one would treat the choice of equipment and cattle use in the same way that we treat the choice of fertilizer use. This was precluded by the small number of farms not using these two inputs and by the desire to keep the model econometrically tractable. Thus we thought it best just to remove these observations.

[8] Respondents were asked how many days it would take a man to plow their land using a pair of oxen. The answer is the amount of land in 'timads', which when divided by four is approximately the amount of land in hectares.

[9] Including the human capital variables in the fertilizer equation but not the production functions can be rationalized if human capital: (1) has an allocative effect, including an impact on the ability to allocate fertilizer; and (2) has no worker (or technical efficiency) effect, so that there is no impact on production except through input use.

[10] With the CES production function, the partial output elasticity of an input j is $\text{POE}_j = \rho a_j x_j^{(\sigma-1)/\sigma} / [\Sigma_k a_k x_k^{(\sigma-1)/\sigma}]$. Since $x_k = 1$ for all inputs at the sample means, this reduces to $\text{POE}_j = \rho a_j$. At the same time, the first-order conditions for profit maximization imply $\text{POE}_j = \rho s_j$, where s_j is the factor share for input j. Thus $a_j = s_j$ at the sample means.

[11] Land's share is $s_L = w_L x_L / C$, where w_L is the price of land, x_L is the quantity, and C is total cost. Let p be the output price and Y be output. Then, since $C = \rho p Y$, $s_L = w_L x_L / (\rho p Y) = (1/\rho)(w_L/p)/(Y/x_L)$. Because fertilizer substitutes for land, yield increases (Y/x_L rises). However, because the supply curve for land is relatively inelastic, the price of land relative to the output price (w_L/p) also rises. If the percentage increase in the relative price of land is greater than the percentage increase in yield, s_L increases.

[12] The importance of perennials in the South also casts serious doubt on measuring output over only the previous year. This is evidenced by the relatively high variation in output among farms in the South, as seen in Table 1, and by the low r^2 shown in Table 3.

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