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Abstract

This study assesses the responsiveness of peasant farmers, and the extent to which empirical estimates and their inferences are sensitive to estimation techniques using farm level survey data from Ethiopia. While non-nested hypotheses tests provide no clear choice among alternative functional forms, the Cobb-Douglas and the quadratic models are preferred to the generalized Leontief and Translog on the basis of statistical performance and consistency with theory. The results indicate that farmers respond only modestly to price incentives. The own-price output supply elasticity is very low and output supply is not responsive to fertilizer prices or the wage rate. Non-price factors are far more important in affecting production and resource use than price incentives. The results are robust to functional forms and to whether the primal or dual approach is used to estimate elasticities. The results underscore the need to strengthen market incentives through effective policies that will improve farmers' access to land and credit, public investment in roads and irrigation.

Outline

I. INTRODUCTION

Agriculture is the single most important sector of the Ethiopian economy, accounting for some 45 per cent of GDP, 90 per cent of total exports, and 80 per cent of employment.[1] The peasant sector, which produces more than 90 per cent of crop output, is characterised by poor and outdated farming technology, acute shortage of purchased inputs particularly fertilizer, poor infrastructure and inefficient marketing systems. Peasant farming is dominated by mixed farming, and is largely subsistence with marketed surplus of only about 15-20 per cent. It is largely rain-fed with only 3 per cent of the land being irrigated. Hence, agricultural output is extremely susceptible to weather conditions, especially the amount and timing of rainfall. In addition, rapid population growth has encouraged continuous cropping and shorter fallow periods, which in turn have resulted in soil degradation for small, fragmented and progressively declining sizes of plots.

These essentially structural problems are compounded by the presence of institutional rigidities and policy constraints. Policies have always been biased against the peasant sector, especially during the 1970s and 1980s due to the complex mix of administrative control on markets and prices, ranging from compulsory delivery of output to controlling the movement of output. These inter-linked factors have contributed to declining productivity and stagnating yields in the peasant sector. Cereal yield, for example, has stagnated at 1.2 tons per hectare between 1980 and 1997. While there are evidently features specific to Ethiopia, this broad picture is applicable to many African economies, and begs the question of what can be done to revitalise the peasant agriculture sector. We examine one aspect of this, how responsive are peasant farmers to prices and what input constraints appear to be binding. We do this by analysing data from a survey of 1154 farm households in 1994.

Since 1992, the government has undertaken reform measures that affect the incentive structure and productivity of the peasant sector. The most important economy-wide policies have been devaluation of the domestic currency and credit policies that withdrew the privileged access of state farms and co-operatives. In addition, direct

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[1] Unless otherwise specified, data and trends reported here are (derived) from various statistical documents of the Central Statistical Authority (CSA) and the Ministry of Economic Development and Co-operation (MeDAC).

(sector-specific) agricultural policies have been adopted that include, among others, early and rapid moves towards deregulating food grains markets[2] and price support for export crops. This was further strengthened by subsequent reforms in agricultural input markets, especially fertilizer. In general, the reform measures of the 1990s mostly focused, directly or indirectly, on 'getting prices right'. It is therefore appropriate to try and determine how responsive farmers are to the resulting price changes.

Fertilizer, the single most important purchased input in terms of increasing yields, has been subjected to confused policy changes with conflicting objectives. On the one hand, price decontrol, input market reforms (to improve supply), and the extension programme (to encourage usage), are intended to increase yields, partly by reducing the effective price to farmers. On the other hand, budgetary concerns motivated the removal of the subsidy, and this increased the effective price. Such policy confusion is not unique to Ethiopia. Farooq *et al* (2001) note the clash between 'output expansion goals' and 'sustainable production' aims in Pakistan. They find that the own-price paddy supply elasticity is quite low, such that 'a support price policy appears to be inadequate', whereas elasticities related to fertilizer were high, concluding that 'fertilizer prices need careful consideration' (Farooq *et al*, 2001: 234). This is equally true of Ethiopia, and we pay particular attention to results for fertilizer inputs.

This paper primarily aims at examining peasant responsiveness to price and non-price factors in Ethiopia using farm-level survey data. A secondary objective of the study is to assess the extent to which empirical estimates and their inferences are sensitive to choice of functional form and to whether or not primal or dual approach is applied. To this end, the analysis is conducted comparing three flexible functional forms, normalized quadratic (NQ), translog (TL) and generalized Leontief (GL), as well as the simpler Cobb-Douglas model (CD). Section 2 provides a very brief overview of the major agricultural policy reforms in Ethiopia in the 1990s, and refers to the results of existing studies of the effects. The theoretical framework is set out in Section 3, distinguishing the primal (production) and dual (profit) approaches used. After a short description of the data (details are in Appendix A), Section 4 discusses the econometric details. Section 5 discusses the criteria for choice of functional form. In section 6, we discuss the

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[2] Deregulation of food grain markets actually started as early as 1989 under a previous government.

elasticities derived from the specification with strongest empirical support. The conclusions are in Section 7, which draws out the policy implications.

II. AGRICULTURAL POLICY AND PERFORMANCE IN ETHIOPIA

With little or no room for extensification, growth of agricultural output in Ethiopia depends on implementing effective yield-increasing measures, particularly the use of fertilizer. Recognising this, the government has, from the outset, placed fertilizer at the centre of its agriculture development strategy. Beginning with the National Fertilizer Policy in 1993, the government has adopted several measures. These include gradual liberalization and deregulation of fertilizer markets and prices, completed in 1998, and elimination of fertilizer subsidies in 1997. Most importantly, a new system of extension programmes was launched in 1994/95.

Following the favourable environment created by these policies, agricultural output has increased. The official assessment of the on-going reform programme is that recovery in agricultural production is mainly due to peasant supply response to price incentives (although there has been little formal testing of this).[3] Nevertheless, how much of this recovery is due to price incentives and how much due to non-price factors is not clear. This is especially pertinent in view of the fact that the growth rate of agricultural output is relatively higher in those years (for example, 1992/93 and 1994/95) of more favourable weather conditions than for drought years such as 1993/94 (when the growth rate was even negative). This is to be expected given the reliance on rain-fed agriculture noted above.

As it is the major purchased input, it is important to account for fertilizer prices and usage in estimating supply response, which the production function approach allows. As mentioned in the introduction, fertilizer policy in the 1990s has been confused and it is not clear what the net effects on prices and usage have been. There is some evidence that fertilizer use increased in the late 1990s, in spite of the elimination of the subsidy, in response to incentive measures, particularly lower retail prices and the recent extension programme (Techane, 1999). However, there are conflicting indications that fertilizer use has not increased. Firstly, this is reflected by the sizeable stock of unsold fertilizer every year. For instance, only about 59 and 64 per cent of the fertilizer made available for sale was sold in 1996 and 1997 respectively (Mulat and Techane, 1999). Secondly, sustainable use of fertilizer can be hampered by rising prices due to the devaluation of the Birr, high local transport costs and the elimination of subsidies.

In spite of a decreasing trend in international prices of fertilizer, farm-gate prices have not decreased proportionately because of continuous devaluation of the Birr and high local transport costs (partly due to high fuel prices), especially during the rainy season. International prices of Urea and DAP fell by 62 and 19 per cent respectively between 1996 and 1999, but retail prices of DAP increased over the same period (Techane, 1999). Prices of fertilizer in Ethiopia are relatively high compared to other developing countries (Mulat, 1995).[4] Although, at the national level, the volume of fertilizer used has been rising in recent years, the level of application at the farm level has not grown proportionally. The total amount of fertilizer used by peasant farmers increased by about 200 per cent during 1991-1996, whereas usage per hectare increased by only 50 per cent.[5] On the other hand, the number of farmers using fertilizer has increased from about 10 per cent in the 1980s to about 35 per cent in recent years.

Ambiguities abound about the precise role and impact of agricultural policies (Farooq *et al*, 2001). Partly this is attributable to a lack of farm-level analysis of the effects of policies (especially relating to prices) on the supply response of peasant farmers. The few supply response studies that have been carried out for Ethiopia used aggregate time series data, and focus on the effects of economy-wide policies on export supply response, particularly coffee (e.g. Dercon and Lulseged 1994; Alem 1995). Dercon and Lulseged (1994) argue that any increase in official exports resulting from devaluation of the Birr are due to reduced smuggling, implying that there is no production response to increased price incentives. Alem (1996) found a low and insignificant price elasticity of export supply in response to changes in the effective exchange rate. Zerihun (1996) used aggregate time series data to examine relationships between producer prices of food grains and the area of cultivated land, arguing that aggregate food grain production

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3 For more details on the recent reform programmes and their effects see Abrar (2000).

4 In 1993 (well before the removal of subsidies), the farm-gate price of fertilizer was US$300 per ton compared to unsubsidized prices of $205, $226, and $257 in Pakistan, Bangladesh and India respectively.

5 Average fertilizer application range from as low as 10 to 50 Kg per hectare, considerably lower than the recommended rate of 150 to 200 kg.

changes only slightly following price incentive measures. Yao (1996) addresses similar concerns to this paper but uses aggregate time series data.

Micro-economic studies of supply response are few in Sub-Saharan Africa given the lack of farm level data, but there are recent examples (e.g. Savadogo, *et al*, 1995; Hattink, *et al*, 1998). A common feature of these studies is that a single function form and the hypotheses of profit maximization are often maintained without *a priori* empirical testing. In Ethiopia, several micro-economic studies of resource use efficiency have shown that the potential for efficiency and productivity gains in peasant agriculture is immense (e.g., Abrar, 1996; Abbay and Assefa, 1996; Croppenstedt and Mulat, 1997). Nearly all of these studies used only Cobb-Douglas production functions to estimate the level of technical efficiency[6], and only provide supply elasticities for changes in physical inputs, ignoring the role of prices on the production and input allocation decisions of farmers. The key non-price factors that condition farmers' response, such as rainfall and infrastructure, are rarely taken into account.

The estimated responsiveness of farmers to policy changes, and the policy inferences based on this, is in general sensitive to the econometric model used, including whether or not production or profit function approaches are used. It is desirable to use information from both production and profit functions, and compare these with relationships suggested by duality theory, particularly in the case of cross-section studies using price data (Quiggin and Bui-Lan, 1984). Very little work has been done on empirical testing of duality relationships by comparing elasticities of the production and profit functions (but see Burgess, 1975; Flinn *et al* 1982).

III. MODELLING FRAMEWORK

Studies of production relationships can be carried out in either of two equivalent approaches: Primal or Dual. Suppose that the production transformation set is represented by:

$$F(\mathbf{y}, \mathbf{x}; \mathbf{z}) = 0 \qquad (1)$$

where $\mathbf{y}$ represents the vector of m outputs; $\mathbf{x}$ represents the vector of n variable inputs; and $\mathbf{z}$ represents the vector of k fixed inputs and other exogenous factors. In the

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[6] Abbay and Assefa (1996) is the only exception. They estimated Cobb-Douglas profit function to examine the impact of education on allocative efficiency of peasant farmers in Ethiopia.

literature, the term primal has been used to refer to an optimisation problem consisting of a behavioral assumption (e.g. maximise profit) and a set of constraints (e.g. the production function). From a differentiable form of this specification, output supply and/or input demand equations can in principle be derived by solving the first order conditions (Shumway, 1995). In the dual approach, the production technology set is not estimated directly. Instead, profit or cost or revenue functions are used to study the production behaviour of firms. That is, with competitive behaviour and regular technology, there is a one-to-one relationship between the technology and its dual transformation, the profit function, and hence it is possible to recover all economically relevant information about the technology using the latter.

Assuming that farmers choose combinations of the variable inputs and outputs that will maximise profit, Lau (1976) has shown that the restricted profit function defined as the excess of total value of output over the costs of variable inputs, can be expressed as:

$$\pi = \pi(\mathbf{p}, \mathbf{w}; \mathbf{z}) \tag{2}$$

where π, $\mathbf{p}$ and $\mathbf{w}$, respectively, represent restricted profit, and vectors of output and input prices. This function depicts the maximum profit the farmer could obtain given prices, availability of fixed factors and the production technology (1). Using Hotelling's Lemma, the profit-maximising level of output supply and input demand functions can be derived from (2), respectively, as:

$$\mathbf{y}_r (\mathbf{p}, \mathbf{w}; \mathbf{z}) = \partial\pi(\mathbf{p}, \mathbf{w}; \mathbf{z})/\partial\mathbf{p}_r, \forall\, r = 1, \ldots, m \tag{3}$$

and

$$-\mathbf{x}_i (\mathbf{p}, \mathbf{w}; \mathbf{z}) = \partial\pi(\mathbf{p}, \mathbf{w}; \mathbf{z})/\partial\mathbf{w}_i, \forall\, i = 1, \ldots, n \tag{4}$$

where r and i index the outputs and variable inputs respectively. In the case of a single output, we can specify a normalised restricted profit function, π^*, defined as the ratio of the restricted profit function to the price of the output. It depicts the maximised value of normalised profits given normalised (relative) prices of the variable inputs, $\mathbf{w}_i^*$, and the quantities of fixed factors, i.e.,

$$\pi^* = \pi^*(\mathbf{w}^*; \mathbf{z}) \tag{5}$$

from which the factor demand equations are derived as:

$$-\mathbf{x}_i (\mathbf{w}^*; \mathbf{z}) = \partial\pi^*(\mathbf{w}^*; \mathbf{z})/\partial\mathbf{w}^*_i, \forall\, i = 1, \ldots, n \tag{6}$$

IV. DATA AND ESTIMATION PROCEDURE

The data we use is the Ethiopian Rural Household Survey (ERHS), a nationally representative survey of rural households conducted during 1994-2000 (we use only data from the first wave, 1994). The survey was undertaken in 15 villages across the country (which include the four largest regions where well over two-thirds of the population live) from which nearly 1500 households are selected randomly.[7] It is believed to represent the diversity of farming systems in the country. The considerable geographic dispersion of the sampled villages on the one hand and large differences in accessibility to input and output markets on the other means that there are large variations in prices faced by different households. This is an important feature of the data as such price variability is essential to estimate supply elasticities from cross-section data.

Two variable purchased inputs, chemical fertilizer and labour, and three fixed inputs, land (total area under crops adjusted for quality), animal power and farm capital, are used to estimate supply response of aggregate crop output. We have also included three 'exogenous' controls - land access, infrastructure, and rainfall. Details of measurement and summary statistics on the variables used are given in Appendix A. The normalized quadratic, translog[8] and generalized Leontief restricted profit functions are, respectively, given by:

$$\Pi^* = \alpha_\circ + \sum_i^2 \alpha_i W_i^* + \sum_k^7 \beta_k Z_k + \frac{1}{2}\left(\sum_i^2 \sum_j^2 \gamma_{ij} W_i^* W_j^* + \sum_k^7 \sum_h^7 \delta_{kh} Z_k Z_h \right) + \sum_i^2 \sum_h^7 \phi_{ih} W_i^* Z_h + DU1 + \varepsilon \ldots\ldots (7)$$

$$\ell n\Pi^* = \alpha_\circ + \sum_i^2 \alpha_i \ell n W_i^* + \sum_k^7 \beta_k \ell n Z_k + \frac{1}{2}\left(\sum_i^2 \sum_j^2 \gamma_{ij} \ell n W_i^* \ell n W_j^* + \sum_k^7 \sum_h^7 \delta_{kh} \ell n Z_k \ell n Z_h \right) + \sum_i^2 \sum_h^7 \phi_{ih} \ell n W_i^* \ell n Z_h + DU1 + \varepsilon \ldots (8)$$

$$\Pi^* = \alpha_\circ + 2\left(\sum_i^2 \alpha_i (W_i^*)^{1/2} + \sum_k^7 \beta_k (Z_k)^{1/2} + \sum_i^2 \sum_j^2 \gamma_{ij} (W_i^* W_j^*)^{1/2} + \sum_k^7 \sum_h^7 \delta_{kh} (Z_k Z_h)^{1/2} + \sum_i^2 \sum_h^7 \phi_{ih} (W_i^* Z_h)^{1/2} \right) + DU1 + \varepsilon \ldots\ldots (9)$$

where, Π^* is the normalised restricted profit; W_i* is the price of input *i*, normalised by output price (*p*), subscript 1 indicates the fertilizer price and subscript 2 the wage rate. Z_k

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[7] The final sample consists of fewer observations (1154 households) than the original as farmers with either cultivated land less than 0.1 hectares, or zero labour or zero output or zero and negative profit are excluded. This procedure excludes one of the villages (Harasaw) altogether as virtually all the farmers did not produce anything in that year. Further observations are excluded through a preliminary analysis of outliers based on the examination of residuals.

is the quantity of fixed input or other exogenous variable *k* (subscripts: 1 for area cultivated, 2 for animal power, 3 for farm capital, 4 for land quality, 5 for land access, 6 for road density, and 7 for rainfall), while *DU1* is a dummy for farming system (1 if in a cereal growing area, 0 otherwise). The α_0, α_i, β_k, γ_{ij}, δ_{kh}, and ϕ_{ih} are parameters to be estimated and ε is an error term with the usual properties. Using Hotelling's Lemma, the corresponding input demand (share) equations are derived as:

$$-X_i = \alpha_i + \sum_j^2 \gamma_{ij} W_j^* + \sum_h^7 \phi_{ih} Z_h + \upsilon_i, i = 1,..2 \text{...}(10)$$

$$-S_i = \alpha_i + \sum_j^2 \gamma_{ij} \ell n W_j^* + \sum_h^7 \phi_{ih} \ell n Z_h + \upsilon_i, i = 1,..2 \text{..}(11)$$

$$-C_i = \alpha_i + \sum_j^2 \gamma_{ij} \left(W_j^*\right)^{1/2} + \sum_h^7 \phi_{ih} \left(Z_h\right)^{1/2} + \upsilon_i, i = 1,..2 \text{..}(12)$$

where X denotes the quantities of variable inputs, S is the share of variable inputs in the total profit, $C_i = X_i \, W_i^{*0.5}$, and ν is the error term. For maximum efficiency, the system of input demand equations and the profit function are estimated simultaneously using iterative Seemingly Unrelated Regression. The parameters of the output supply equation are recovered residually from:

$$Y = \Pi^* + \sum_i^2 W_i^* X_i \qquad (13)$$

where Y is the aggregate output index. In our estimation of the production function, we used a similar structure to the normalized restricted profit function. For brevity, similar notations are used for the parameters. The only difference is that we have variable input quantities instead of normalized variable input prices and aggregate output index instead of normalized restricted profit. For the NQ model, we estimated the first order conditions for variable inputs along with the production function using iterative SUR. For the other three models, we just estimated a single equation production function by OLS. The quadratic functional form is self-dual if there is only one production function and profits are maximized (Lau, 1976; Jegasothy et al, 1990). Thus, the production function consistent with the restricted profit function is also quadratic. The quadratic production function is expressed as:

$$Y = \alpha_{\circ} + \sum_i^2 \alpha_i X_i + \sum_k^7 \beta_k Z_k + \frac{1}{2}\left(\sum_i^2 \sum_j^2 \gamma_{ij} X_i X_j + \sum_k^7 \sum_h^7 \delta_{kh} Z_k Z_h \right) + \sum_i^2 \sum_h^7 \phi_{ih} X_i Z_h + DU1 + \varepsilon \ldots (14)$$

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[8] Note that the Cobb-Douglas model is arrived at by setting all the interaction terms of the translog model to zero.

Following Just *et al* (1983) and Jegasothy *et al* (1990), we estimated the production function simultaneously with the first order conditions. [9] Assuming that second order conditions are satisfied for the relevant constrained profit maximization and also assuming efficiency in production (full allocation of fixed inputs), we derive the system of first order equations (inverse demand functions) of the variable inputs for estimation along with the production function. [10] Rearranging these equations in linear form to facilitate simultaneous solution for the variable input allocations, we have:

$$W_i^* = \alpha_i + \sum_j^2 \gamma_{ij} X_j + \sum_h^7 \phi_{ih} Z_h + \upsilon_i , i = 1,..,2. \tag{15}$$

Theoretically, the primal and dual results from estimation of such a system are equivalent, although in practice they differ in stochastic specification and functional forms. Only a few studies actually estimate the production function along with first-order conditions (e.g., Burgess, 1975; Jegasothy *et al*, 1990; Savadogo *et al*, 1994), and very few compare these results with estimates from the dual approach (e.g., Burgess, 1975 using translog cost function). We are not aware of any empirical study of production relationships which compares estimates from primal and dual approaches using quadratic functional form.

V. CHOICE OF FUNCTIONAL FORM

To determine which functional form best describes the Ethiopian data, we compared the models based on goodness-of-fit and other diagnostic tests, formal non-nested hypothesis tests and conformity to neo-classical assumptions. The goodness-of-fit criteria include: adjusted R-squared, root mean squared error (root MSE), Ramsey RESET test, Akaike information criterion (AIC) and Schwartz information criterion (SC). Diagnostic criteria used are: Cook-Weisberg test for heteroscedasticity, a measure of variance information factor (VIF) for multicollinearity, and Skewness/Kurtosis tests for normality. In comparing non-nested models, traditional discrimination criteria should

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[9] Hausman (2SLS) endogeniety test was carried out to determine the extent of simultaniety in the production function using predicted values. *A priori* we assumed labour and fertilizer to be endogenous, and cannot be rejected. Thus predicted values are accordingly used in these models. The instruments used include: expenditure on other inputs, non-farm income, total number of crops intercropped, age, non-food expenditure, real prices of fertilizer and labour, and some of the exogenous variables included in the production function.

[10] The maximization problem is essentially a short-run constrained maximization, but since we are assuming that fixed inputs are fully allocated, the lambda equations in the Lagrangian and thus the first order conditions for the fixed inputs will become identities. If some equations do not have stochastic disturbances, they may be treated as identity equations and not incorporated in the ultimate estimation procedure (Just *et al*, 1983).

be accompanied by appropriate hypothesis tests (Doran, 1993).[11] We conducted two regression based tests, known as J and JA, derived from the basic Cox principle, to choose among the three flexible forms.

The profit function needs to be compatible with the theoretical requirements of homogeneity, symmetry, monotonicity and convexity. Homogeniety is maintained in all estimation by normalizing by the price of output, and hence cannot be tested. We first conducted a test for symmetry globally, subject to homogeniety. The null hypothesis is that the parameters of the input demand equations are equal to the corresponding parameters of the profit function. For example, for the NQ profit model, the following restrictions hold:

$$\alpha_i(-X_i) = \alpha_i(\Pi^*) \qquad (16)$$

$$\gamma_{ij}(-X_i) = \gamma_{ij}(\Pi^*) \qquad (17)$$

$$\phi_{ih}(-X_i) = \phi_{ih}(\Pi^*) \qquad (18)$$

where i,j=1,…,2 ($i{\neq}j$); h=1,…7. This is a joint hypothesis on the validity of imposing 20 restrictions in estimating the input demand and the profit functions jointly. We also tested symmetry individually. A Wald test is carried out for this purpose, and it is asymptotically distributed as chi-square with the number of degrees of freedom equal to the number of restrictions imposed by the null hypothesis. Then we checked for monotonicity and convexity after estimation. Monotonicity requires that the fitted values of the input demand equations are negative. We checked for monotonicity both locally (at data mean points) and globally (counting individual observations). Convexity is checked by looking at the signs of the estimated input demand equations and the Hessian of the profit function. The necessary condition for convexity is that all terms on the leading diagonal of the Hessian of normalized prices be positive, or alternatively the own-price elasticities should have the expected signs. The sufficient condition is that this Hessian must be positive definite.

Goodness-of-fit and other diagnostic tests:

These are the first set of criteria we used to compare the models and the results are reported in Table 1. In general, given that we have cross-section data, all models have

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[11] If a model can not be expressed as a special case of another model by parameter restrictions, the models are said to be non-nested. The three flexible forms are non-nested in this sense, while the Cobb-Douglas is nested in the translog model.

achieved a reasonably good explanatory power. Regarding goodness-of-fit, the NQ and GL models have very similar values for most of the statistics for both the profit and production functions. Surprisingly, both have exactly equal values of R-squared on the dual side (0.71). Based on R-squared, the NQ and the GL are superior to the TL on both the primal and dual sides.

Based on the R-squared, the TL appears to perform better than the CD, but the two information criteria lead to conflicting results. A formal test of the CD hypothesis was conducted using the TL model and it was barely rejected on the primal side, whereas it cannot be rejected when it was tested using the profit function. Therefore, in light of the substantial difference in the number of variables between the two models, the higher value of the R-squared for TL (0.68, as opposed to 0.62 for the CD) can be considered marginal. Hence the superiority of the TL over the CD cannot be assumed. The results suggest that, depending on the purpose of the study, one can use the simpler CD form.

Table 1 Goodness-of-fit and Other Diagnostic Statistics[1]

	Goodness-of-fit Criteria						**Other Diagnostic Criteria**		
Model	Adj R^2 (F-value)^2	Sig. Par. 5%(1%)^3	MSE^4	Ramsey^5	Akaike	Schwarz	Heter.^{6}	Mean VIF	Normaliy^7
Dual									
NQ	0.71(52.7)	29(22)	448.6	20.8	12.3	12.5	787.1	32.6	1.0
GL	0.71(52.7)	24(17)	448.6	25.8	12.3	12.5	954.9	63.6	3.2
TL	0.68(44.7)	18(10)	0.7	7.3	-0.6	-0.4	55.8	150.0	18.0
CD	0.62(190.4)	9(9)	0.8	2.6	-0.5	-0.5	38.1	1.7	7.7
Primal									
NQ	0.74(59.6)	17(14)	456.7	16.1	12.3	12.5	663.1	23.9	1.4
GL	0.73(56.8)	9(7)	464.9	36.0	12.3	12.6	756.7	44.5	3.4
TL	0.72(53.8)	13(8)	0.7	6.4	-0.8	-0.6	62.3	127.2	11.9
CD	0.65(213.1)	10(10)	0.7	0.2	-0.7	-0.6	28.3	1.5	5.8

1. Based on single equation OLS estimates except for the number of significant variables (dual side) which is from the final SUR estimates.
2. F-values in brackets are the standard F-statistcs for joint significance of the explanatory vaiables with k and N-1-k for the numerator and denominator respectively and N and k are number of observations and number of explanatory variables respectively. All models are highly significant at all levels.
3. There are 55 explanatory variables in both the profit and production functions in all the three models, and they have 10 for the fertilizer and labour demand equations on both sides. Note that the CD has only 10 variables.
4. The square root of residual mean square.
5. Ramsey RESET (omitted variable) test using powers of the fitted values of the independent variable. This is an F-test with 3 and [(N-1-k)-3] degrees of freedom for numerator and denominator respectively. Critical values are 2.6(3.78) at 5%(1%) levels.
6. Cook-Weisberg test for heteroscedasticity using fitted values of the dependent variable which is distributed as chi-squared (1).
7. Univariate Skewness/Kurtosis test for normality (D'Agostino *et al*, 1990) of the distribution of the residuals which is distributed as chi-squared (2).

In terms of the number of significant parameters, there is a clear superiority of the NQ model over the TL and GL. On the dual side, just over one-half (53%) of the parameters of the NQ model are significant at 5%. The comparative figures for GL and TL are, respectively, 40% and one-third. Besides, about 40% of the parameters of the NQ model are significant at 1%, while only 31% and 18% of the parameters of the GL and TL, respectively, are significant at 1%. On the primal side as well, the NQ model has generated far more significant parameters than the other two flexible forms. Nearly all parameters of the CD model are significant at 1%.

Regarding multicollinearity, the NQ model is the most preferred of the three flexible forms (with a VIF of only 32.63), while the TL is the least preferred (with a VIF of 149.98, more than twice and about five times as much as that of the GL and NQ models, respectively). As a result of including the profit function in the estimation, we would normally expect high multicollinearity. Thus, the NQ appears to be the most preferable of the three as it rendered such a large number of significant parameters along with relatively low multicollinearity under the circumstances.

Overall, there is very little difference in the test statistics of the primal and dual side although the former seems to be slightly better in terms of adjusted R-squared and multicollinearity. A small difference in the adjusted R-squared of the production and profit functions is to be expected as they have different dependent variables. However, the dual specification seems to be superior in providing more precise (and low standard error) parameter estimates because it has produced a much larger number of significant parameters.

Non-nested Specification tests:

The non-nested hypotheses tests are formulated along the lines of Doran (1993), and the test statistics and associated t-values are reported in Table 2. On the dual side, the J-test results do not discriminate among the three models. The JA-test results however accept the NQ profit function at 5% against the GL. Therefore, with both the J- and JA-tests, no model is accepted at 10% against the alternatives when it comes to the profit function. The picture is more or less the same on the primal side. Here, the NQ production function is accepted against the GL at 10%. The TL production function is also accepted against both NQ and GL at 10%. But, like in the dual case, the J-tests do not discriminate among the models. The only common result from both the dual and primal side is that the NQ model is accepted with the JA-test at 5% (dual) and 10% (primal). Unfortunately, lack of conclusive evidence from tests of non-nested hypotheses is very common in the literature (e.g., Frank *et al*, 1990; Doran, 1993; Hall, 1998).

Table 2 Non-nested Hypotheses Tests

Null Hypothesis	**Alternative Hypothesis**					
	Dual			**Primal**		
	NQ	**GL**	**TL**	**NQ**	**GL**	**TL**
GL	5.74	--------	24.51	8.48	------	26.46
	3.09	--------	-5.30	2.22	------	-6.83
NQ	--------	5.87	23.98	------	3.69	25.96
	--------	1.79**	-5.01	-----	-0.58*	-5.00
TL	24.74	24.62	------	26.72	26.66	-------
	-2.45	-3.06	------	-0.04*	-0.20*	-------

Notes: The upper number is J-statistic and the lower number is JA-statistics (both of which are t-values).
No asteriks, two asteriks and single asteriks indicate significance at 1%, 5% and 10% respectively.

Regularity tests

The first check on consistency of the results with theory is to see if the own price parameters have expected signs (see Appendix C). The NQ model has not only generated the correct signs for fertilizer and labour demand own prices, they are also significant at 1%. This is so even before any of the symmetry restrictions are imposed, and this is the case for both the primal and dual sides (the only exception is the parameter for own price of fertilizer on the primal side which, though having the right sign, is statistically insignificant). The CD model also produced correct signs for both the primal and dual sides, all of which are highly significant at 1%. The GL produced unexpected sign for own prices of fertilizer demand (but insignificant), whereas that of labour is correct sign and significant at 1%. Most disturbing is the TL for which the own price parameters have wrong signs, and are also statistically significant at 1% (for fertilizer) and at 5% (for labour). In addition the high significance of most of the own-price parameters may be an indication of sufficient variation in the prices used.

The results of technology tests are reported in Table 3. We first checked only symmetry, and it cannot be rejected for TL (at 1%) and NQ (at 10%), but was rejected for GL. Then we tested for equality (with symmetry implicit) individually, and it was accepted for more than 75% of the cases for all the three flexible forms. A joint test of symmetry was rejected for all models. The majority of dual studies which reported tests for symmetry also rejected the hypothesis (e.g., see Shumway, 1983; Higgins, 1986; Fisher and Wall, 1990; Savadogo *et al*, 1995). Shumway (1995) provide surveys of dual studies that have appeared in agricultural economics journals and find that many of them failed to satisfy theoretical requirements. It needs to be stressed that symmetry is not a behavioural assumption, rather it is a mechanical consequence of applying Young's theorem, and as such asymmetric responses are not contradictory with the hypothesis of profit maximization (Savadogo *et al*, 1995). However, since symmetry is a necessary condition for deriving the input demand equations from the profit function, we impose it in our estimation.

Table 3 Regularity Tests[1]

	Symmetry			**Monotonicity[5]**		**Convexity[6]**	
Model	**Only sym[2].**	**Individual[3]**	**Joint[4]**	**Fertilizer**	**Labour**	**Necessary**	**Sufficient**
NQ							
Dual	6.58	16	111.61	yes	yes	yes	yes
	2.83	17	57.66	yes	yes	yes	yes
Primal							
GL	23.03	15	159.3	yes	yes	no	no
TL	1.86	17	141.66	yes	yes	no	no
CD	---	1	192.26	yes	yes	yes	yes

1. These tests are carried out only for the dual side except for the NQ model. In all cases linear homogeniety of the profit function is maintained by normalizing by ourput price.
2. The test statistic is Wald which has a chi-squared distribution with 2 degrees of freedom as there are only two restriction. Critical values are 5.99 and 4.61 at 5% and 10% levels respectively. Note that this test does not apply for the CD model.
3. The number of independent equality restrictions (out of a total of 20) accepted at 5%.
4. A joint test of all the 20 equality and symmetry restrictions which is distributed chi-squared with 20 degrees of freedom. Critical values are 31.4 and 28.4 at 5% and 10% respectively. Note that the CD has only 2 restrictions.
5. Decision based on local test at data mean points of prices and fixed inputs and other non-price factors.
6. For the NQ primal model, this represents concavity.

Monotonicity (at data mean points) cannot be rejected for all models. Both the CD and the NQ models satisfied convexity globally, but not the other two models which do not meet even the necessary conditions because of the wrong signs for the input demand functions. The rejection of convexity casts a serious doubt on the validity of the assumption of profit maximaization, although there might be other reasons for its rejection (see Shumway, 1983; and Higgins, 1986 for details). The failure to satisfy curvature properties is fatal to efforts to derive technology implications from a dual model (Jegasothy *et al*, 1990). We also tested and checked for symmetry, monotonicity, and concavity of the NQ production function[12]. As can be seen from Table 3, the outcomes are similar to the dual side, i.e., except for joint test of symmetry, it passes all the others. Therefore, based on theoretical consistency, the CD and NQ models are clearly preferred to the other two models.

VI. ELASTICITIES AND POLICY IMPLICATIONS

Since the CD and the NQ models satisfied curvature properties, we computed elasticities from the two models. For comparison, we have also presented elasticities from the GL model (see Appendix B).[13] It should be pointed out that, in general, there is no remarkable difference in the policy implications of the elasticities calculated from the alternative models. For this reason and partly because of the highly restrictive assumptions of the CD model, the discussion of elasticities is based on the NQ elasticities. Notwithstanding the robustness of most of the results, some important differences in the elasticity estimates are found across functional forms. For example, output supply and input demand elasticities of variable inputs are more sensitive to functional forms than those of non-price factors. Further, input demand elasticities are in general more sensitive to functional forms than output supply elasticities.

Dual Elasticities

The elasticities estimated from the quadratic profit function, at mean values of prices and fixed factors, are presented in Table 4. All elasticities have expected sign (positive for output supply and negative for input prices), and are all less than unity, often considerably so. The own-price elasticity of output, although significant, is very low. As we are considering aggregate output (hence abstracting from substitution possibilities), this is to be anticipated. The responsiveness of output to input prices (particularly to fertilizer prices) is negligible and insignificant. There is no evidence that output responds to fertilizer price (dual) or usage (primal). This is surprising, but is likely to

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[12] Monotonicity requires that the fitted values of the inverse demand functions be positive. The necessary condition for concavity is that the leading diagonal terms be negative, the sufficient condition being the Hessian of the production function be negative semi-definite.

[13] Note that all the elasticities from GL model rendered expected signs, and the only parameter with a wrong sign is highly insignificant. In any case, any inference from the GL elasticities should be cautiously interpreted.

reflect the low usage of chemical fertilizer, partly because the effective price is too high for small, poor farmers.

Table 4 Estimated Elasticities from Dual and Primal Specifications.

	Dual			Primal		
Elasticities	Output	Fertilizer	Labour	Output	Fertilizer	Labour
with respect to:						
Output price	0.013*	0.16*	0.48*	0.08	0.24	0.78
Fertilizer Price	-0.002	-0.09*	-0.05	-0.03	-0.13	-0.10
Wage rate	-0.01	-0.07	-0.43*	-0.05	-0.11	-0.68
Area cultivated	0.43*	-0.09	0.27*	0.83	-0.54	0.42
Animal power	0.29*	0.68*	0.28*	0.45	1.30	0.05
Farm capital	0.16*	0.19	0.18	0.23	0.61	-0.36
Land quality	0.31*	0.22*	-0.31	0.72	0.47	-0.16
Land access	0.07*	0.01	0.02*	0.12	0.30	0.08
Infrastructure	0.27*	0.49*	0.18*	0.56	1.82	0.41
Rain	0.39*	0.04*	0.39*	0.67	-0.16	-0.02

Notes: Elasticities indicated by * are based on derivatives of the restricted profit function, significant at 5%. For convenience of interpretation, the sign of elasticities for land quality are the reverse of the relevant parameter estimates. For the primal model, we derived the profit maximizing fertilizer and labour demand equations by simultaneously solving the system. The output supply equation was obtained by substituting these input demand equations for the exogenous factors back into the production function. Then conditional input demand and output supply elasticities are calculated at mean values of prices and fixed inputs (Abrar, 2001).

The insignificance of fertilizer inputs may be due to low levels of fertilizer application on a per hectare basis, misuse and inefficiency arising from lack of knowledge, institutional and infrastructural impediments. Farmers often use considerably less fertilizer than the recommended level. The loss of output due to nutrient imbalance is also significant as farmers' application is biased towards DAP instead of using it with Urea in equal proportions, in line with agronomic recommendations. Croppenstedt and Mulat (1997) found a very high degree of inefficiency of fertilizer use among cereal farmers in Ethiopia. They estimated mean efficiencies at 40 per cent for fertilizer, compared to 76 per cent and 55 per cent respectively for land and labour. Furthermore, bad timing in application and lack of experience and knowledge is problem. Partly, this is due to the inability of farmers to acquire fertilizer and fertilizer credits at the right time. Fertilizer is usually scheduled for delivery in June and July, but this fails to take into account the different planting calendars for different regions and different crops. Finally, we can see from the significant elasticities of fertilizer demand with respect to land quality and infrastructure that fertilizer use and its yield-increasing effect crucially depend on soil quality and market access.

If farmers do not report use of purchased fertilizer, we impute a cost corresponding to average usage in the region (see Appendix A). This may be the reason why the elasticity is so low. Farmers who cannot afford chemical fertilizer do not use it and, consequently, their output/profit is lower (than if they had used it). The price of fertilizer would need to fall considerably to enable them to purchase it. However, animal power (measured as numbers of oxen) is a proxy for access to manure, at least for poor farmers (for rich farmers, it is a wealth effect and they should be able to afford chemical fertilizer). The output elasticity with respect to animal power is positive and significant, which is consistent with this as a proxy for manure.

Although own-price elasticities of input demands are significant, the own-price elasticity of fertilizer is low, suggesting that fertilizer prices would have to decrease substantially to increase the low level of fertilizer use in rural Ethiopia. Quantitatively, to increase the current adoption rate of about 50 kg per hectare to at least 100 kg (the average for low income economies) is an increase of 100 per cent. The estimates suggest that even a 50% fall in fertilizer prices would only increase the quantity applied by about five per cent. Furthermore, fertilizer prices seem to have been increasing in the 1990s, as discussed in Section 2. Fertilizer demand is more responsive to output than to fertilizer prices (elasticities of 0.16 and 0.09 respectively). More favourable output prices would be more effective in encouraging increased use of fertilizer than would reductions in fertilizer prices, therefore the appropriate policy focus is on output markets (and input supply) rather than input prices.

Labour has the highest own-price elasticity (0.43) compared to output (0.013) and fertilizer (0.09). This and labour's relatively high elasticity with respect to output price implies that labour is far more responsive to price incentives than fertilizer. The low productivity of labour is evident from the low elasticity of output with respect to the wage rate. Yao (1996) found declining elasticity of labour over time, suggesting that stagnation of yields and increasing population growth have gradually depressed labour productivity. Labour demand is equally responsive to changes in output prices and wage rates, again supporting a policy focus on output markets and prices.

Output elasticities are significant for all fixed inputs and structural variables and quite high for most, especially area and rainfall. Output is far more responsive to non-price factors than to prices. The most important fixed inputs in terms of output response are area of cultivated land (elasticity of 0.43) and animal power (0.29). This suggests that larger farms are more profitable but need not imply support for a general policy of increasing the size of holdings. It may be that there are many holdings that are smaller than the minimum efficient size, so the objective would be to get all holdings above this size. Though production is least responsive to farm capital, the results indicate that the availability of this input increases output without generating significant demand for variable inputs. The control factors to which output is most responsive are rain, land quality and market access (infrastructure) with elasticities of 0.39, 0.31, and 0.27 respectively. The combined effect of more land of better quality is therefore substantial. Policies cannot directly affect land quality and rainfall but the importance of these factors suggests a focus on irrigation and soil quality. The latter could include appropriate use of fertilizers, although it is notable that fertilizer demand is not responsive to land area.

Fertilizer demand appears unresponsive to land area, farm capital and access to land, and has a very low response to rainfall (suggesting that areas with good rainfall have less need for chemical fertilizer). Labour demand appears unresponsive to farm capital and land quality. Otherwise, variable input demands respond significantly to non-price factors. The major influences on labour demand are rainfall, animal power and land area. The latter two are probably correlated (larger, richer farmers have more animals) while the former captures the effect of the size of the harvest. Fertilizer demand is most responsive to animal power (elasticity of 0.68), followed by infrastructure and land quality (elasticities of 0.49 and 0.22 respectively). As cattle in rural Ethiopia are major stores of wealth, animal power is likely to be positively correlated with credit availability, and in turn usage of purchased inputs. The high elasticity of fertilizer demand to infrastructure is expected. Given uniform prices within a village, the road density variable may represent transport cost differences and market access, both of which affect fertilizer elasticity with respect to the delivered price (Bapna *et al*, 1984). Land quality has also a strong and positive impact on fertilizer demand, which can be attributed to the fact that better quality land is usually closer to roads and markets. Furthermore, hill farmers with a slope higher than five per cent are not eligible to benefit from government support through modern input packages (Zerihun, 1996).

The negative and insignificant elasticity of fertilizer demand to area of cultivated land is not entirely unexpected in light of the extremely low intensity of fertilizer use of Ethiopian farmers. Most farmers in Ethiopia apply substantially lower amount of fertilizer than the recommended rate. This result, together with the relatively low and insignificant elasticity of fertilizer to land access, indicate that land is not as severe a constraint for fertilizer demand as it is, for instance, for labour. This is consistent with the observation that fertilizer, unlike labour, is relatively scale neutral.

Primal Elasticities

Since monotonicity and curvature conditions are satisfied for the system of first-order conditions (12), following Jegasothy *et al* (1990), we derived the profit maximizing fertilizer and labour demand equations by simultaneously solving the system using Cramer's Rule. The output supply equation was obtained by substituting these input demand equations for the exogenous factors back into the production function. Then conditional input demand and output supply elasticities are calculated at mean values of prices and fixed inputs which are also reported in Table 4. The output elasticities are in general consistent with previous works on peasant production in Ethiopia (see for e.g., Croppenstedt and Mulat, 1997; Abrar, 1996; Yao, 1996). Croppenstedt and Mulat (1997), using the same data set, in their study of technical efficiency reported land and fertilizer elasticities in the range of 0.46 to 0.58 and 0.03 to 0.09 respectively. Yao (1996), using aggregate time series data, reported elasticities in the range of 0.20 to 0.45, 0.05 to 0.10 and 0.35 to 0.97 for land, fertilizer and rainfall respectively.

These conditional elasticites reinforce the major result of the dual elasticities namely fixed inputs and other non-price variables are more important than prices. The relative importance of various variables is somewhat similar to the dual case. The only difference is in the relative importance of effects of rain and land quality on output, and of animal power and infrastructure on fertilizer. With the exception of elasticities of fertilizer demand with respect to animal power and infrastructure, all primal elasticities are less than unity. These elasticities also produced similar signs except in three cases, all of which are elasticities of input demands. The weak response of output to fertilizer is particularly evident.

However, in nearly all cases, the production elasticities calculated from the primal model are larger in magnitude than those derived from the profit function[14]. These elasticities are generally found to be larger in absolute magnitude than their dual counterparts (Jegasothy *et al*, 1990; Applebaum, 1978). On the basis of estimates of translog production and cost functions, Burgess (1975) reported markedly different inferences concerning elasticities of substitution while Applebaum (1978) found that magnitudes of price elasticities are sensitive to primal-dual specifications. On the other hand, studies by Dixon *et al* (1985) and Haughton (1986), using production and profit functions, indicate that parameter estimates and elasticities are more sensitive to functional forms than to primal-dual representation of the technology. In our case, despite differences in magnitudes, the inferences made from the primal and dual elasticities are not quite different from each other.

V. CONCLUSIONS AND POLICY IMPLICATIONS

Increasing the efficiency and productivity of agriculture has been an important objective of the Ethiopian government in the 1990s. Market liberalisation, in particular price incentives, have been a major policy instrument. However, the farming sector in Ethiopia is dominated by poor, peasant farmers with relatively small holdings. We analyse survey data on almost 1500 peasant households in 1994 to assess how responsive are Ethiopian farmers to price incentives and to identify the major constraints to expanding output. As a secondary objective, we tried to assess the extent to which empirical estimates and their inferences are sensitive to choice of functional form and to whether or not primal or dual approach is applied.

A number of important conclusions emerge. First, based on the alternative criteria set out, the quadratic and the Cobb-Douglas forms seem to provide better approximations of

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[14] In the case of the CD model, while output elasticities with respect to variable inputs is higher for the primal than the dual, nearly all output elasticities with respect to Z-variables are larger for the dual than the primal. In general, the primal-dual discrepancy is much lower for the CD model than the NQ model.

the underlying data. While non-nested hypotheses tests provide no clear choice among the three flexible forms, the quadratic model is found to be superior on the basis of statistical performance and consistency with theory. Second, in general, both production and profit functions have produced similar test results. On the basis of the criteria adopted, it is not possible to say which procedure is superior. Nor is there remarkable difference in the inferences made from elasticity estimates of the primal and dual specifications. Notwithstanding the robustness of most of the results, some important differences in the elasticity estimates are found across functional forms and estimation procedures. Differences in the magnitude of the elasticities are particularly significant when comparing the conditional and unconditional elasticities of the quadratic model.

Third, the results suggest that aggregate output of peasant farmers in Ethiopia responds only modestly to price incentives, and responsiveness to output prices is greater than that to variable input prices. While changes in variable input prices significantly affect the demand for these inputs, albeit with a very low elasticity in the case of fertilizer, the influence of input prices, especially for fertilizer, on output is insignificant. Policies directed at output and fertilizer prices are unlikely to have an appreciable effect on aggregate output. This is not to argue against 'getting prices right' as there may be effects on the crop mix not captured in our focus on aggregate output, and one would expect price elasticities to increase as agriculture becomes more commercialised. Furthermore, input demands are more responsive to output prices than to input prices. Our survey data are from 1994, relatively early in the agricultural reform process, but identify important constraints facing peasant farmers that should guide policies.

Finally, the most important finding is that non-price factors are far more important in affecting production and resource use than price incentives. This is demonstrated by the substantially higher magnitudes of the elasticities of output and input demands with respect to these factors. The most important non-price factors determining output, and hence the major constraints on increasing output, are size of holdings, rainfall, land quality and infrastructure (transport and access to markets). Extensification is not an option for increasing the size of land holdings. However, consolidation may be desirable as output is very responsive to land area, suggesting scale economies. In this context, the current land policy prohibiting land transfer is a constraint on increasing average profitability and productivity.

Government policy cannot affect rainfall and land quality, but can compensate for these as constraining factors by investing in irrigation, promoting efficient use of water and encouraging adoption of land-augmenting bio-chemical technology that increases soil quality. The latter emphasises the importance of fertilizer policy. Our results suggest that only the richer farmers with better quality land use fertilizer. Fertilizer demand is most responsive to the number of oxen a farmer owns (a measure of wealth), infrastructure (a measure of access to markets) and land quality. The low output supply and input demand elasticities with respect to fertilizer prices are evidence of the low usage rates, partly because prices are high.

There are many possible reasons for the relatively high price of fertilizer, so that many farmers cannot afford to use it. Successive devaluation of the Birr, high local transport costs and the elimination of subsidies all contribute to high domestic fertilizer prices. The effective price to farmers is even higher as over 80 percent of farmers who use chemical fertilizer require access to credit to finance purchases, and interest rates are generally very high. Another factor is that fertilizer markets, especially retail markets, are subject to local monopolies for supply and distribution. In the light of the evidence here and given the central role fertilizer plays in the drive for sustainable growth and increased productivity in the agricultural sector (core aims of government policy), the decision to remove fertilizer subsidies is questionable. Price support mechanisms, perhaps as part of the extension programme, may be necessary to encourage fertilizer use (at least until such time as average farm incomes increase).

Given the features of peasant farming in Ethiopia, getting prices right is not in itself an adequate policy to increase output and productivity in agriculture. Output prices are clearly an important part of the incentive structure, but non-price factors are the binding constraints. In addition to price incentives, effective policies that improve farmer’s access to land, credit and inputs, and public investment in roads and irrigation, are required. Such policies are likely to have direct effect on output, facilitating increased profitability, but equally important are the indirect effects by encouraging increased usage of fertilizer. Finally, we can note that elasticities for labour inputs are relatively high, implying that labour is not a constraint (although productivity appears to be very low).

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Appendix A Definition of Variables

Aggregate output is defined as the implicit aggregate quantity index derived by dividing total value of output by the price index. The output and price indices correspond to those used by Croppenstedt and Mulat (1997); we are grateful to Dr. Croppenstedt for providing his set of variables from the first round of the survey. The aggregate price index is defined as the Laspeyer's price index calculated from the major crops using the value share of each crop as a weight. We used the prices collected by an independent price survey simultaneously with the main survey. In a very few cases where the price of a crop is not reported, we used unit values.

Fertilizer is measured as total amount of chemical fertilizer applied in kilograms. Labour is defined as the number of person-days of traditional (share) and hired labour used in ploughing and harvesting. The wage rate per person-day is calculated from the wage bill of hired labour. For those farmers (villages) with no hired labour, we imputed the wage rate from the off-farm income of farm-related employment. Labour used in weeding is also given in the data, but we have not included it for two reasons. First, as weeding is predominantly carried out by women and children, the labour is not traded and/or has very low opportunity cost in terms of off-farm employment (women and children rarely participate in off-farm work). The data also show that weeding constitute a very low component of hired labour. Excluding it is justified as we use off-farm and hired wage bills to derive the wage rate. Second, weeding is least important in tree crop areas. Family labour is not included as it is treated as fixed. Also, share labour is adjusted for quality using average product as a weight. The implicit assumption here is that hired labour is more productive than share and family labour, an assumption justified by the data.

The price of fertilizer is calculated by dividing total expenditure on the amount applied. For those farmers who do not report use of purchased fertilizer, the mean of those who applied (in the same village) is used (to impute the cost of non-purchased fertilizer usage). In two villages where no farmer reported applying fertilizer, the mean of the nearest village is used. Animal power is defined as the total number of oxen owned (and may capture access to 'natural' fertilizer in addition to wealth effects). Farm capital is measured by the value of hoes and ploughs owned.

Land is total area of land cultivated in hectares. Land quality is defined as an index of the quality of cultivated land (1 being best, 2 mediocre and 3 worst). We combined the two indices of land quality given in the data (one for fertility and another for steepness) into one index using total area cultivated as a weight. Other inputs used in the preliminary analysis included a proxy for manure use and expenditure on all other inputs. The former was omitted due to multicollinearity (given animal power and imputed fertilizer cost) and the latter due to statistical insignificance.

A proxy for access to land is measured by the share of the harvest paid in the form of rent for land. Following Bapna *et al* (1984), infrastructure (and/or market access) is measured by dividing the total population of the nearest town (or big market) to the road distance between the town and the village. The level of rainfall is measured by multiplying the amount of rain in milimetres by the dummy for rain included in the questionnaire, where the farmer is asked if rain was enough or on time. We also included a dummy variable to capture the two most important cereal and tree cropping systems (1 if household is in cereal growing zone, 0 otherwise). Other alternative dummies were initially used for this purpose that split the sample into villages or regions or sub-farming systems. Village level dummies were excluded due to extreme multicollinearity with rain and market access, which are also village level measures, whereas region dummies were avoided as they performed no better than the farming system dummy used. Some other variables, such as education, age, household size, number of crops inter-cropped, number of plots, access to credit, and non-farm income, included in the preliminary estimation are left out due to multicollinearity.

Table A1 Descriptive Statistics of Principal Variables Used

Variables	Mean	Standard Deviation
Output (Birr)	710.30	889.85
Fertilizer (Kg)	39.87	70.43
Labour (Man-days)	32.14	75.10
Output Price (Birr/Kg)	3.19	3.00
Fertilizer Price (Birr/Kg)	1.52	0.37
Wage rate(Birr/Man-days)	2.83	1.62
Area Cultivated (hectares)	1.74	1.56
Animal Power (numbers)	1.80	2.00
Farm Capital (Birr)	24.31	32.43
Land Quality (index)	1.53	0.44
Land Access (Kg)	72.43	384.30
Infrastructur(road density)	3880.45	3817.45
Rain (mm)	548.16	677.21

Appendix B Estimated Elasticities: Dual

Elast. of:	Out Price	fert. Price	Wage Rate	Cult. land	Anim Power	Farm Capit.	Land Qualit.	Land Access	Mark. Access	Rain
CD										
output	0.11	-0.05	-0.06	0.52	0.36	0.05	0.52	0.09	0.14	0.11
fertil.	1.05	-1.05	-0.06	0.52	0.36	0.05	0.52	0.09	0.14	0.11
labour	1.06	-0.05	-1.06	0.52	0.36	0.05	0.52	0.09	0.14	0.11
NQ										
output	0.013	-0.002	-0.01	0.43	0.29	0.16	0.31	0.07	0.27	0.39
fertil.	0.16	-0.09	-0.07	-0.09	0.68	0.19	0.22	0.01	0.49	0.04
Labour	0.48	-0.05	-0.43	0.27	0.28	0.18	-0.31	0.02	0.18	0.39
GL										
output	0.035	-0.013	-0.022	0.281	0.201	0.104	0.331	0.038	0.601	0.332
fertil.	0.494	-0.51	0.016	0.061	0.428	0.209	0.153	0.048	0.511	0.140
Labour	0.56	0.014	-0.57	0.164	0.201	0.065	0.190	0.015	0.145	0.071

Appendix C1 Restricted Profit Function Estimates

Parameters	NQ	GL	TL	CD	Parameters	NQ	GL	TL	CD
α_o	126.033	10.01	18.49	3.823	δ_{26}	0.020	1.590	0.019	
	(0.61)	(0.01)	(16.03)***	(25.65)***		(7.31)***	(4.22)***	(0.54)	
α_1	-6.77	45.083	-0.027	-0.052	δ_{27}	0.064	1.174	0.006	
	(0.88)	(3.28)***	(0.74)	(9.43)***		(3.32)***	(1.69)*	(0.45)	
α_2	-5.49	-6.723	-0.32	-0.055	δ_{34}	0.449	9.441	0.026	
	(0.59)	(0.78)	(4.73)***	(5.35)***		(0.39)	(0.58)	(0.42)	
β_1	154.58	336.475	0.086	0.519	δ_{35}	0.005	0.606	0.021	
	(2.56)**	(2.11)**	(0.42)	(17.95)***		(1.68)*	(1.47)	(2.30)**	
β_2	122.560	49.238	0.03	0.361	δ_{36}	0.000	0.159	-0.004	
	(2.94)***	(0.55)	(0.11)	(7.94)***		(2.63)***	(1.69)*	(0.28)	
β_3	0.662	-14.949	-0.07	0.050	δ_{37}	0.000	0.284	0.021	
	(0.27)	(0.63)	(0.65)	(2.57)**		(0.43)	(1.59)	(3.93)***	
β_4	-8.505	320.514	-1.64	-0.516	δ_{45}	-0.203	-10.273	-0.033	
	(0.04)	(0.53)	(2.92)***	(6.17)***		(1.26)	(1.57)	(0.76)	
β_5	0.923	12.499	-0.005	0.091	δ_{46}	-0.003	-0.547	0.169	
	(2.93)***	(1.35)	(0.14)	(7.85)***		(0.27)	(0.34)	(2.40)**	
β_6	-0.105	-15.605	-3.70	0.144	δ_{47}	-0.055	-5.649	-0.025	
	(4.46)***	(6.41)***	(11.68)***	(7.19)***		(1.06)	(2.11)**	(0.99)	
β_7	-0.14	-8.714	-0.232	0.110	δ_{56}	0.000	0.073	-0.012	
	(1.04)	(1.59)	(0.86)	(13.56)***		(4.56)***	(2.29)**	(1.40)	
γ_{11}	7.761	-7.505	-0.035		δ_{57}	0.000	0.043	-0.008	
	(3.38)***	(1.20)	(3.02)***			(1.42)	(0.64)	(2.25)**	
γ_{22}	15.618	8.167	-0.02		δ_{67}	0.000	0.212	0.018	
	(8.61)***	(3.96)***	(2.43)**			(8.28)***	(7.56)***	(1.67)*	
γ_{12}	3.140	-0.991	-0.002		ϕ_{11}	1.998	-3.033	0.007	
	(2.20)**	(0.36)	(0.36)			(1.51)	(0.84)	(0.96)	
δ_{11}	-34.867	-121.699	-0.108		ϕ_{12}	-15.059	-24.080	-0.022	
	(3.77)***	(2.24)**	(2.22)**			(14.72)***	(10.63)***	(2.12)**	
δ_{22}	-7.779	42.112	0.027		ϕ_{13}	-0.313	-3.046	0.010	
	(1.37)	(1.50)	(0.20)			(5.69)***	(5.23)***	(2.10)**	
δ_{33}	-0.017	-1.546	0.028		ϕ_{14}	5.756	7.414	-0.034	
	(0.97)	(1.15)	(1.20)			(1.53)	(0.86)	(1.70)*	
δ_{44}	12.064	-55.188	-0.068		ϕ_{15}	-0.006	-0.971	0.001	
	(0.10)	(0.12)	(0.12)			(1.47)	(5.09)***	(0.26)	
δ_{55}	0.000	0.125	0.062		ϕ_{16}	-0.005	-0.557	-0.006	
	(5.09)***	(1.70)*	(3.58)***			(10.07)***	(10.53)***	(1.25)	
δ_{66}	0.000	0.210	0.509		ϕ_{17}	-0.003	-0.525	0.001	
	(3.92)***	(7.98)***	(11.48)***			(1.07)	(5.12)***	(0.77)	
δ_{77}	0.000	0.323	0.047		ϕ_{21}	-5.047	-6.651	0.005	
	(1.09)	(1.68)*	(0.79)			(3.16)***	(2.89)***	(0.42)	
δ_{12}	-12.148	1.578	0.021		ϕ_{22}	-4.969	-9.234	0.021	
	(1.68)*	(0.06)	(0.37)			(4.03)***	(6.43)***	(1.06)	
δ_{13}	0.914	7.927	-0.016		ϕ_{23}	-0.237	-0.783	0.011	
	(2.01)**	(1.15)	(0.77)			(3.59)***	(2.12)**	(1.32)	
δ_{14}	-16.580	-209.400	-0.019		ϕ_{24}	-6.473	7.506	-0.014	
	(0.53)	(1.98)**	(0.20)			(1.44)	(1.37)	(0.38)	
δ_{15}	-0.015	0.554	-0.018		ϕ_{25}	-0.009	-0.248	0.005	
	(0.27)	(0.22)	(1.08)			(1.74)*	(2.05)**	(0.91)	
δ_{16}	0.013	2.774	0.046		ϕ_{26}	-0.001	-0.132	0.023	
	(3.56)***	(4.12)***	(1.78)*			(2.51)**	(3.96)***	(2.70)***	
δ_{17}	0.105	4.804	0.016		ϕ_{27}	-0.023	-0.221	0.009	
	(3.82)***	(3.80)***	(1.65)*			(6.75)***	(3.39)***	(2.65)***	
δ_{23}	0.016	6.984	0.048		DU1	55.960	-17.261	-0.180	0.278
	(0.08)	(1.91)*	(1.51)			(1.20)	(0.36)	(2.40)**	(4.27)***
δ_{24}	-50.113	-85.430	0.068		Adj. R^2	0.71	0.71	0.68	0.62
	(2.18)**	(1.35)	(0.45)			(52.74)	(52.74)	(44.71)	(190.40)
δ_{25}	-0.109	-0.947	-0.020		Wald	35.78	88.75	162.56	148.72
	(2.00)**	(0.56)	(0.93)						

Notes: Absolute value of z-statistics in parentheses. *significant at 10%; ** significant at 5%; *** significant at 1%. The Wald statistics is the chi-squared statistics (three degrees of freedom) of the Breusch-Pagan test of independence among the three equations in the system.

Appendix C2 Production Function Estimates

Parameter	NQ	GL	TL	CD	Parameter	NQ	GL	TL	CD
α_o	146.230	276.783	17.769	4.130	δ_{25}	-0.110	-0.705	-0.015	
	(0.72)	(0.33)	(13.29)***	(28.49)***		(2.02)**	(0.40)	(0.73)	
α_1	0.868	-13.010	0.161	0.091	δ_{26}	0.020	1.338	0.039	
	(11.23)***	(0.80)	(1.44)	(7.44)***		(7.54)***	(3.12)***	(1.06)	
α_2	1.873	8.781	-0.020	0.086	δ_{27}	0.073	1.788	0.010	
	(14.40)***	(0.53)	(0.20)	(6.28)***		(3.78)***	(2.27)**	(0.74)	
β_1	130.038	228.028	0.453	0.459	δ_{34}	0.015	14.952	-0.004	
	(2.16)**	(1.36)	(2.17)**	(16.95)***		(0.01)	(0.89)	(0.06)	
β_2	80.78	-8.413	-0.074	0.252	δ_{35}	0.005	0.701	0.013	
	(1.95)*	(0.09)	(0.27)	(5.79)***		(1.90)*	(1.60)	(1.44)	
β_3	0.776	-30.168	-0.004	0.066	δ_{36}	0.000	0.083	-0.004	
	(0.32)	(1.25)	(0.04)	(3.66)***		(2.69)***	(0.79)	(0.30)	
β_4	17.943	276.986	-1.955	-0.453	δ_{37}	0.001	0.330	0.014	
	(0.08)	(0.45)	(3.58)***	(5.88)***		(1.12)	(1.76)*	(2.81)***	
β_5	0.93	9.081	0.006	0.079	δ_{45}	-0.194	-9.832	-0.020	
	(2.96)***	(0.94)	(0.07)	(7.29)***		(1.21)	(1.44)	(0.48)	
β_6	-0.095	-14.521	-3.516	0.093	δ_{46}	-0.005	-1.183	0.231	
	(4.03)***	(5.29)***	(9.53)***	(4.67)***		(0.44)	(0.67)	(3.26)***	
β_7	0.25	-7.425	-0.083	0.095	δ_{47}	-0.015	-4.889	-0.017	
	(1.90)*	(1.18)	(0.32)	(12.32)***		(0.30)	(1.69)*	(0.70)	
γ_{11}	-0.00032	1.288	0.047		δ_{56}	0.000	0.053	-0.016	
	(1.06)	(1.60)	(1.95)*			(4.65)***	(1.55)	(1.83)*	
γ_{22}	-0.004	-0.749	0.023		δ_{57}	0.000	0.035	-0.007	
	(9.85)***	(1.32)	(1.47)			(1.61)	(0.49)	(2.12)**	
γ_{12}	-0.001	0.111	-0.003		δ_{67}	0.000	0.180	0.016	
	(2.95)***	(0.25)	(0.37)			(8.18)***	(5.61)***	(1.46)	
δ_{11}	-35.086	-113.218	-0.020		ϕ_{11}	-0.011	-6.342	0.010	
	(3.80)***	(1.94)*	(0.40)			(0.73)	(1.33)	(0.50)	
δ_{22}	-6.639	52.364	0.104		ϕ_{12}	0.010	0.270	-0.046	
	(1.17)	(1.69)*	(0.77)			(0.79)	(0.09)	(2.00)**	
δ_{33}	-0.026	-0.607	0.009		ϕ_{13}	0.000	0.887	-0.002	
	(1.47)	(0.43)	(0.43)			(0.74)	(1.42)	(0.17)	
δ_{44}	-7.936	-42.553	0.053		ϕ_{14}	-0.096	0.921	-0.065	
	(0.07)	(0.09)	(0.10)			(2.33)**	(0.08)	(1.54)	
δ_{55}	0.000	0.213	0.073		ϕ_{15}	0.000	0.336	0.003	
	(5.71)***	(2.39)**	(4.31)***			(1.21)	(1.71)*	(0.50)	
δ_{66}	0.000	0.183	0.474		ϕ_{16}	0.000	0.244	-0.010	
	(2.68)***	(6.15)***	(9.31)***			(6.87)***	(3.13)***	(0.72)	
δ_{77}	0.000	0.166	0.010		ϕ_{17}	0.000	-0.078	-0.011	
	(1.25)	(0.73)	(0.18)			(3.85)***	(0.52)	(2.57)**	
δ_{12}	-11.584	9.214	0.037		ϕ_{21}	-0.022	1.392	-0.048	
	(1.61)	(0.31)	(0.67)			(0.92)	(0.33)	(2.99)***	
δ_{13}	0.920	9.040	-0.016		ϕ_{22}	0.023	0.330	-0.036	
	(2.03)**	(1.27)	(0.78)			(1.17)	(0.11)	(1.36)	
δ_{14}	-15.902	-156.327	-0.007		ϕ_{23}	0.000	-0.832	0.002	
	(0.51)	(1.42)	(0.08)			(0.26)	(1.38)	(0.15)	
δ_{15}	-0.016	0.192	-0.015		ϕ_{24}	-0.138	-0.829	0.001	
	(0.29)	(0.07)	(0.95)			(2.00)**	(0.07)	(0.03)	
δ_{16}	0.015	3.017	-0.005		ϕ_{25}	0.000	-0.101	-0.006	
	(4.19)***	(3.92)***	(0.19)			(0.25)	(0.46)	(1.00)	
δ_{17}	0.125	5.029	0.023		ϕ_{26}	0.000	0.043	0.011	
	(4.55)***	(3.52)***	(2.47)**			(6.18)***	(0.50)	(0.85)	
δ_{23}	0.012	6.819	0.035		ϕ_{27}	0.000	0.118	0.000	
	(0.06)	(1.64)	(1.10)			(7.81)***	(0.83)	(0.02)	
δ_{24}	-49.097	-86.557	0.074		DU1	46.989	-5.738	-0.144	0.201
	(2.14)**	(1.27)	(0.50)			(1.01)	(0.10)	(1.85)*	(3.39)***
					Adj. R^2	0.74	0.73	0.72	0.65
						(59.62)	(56.85)	(53.81)	(213.17)

Notes: Absolute value of t-statistic (OLS) and z-statistics (SUR) in parentheses.*significant at 10%; ** significant at 5%; *** significant at 1%. Note that the estimates for quadratic are iterated SUR estimates of the production function along with first order equations with equality and symmetry imposed. For others it is the single equation OLS results.

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