ESTIMATING SUPPLY RESPONSE IN THE PRESENCE OF TECHNICAL INEFFICIENCY USING THE PROFIT FUNCTION: An Application to Ethiopian Agriculture

by

Suleiman Abrar *

Department of Economics, University of Leicester

University Road, Leicester, LE1 7RH, The UK

Email: as210@leicester.ac.uk

Abstract:

Studies of supply response using the profit function have typically maintained the neo-classical assumption of efficiency. Using farm-level data from Northern Ethiopia, this study examines the impact of technical inefficiency on the response of small holder farmers. Two systems of output supply and input demand functions are estimated and compared: one the standard model in which technical efficiency is assumed and another in which technical inefficiency is explicitly incorporated into the profit function. While the results from non-nested hypotheses tests are inconclusive, the model with technical inefficiency is preferred to the other model for theoretical consistency. Incorporation of inefficiency has generally increased the magnitudes and the statistical significance of own price elasticities, substantially so in the case of *teff* and fertilizer. The results indicate that farmers in Ethiopia do respond positively and significantly to price incentives. The results also underscore the need to improve farmer's access to better quality land, farm inputs and credit, and public investment in roads and irrigation.

JEL: O13, Q11, Q12.

Keywords: Supply Response, Technical Inefficiency, Elasticities, Profit functions

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1 Introduction

Agriculture dominates the Ethiopian economy, accounting for the bulk of exports and employment, and is almost totally a small holder sector. As in many other developing countries, economic policies have not favored agriculture, and per capita agricultural production declined steadily since the 1970s, but reforms have been implemented since the early 1990s. Market liberalization policies, in particular price incentives, were implemented in the 1990s, with some improvement in the overall performance of the economy (Abrar, 2000).

Nevertheless, how much of this recovery is due to price incentives and how much due to non-price factors is not clear. Nor is clear whether small holder farmers are more responsive to prices of some outputs and inputs than others. 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. Nearly all studies of supply response in Ethiopia use aggregate time series data, and estimate export supply response for coffee (Dercon and Lulseged 1994, 1995; Alem 1996) or supply response of food grains (Abebe, 1998; Zerihun, 1996).

Several studies have shown that there is impressive potential for increasing the efficiency and productivity of peasant agriculture in Ethiopia (e.g., Seyoum *et al*, 1998; Croppenstedt and Mulat, 1997). Nearly all of these studies only estimated the level of technical efficiency, ignoring the role of prices on the production and input allocation decisions of farmers. However, this is rather the general trend and not unique to Ethiopia. On the other hand, most micro-economic studies of supply response to prices have maintained the neo-classical assumption of efficiency. Only a few studies in the literature have combined these two issues and estimated farm responses to prices in the presence of inefficiency (e.g., Kumbahakar, 1996).

One of the most comprehensive works in the area has shown that elasticities estimated based on a model without inefficiency are incorrect (Kumbahakar, 2001). This study addresses supply response and inefficiency simultaneously within the framework of profit functions, so does it augment previous work which ignores inefficiency (Abrar, 2002), but used the same data set to estimate supply response. The current study also adds to the small literature on supply response in Sub-Saharan Africa using farm-level data (e.g. Savadogo, *et al*, 1995; Hattink, *et al*, 1998).

Based on the established theory of duality, Arnade and Trueblood (2002) recently introduced a method to incorporate technical inefficiency into the profit functions, and the resulting system of output supply and input demand equations. We follow this approach to explore whether the standard profit function is mis-specified by not taking technical inefficiency into account, and if so, how that influences parameter estimates and elasticities. Arnade and Trueblood (2002) illustrated this novel approach using state level data from Russian agriculture, focussing mostly on the price elasticities.

Apart from serving the main goal of demonstrating the theoretical approach, the empirical results provide some useful insights into Russian agriculture. However, the empirical application suffers from the well-known problems of inconsistency associated with applying farm-level theory to aggregate data. In calculating inefficiency and elasticities, they have assumed, without testing, that corporate farms in each state have similar technology. Since the underlying producer theory behind these estimates is based on a profit maximizing individual producer, it cannot be readily applied at higher levels of aggregation without *a prior* testing. Further, they have not provided tests of the consistency of the results with the curvature and symmetry restrictions implied by the underlying duality theory. To conduct a critical test of these assumptions requires farm-level data (Shumway, 1995).

We use farm-level survey data from Northern Ethiopia covering 630 rural households in 1994-2000 to estimate two systems of output supply and input demand (with and without incorporating technical inefficiency). We compare the two models based on non-nested hypotheses tests as well as conformity to neo-classical assumptions of production theory. We also include a full range of non-price factors that are believed to be important in affecting agricultural production in Ethiopia. While the results from non-nested hypotheses tests are inconclusive, the model with technical inefficiency is found to be more appropriate for theoretical consistency. A comparison of parameter estimates and elasticities from the two models shows that the presence of technical inefficiency has restricted responses of farmers to changes in price and non-price incentives.

The rest of the paper is organised as follows. Section 2 outlines the procedure for incorporating technical inefficiency into the profit function framework. The data and econometric approach are set out in Section 3. Section 4 presents and discusses the results. The conclusions are in Section 5.

2 Modelling Framework

One method for addressing inefficiency and supply response involves a simultaneous estimation of efficiency and profit function parameters in a single step (Kumbhakar, 1996, 2001). While this approach has many advantages, such as estimating inefficiency scores and the parameters jointly and allowing standard statistical testing procedures to establish a level of confidence in the inefficiency scores, it relies on computationally demanding estimation techniques, and imposes restrictions on the distribution of model errors. Furthermore, it is not always possible to overcome the difficult task of distinguishing between technical and allocative inefficiency.

Arnade and Trueblood (2002) develop an alternative approach for incorporating technical inefficiency into a system of output supply and input demand equations. Their approach relies on less restrictive assumptions and sorts out the effects of technical and allocative inefficiency, but must be implemented in two steps. Using the existing dual relationships among cost functions, distance functions and technical inefficiency, they show how technical inefficiency is incorporated into the profit function as an exogenous variable through output prices.

Suppose that the production technology is homogeneous of degree k, and that outputs are separable from inputs. Fare and Primont (1995) have shown that the input distance function is homogeneous of degree -1/k in outputs if the technology is homogeneous of degree k, i.e.,

$$(1) \qquad \gamma^{-1/k} D_I(\mathbf{y},\mathbf{x}) = D_I(\gamma\mathbf{y},\mathbf{x}),$$

where $D_I(.)$ is the input distance function; **y** represents a vector of *m* outputs; **x** represents a vector of *n* inputs; and γ is a parameter. Assuming efficiency, the duality between the input distance function and the cost function can be expressed as:

$$(2) \qquad C(\mathbf{y},\mathbf{w}) = \min_{\mathbf{x}} \mathbf{w}'\mathbf{x}, \quad s.t. D_I(\mathbf{y},\mathbf{x}) = 1,$$

where **w** represents a vector of input prices; and $C(.)$ is the cost function. Fare *et al* (1990) established that the distance function is equal to the reciprocal of technical inefficiency, denoted by τ. Thus, the cost minimization problem (bearing in mind the assumption of homogeneity and the properties of the corresponding cost function) can be expressed as follows:

$$(3) \qquad \min_{\mathbf{x}} \mathbf{w}'\mathbf{x}, \quad s.t.\, D_I(\mathbf{y},\mathbf{x}) = \frac{1}{\tau}$$

$$(4) \qquad = \min \mathbf{w}'\mathbf{x}, \quad s.t.\, \tau D_I(\mathbf{y},\mathbf{x}) = 1$$

$$(5) \qquad = \min \mathbf{w}'\mathbf{x}, \quad s.t.\, D_I(\tau^{-k}\mathbf{y},\mathbf{x}) = 1$$

$$(6) \qquad = C(\tau^{-k}\mathbf{y},\mathbf{w}) = \tau^{-1}C(\mathbf{y},\mathbf{w}).$$

The profit maximization problem is therefore given by:

$$(7) \qquad \max_{\mathbf{y}} \ \mathbf{p}'\mathbf{y} - \tau^{-1}C(\mathbf{y},\mathbf{w}),$$

where **p** is a vector of output prices. The first order condition for each y_i is:

$$(8) \qquad p_i = \tau^{-1}\left(\frac{\partial C}{\partial y_i}\right), \quad or$$

$$(9) \qquad \tau p_i = \left(\frac{\partial C}{\partial y_i}\right), \qquad i = 1,\ldots,m.$$

The profit function at the optimal output level is:

$$(10) \qquad \pi(\tau\mathbf{p},\mathbf{w}) = \max \ \mathbf{p}'\mathbf{y}^{\circ} - \tau^{-1}C(\mathbf{y}^{\circ},\mathbf{w}),$$

where $\mathbf{y}^{\circ}$ denotes the optimal output levels. Using Hotelling's Lemma, the profit maximizing levels of output supply and input demand equations are, respectively, derived from (10) as:

(11) $y_i(\tau\, \mathbf{p}, \mathbf{w}) = \partial\pi(\tau\, \mathbf{p}, \mathbf{w})/\partial p_i, \quad i = 1, \ldots, m,$ and

(12) $-x_r(\tau\, \mathbf{p}, \mathbf{w})/\, \tau = \partial\pi(\tau\, \mathbf{p}, \mathbf{w})/\partial w_r, \quad r = 1, \ldots, n.$

where i and r index the outputs and inputs respectively. In this model, therefore, technical inefficiency interacts with output prices multiplicatively.

To implement this model, technical inefficiency scores need to be calculated first using the non-stochastic programming approach. Then, the inefficiency scores are specified as an explanatory variable in a profit function and the corresponding system of output supply and input demand equations. The most widely used approaches for measuring technical efficiency are the Stochastic Frontier Approach and Data Envelopment Analysis (see for e.g., Coelli, Rao, and Battese, 1998; Coelli, 1995). Technical efficiency scores calculated from the non-stochastic programming approaches can be used as explanatory variables without resorting to sequential econometric estimation (Arnade and Trueblood, 2002). For this reason, we compute technical efficiency scores using the DEA approach.

3 Data and Estimation Procedures

The data we use is the Ethiopian Rural Household Survey (ERHS), a nation-wide survey of rural households conducted during 1994-2000. The survey was undertaken in 18 villages across the country from which nearly 1500 households were selected randomly[1]. For this study, we consider only 630 farmers from nine villages of Northern Ethiopia. The considerable geographic dispersion of the sampled villages represents the diversity of farming systems in the country and, given large differences in accessibility to input and output markets, means that there are large variations in prices faced by different households.

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[1] The sample consists of nine peasant associations (PAs) namely, Haresaw Tabia, Geblen Tabia, Dinki, Shumshaha, Yetmen, and four PAs in the vicinity of Debre Birhan town. All the study villages are found in region 3, with the exception of Geblen and Harasaw, for which a dummy is included (*du12*). The final sample consists of only 514 as farmers with either cultivated land less than 0.1 hectares, or zero labour or zero output or zero and negative profit are excluded.

Six outputs, two variable inputs (chemical fertilizer and labour) and three fixed inputs (land adjusted for quality, animal power and farm capital) are used in the final estimation. We include four 'exogenous' controls -extension services, land access, market access, and rainfall. We consider five major cereals - *teff*[2], wheat, barley, maize, and sorghum. A sixth output variable is formed as 'other crops'. This is an aggregate of three minor cash crops categories - legumes, root crops and vegetables. Details of measurement of variables and summary statistics on production, input use and prices are given in Appendix A.

The Empirical Model

We use the quadratic functional form, which has the advantageous feature of self-duality (Abrar, 2001 provides a detailed analysis of the choice of functional form based on this survey data). The quadratic normalised restricted profit function is given by:

$$\pi^* = \alpha_\circ + \sum_i^6 \alpha_i \tau p_i^* + \sum_r^2 \alpha_r w_r^* + \sum_k^8 \beta_k z_k + \frac{1}{2}\left(\sum_i^6 \sum_j^6 \gamma_{ij} \tau^2 p_i^* p_j^* + \sum_r^2 \sum_q^2 \gamma_{rq} w_r^* w_q^* + \sum_k^8 \sum_h^8 \delta_{kh} z_k z_h \right) + \sum_i^6 \sum_r^2 \gamma_{ir} \tau p_i^* w_r^* + \sum_i^6 \sum_k^8 \phi_{ik} \tau p_i^* z_k + \sum_r^2 \sum_k^8 \phi_{rk} w_r^* z_k + \varepsilon. \tag{13}$$

where π^* is the normalised restricted profit, p_i^* is the normalised price of output i, w_r* is the normalised price of input r, z_k is the quantity of fixed input or other exogenous variable k, and τ is technical inefficiency. The α_0, α_i, α_r, β_k, γ_{ij}, γ_{rq}, γ_{ir}, δ_{kh}, ϕ_{ik} and ϕ_{rk} are parameters to be estimated and ε is an error term with the usual properties. The corresponding output supply and input demand equations are derived from (13), respectively, as:

$$y_i = \alpha_i \tau + \sum_j^6 \gamma_{ij} \tau^2 p_j^* + \sum_r^2 \gamma_{ir} \tau w_r^* + \sum_k^8 \phi_{ik} \tau z_k + \nu_i, \qquad i = 1,...6, \text{ and} \tag{14}$$

$$-x_r = \alpha_r \tau + \sum_i^6 \gamma_{ri} \tau^2 p_j^* + \sum_q^2 \gamma_{rq} \tau w_q^* + \sum_k^8 \phi_{rk} \tau z_k + \nu_r, \qquad r = 1,..2. \tag{15}$$

where y_i and x_r denote the quantities of outputs and variable inputs, respectively, and ν is the error term. Note that, in the absence of technical inefficiency, $\tau = 1$, the model reduces to the traditional output supply and input demand system. Homogeneity is

[2] *Teff* is a cereal unique to Ethiopia, a non-exportable cash crop that is an important staple food in Northern and Central Ethiopia.

imposed by dividing profit and all prices by the wage rate, so the labour demand equation is excluded. The final estimation is for the system of six output supply equations and one input demand equation (fertilizer) using iterative Seemingly Unrelated Regression (SUR).

Not all farmers in the sample use fertilizer. In countries like Ethiopia, where there is low level of market integration and other forms of input market imperfections prevail, low use of fertilizer could be the result of these external factors rather than a rational decision based on prices. To correct for selectivity bias (to ensure zero expectation of the error terms) we estimated the fertilizer demand equation using the two-stage Heckman procedure. First, the probability of using fertilizer is estimated by probit maximum likelihood using the following binary choice model:

(16) $$F^* = H\Theta + u$$

where F^* is an unobserved latent variable determining the farmers' decision to buy fertilizer, and may be thought of as the expected benefit (known only to the farmer) of buying fertilizer, H is a set of household characteristics hypothesised to affect fertilizer use, and u is error term. The observed binary variable F will be:

(17) $$F = \mathbf{1} \; (F^* > 0, \text{ i.e., users})$$
$$F = \mathbf{0} \text{ otherwise (i.e., } F^* \leq 0, \text{ non-users)}$$

The resulting values of the vector Θ are used to compute the vectors of inverse Mills ratios, $M_1 = (\phi/\Phi)$ and $M_2 = (-\phi\ /1-\ \Phi)$, respectively, for sub-samples of users and non-users (ϕ and Φ are respectively the standard normal density and cumulative distribution evaluated at the point $H\Theta$). In the second stage, the adjusted demand function for fertilizer for each sub-sample is estimated along with the other equations in the system by including M_1 and M_2 as regressors for user and non-user sub-samples respectively. Once this correction is made all observations, including zero observations, can be used to estimate the fertilizer demand equation.

4 Results and Discussion

In what we believe is the only attempt to apply DEA to Ethiopian data, Abrar (1995b) used the same data set used here and estimated different variants of output-oriented DEA technical efficiency scores for a sample of Central Ethiopian farmers, and found that a large proportion of the farmers are operating under CRS. Hence, we calculated technical inefficiency measures using the output oriented CRS DEA approach from the DEAP software (Coelli, 1996), and the results are reported in Table A3.

The mean technical efficiency is 0.55, confirming the established fact that there is a significant potential to improve the efficiency of Ethiopian small holders (see for e.g., Abrar, 1996; Croppenstedt and Mulat, 1997; Battesse and Senait, 1998).[3] This figure is slightly higher compared to the (CRS) mean efficiency calculated by Abrar (1995b), which is in the range of 0.39-0.44. We can see from Table A3 that about 45 percent of the farmers have technical efficiency scores less than 0.50.

Two different models of output supply and input demand systems are estimated. Model 1 is the standard model where technical efficiency is assumed, and Model 2 is the model that allows for technical inefficiency. Estimated parameters from the seven-equation systems of output supply and fertilizer demand equations for Models 1 and 2, with symmetry imposed, are given in Appendix Tables B1 and B2 respectively. The signs and magnitudes of the parameters are generally consistent with theory. All own price coefficients have expected signs except for barley in Model 1, which is statistically insignificant. There are a few unexpected signs as well for non-price variables, all of which are insignificant with the exception of rainfall for sorghum, again in Model 1. Nearly half of the parameters are significant at five percent. We limit our discussion to the estimated elasticities at data mean points derived from the two models.

[3] For a comparison of technical efficiency estimates from the DEA and the Stochastic approaches using the same data set, see Abrar (1995a).

For ease of comparison between the two models, own price, cross-price, non-price and fertilizer demand elasticities are separately reported in Tables 1 through 4 respectively.

Table 1 Own-Price Elasticities of Output Supply

Model 1		Model 2	
Crop	Elasticity	Crop	Elasticity
Wheat	0.21***	Wheat	0.52***
Sorghum	0.20**	Sorghum	0.16***
Other Crops	0.09*	Other Crops	0.17***
Maize	0.08	Maize	0.02
Teff	0.06	*Teff*	0.30
Barley	-0.02	Barley	0.02

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.

Table 2 Fertilizer Demand Elasticities

With Res. To:	Model 1		Model 2	
	Variable	Elasticity	Variable	Elasticity
Prices	Barley	-0.18**	Barley	-0.28*
	Wheat	0.13***	Wheat	0.57***
	Sorghum	0.10*	Sorghum	0.12*
	Fertilizer	-0.02	Fertilizer	-0.38***
	Teff	0.02	*Teff*	0.05
	Other Crops	0.01	Other Crops	0.003
	Maize	-0.003	Maize	-0.05
Non-Prices	Rain	0.94***	Rain	1.45***
	Animal Power	0.22***	Animal Power	0.40***
	Extension	0.22**	Extension	0.33***
	Land Size	0.16***	Land Size	0.25***
	Infrastructure	0.15***	Infrastructure	0.26***
	Land Quality	0.13	Land Quality	0.12
	Farm Capital	0.07**	Farm Capital	0.11*
	Land Access	0.03	Land Access	0.60***

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.

Own Price Elasticities

Own price elasticities are all less than unity, often considerably so in Model 1. Magnitudes of these elasticities range from -0.02 for barley to 0.21 for wheat in Model 1. Further, only wheat and sorghum have own price elasticities that are significant at 5 percent. Such a response of farmers to prices of wheat and sorghum could be driven by subsistence needs (i.e. higher prices encourage higher production for own-consumption so as to avoid the need to purchase these foods) as shares of marketed surplus are much higher for other crops and *teff* than for wheat and sorghum (see Table A1).

Table 3 Cross-Price Elasticities

Model 1		Model 2	
Crop/Prices	Elasticity	Crop/Prices	Elasticity
Teff		*Teff*	
Barley	-0.20**	Barley	-0.36**
Wheat	0.11**	Wheat	0.18
Sorghum	0.08	Sorghum	-0.08
Other Crops	-0.07*	Other Crops	-0.07
Maize	0.02	Maize	0.02
Fertilizer	-0.01	Fertilizer	-0.02
Maize		Maize	
Barley	-0.11	Barley	-0.05
Teff	0.11	*Teff*	0.10
Sorghum	-0.05	Sorghum	-0.02
Other Crops	-0.03	Other Crops	-0.03
Wheat	0.01	Wheat	-0.11
Fertilizer	0.004	Fertilizer	0.08
Wheat		Wheat	
Sorghum	-0.19***	Sorghum	-0.22**
Teff	0.14**	*Teff*	0.25
Fertilizer	-0.06***	Fertilizer	-0.27***
Barley	-0.04	Barley	-0.14
Other Crops	-0.04	Other Crops	-0.16*
Maize	0.002	Maize	-0.03
Barley		Barley	
Sorghum	0.12***	Sorghum	0.14**
Teff	-0.11**	*Teff*	-0.19**
Fertilizer	0.03**	Fertilizer	0.05*
Wheat	-0.03	Wheat	-0.05
Other Crops	0.02	Other Crops	0.05
Maize	-0.01	Maize	-0.01
Sorghum		Sorghum	
Barley	0.35***	Barley	0.39**
Wheat	-0.21***	Wheat	-0.24**
Teff	0.12	*Teff*	-0.12
Fertilizer	-0.05*	Fertilizer	-0.06*
Other Crops	0.03	Other Crops	-0.11
Maize	-0.02	Maize	-0.01
Other Crops		Other Crops	
Teff	-0.11*	*Teff*	-0.10
Barley	0.05	Barley	0.15
Wheat	-0.04	Wheat	-0.17*
Sorghum	0.03	Sorghum	-0.01
Maize	-0.01	Maize	-0.11
Fertilizer	-0.003	Fertilizer	-0.001

Notes: *significant at 10%; ** significant at 5%; *** significant at 1%.

Table 4 Non-Price Elasticities of Output Supply

Model 1		Model 2	
Non-Price Variable	Elasticity	Non-Price Variable	Elasticity
Teff		*Teff*	
Rain	1.56***	Rain	2.48***
Land Size	0.76***	Land Size	1.02***
Land Quality	0.19***	Land Quality	0.38***
Farm Capital	0.18***	Farm Capital	0.03
Land Access	0.11***	Land Access	0.38*
Market Access	-0.03	Market Access	0.01
Animal Power	0.01	Animal Power	0.06
Extension	0.01	Extension	0.28**
Maize		Maize	
Land Size	3.39***	Land Size	3.56***
Rain	0.42***	Rain	0.33***
Land Quality	0.30***	Land Quality	0.32***
Extension	0.06	Extension	0.12
Farm Capital	0.05**	Farm Capital	-0.01
Animal Power	0.03	Animal Power	0.02
Land Access	0.01	Land Access	-0.01
Market Access	0.00	Market Access	0.05
Wheat		Wheat	
Land Size	1.83***	Land Size	1.90***
Rain	0.82***	Rain	0.93***
Farm Capital	0.13***	Farm Capital	0.04
Land Quality	0.10*	Land Quality	0.13***
Animal Power	0.08**	Animal Power	0.16***
Extension	0.07	Extension	0.17**
Land Access	0.02*	Land Access	0.26
Market Access	0.00	Market Access	0.15***
Barley		Barley	
Market Access	0.39***	Market Access	0.24***
Animal Power	0.20***	Animal Power	0.07
Land Size	0.19***	Land Size	0.25***
Rain	0.19**	Rain	0.46***
Land Quality	0.14***	Land Quality	0.39***
Extension	0.12*	Extension	0.25**
Land Access	0.03**	Land Access	0.17
Farm Capital	-0.003	Farm Capital	0.05**
Sorghum		Sorghum	
Rain	-0.63***	Rain	-0.34
Market Access	0.43***	Market Access	0.41***
Land Quality	0.32***	Land Quality	0.22*
Land Size	0.18***	Land Size	0.36***
Land Access	0.08***	Land Access	-0.09
Extension	0.07	Extension	0.34**
Farm Capital	0.05*	Farm Capital	0.08
Animal Power	0.02	Animal Power	0.16*
Other Crops		Other Crops	
Rain	0.52***	Rain	0.26**
Land Quality	0.27***	Land Quality	0.44**
Land Size	0.20***	Land Size	0.46***
Animal Power	0.19***	Animal Power	0.17
Market Access	0.15***	Market Access	0.08
Extension	0.11	Extension	0.24
Farm Capital	0.07**	Farm Capital	0.07
Land Access	0.002	Land Access	0.13

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%.

In Model 2, all but two own price elasticities have increased. In percentage terms, the highest increase in own price elasticity is for fertilizer followed by *teff* and wheat. Magnitudes of these elasticities range from 0.02 for maize and barley to 0.52 for wheat. Own price elasticity of wheat has more than doubled, and is still the highest. The own price elasticity of teff has increased substantially from 0.06 to 0.30, and has now become the second highest.

The most dramatic increase has occurred for fertilizer, which has increased from -0.02 to -0.38. What is more, it has now become significant at one percent. Other crops has also become significant at one percent. The only change in sign occurred for the own price elasticity of barley, which now has the appropriate (positive) sign, but is still statistically insignificant. On the other hand, own price elasticities of maize and sorghum have decreased. In general, therefore, taking efficiency into account has increased the magnitudes and significance of own price elasticities, substantially so in the case of fertilizer and teff.

Cross-Price Elasticities

In Model 1, ten of the thirty (excluding fertilizer) cross-price elasticities are statistically significant, most involving wheat and sorghum (the only two crops with significant own-price elasticities). *Teff* is a strong complement to wheat, a weak substitute with other crops and a strong substitute with barley. Wheat is a strong substitute with sorghum. On the other hand, barley and sorghum are strong complements to each other (with the highest cross-price elasticity of 0.35). All but two crops have the expected negative output elasticity with respect to fertilizer price. The elasticity for maize and barley with respect to fertilizer is positive (and statistically significant for the latter). This could be due to the lower use of fertilizer for barley and opportunistic planting of fertilizer-intensive crops like *teff* (a substitute for barley). Lower barley prices could result in more land for, and higher production of, *teff* and hence higher demand for fertilizer.

In Model 2, most of the cross-price elasticities have increased in absolute terms. Elasticities of all crops with respect to price of barley have now become substantially higher. So is the elasticity of fertilizer demand to the price of wheat, which has increased from 0.13 to 0.57, becoming the highest price elasticity. However, there are only few instances of changes in the relationships of the crops, mostly for sorghum. Sorghum, which was complementary to *teff* and other crops, has now become a substitute. The only other change in sign is between wheat and maize, which have now become substitutes. In terms of significance, a major shift has occurred in the complementarity of wheat and teff, which has changed from being significant at five percent to insignificant. Also, the relationship between fertilizer and barley has now become statistically insignificant.

In general, the pattern that emerges is complementary *teff* and wheat competing with (being substitutes for) complementary barley and sorghum. Note that *teff* and wheat are opportunity crops that are produced in large quantities only when there is good rain and when fertilizer is available. They are usually produced by shifting land away from the regular crops (barley, sorghum and other crops) to which a disproportionately larger share of the land (just over 80 percent) is allocated. The complementarity of *teff* and wheat may have to do with the fact that they are often grown on share cropped land, which means that they share access to land inputs. This may explain why *teff* is not found to respond significantly to fertilizer price although wheat has the expected negative and significant response.

Non-Price Elasticities

In Model 1, land size, rain and land quality, seem to be most important factors. Output responses to the size of land holding and land quality are positive and statistically significant for all crops, and response to land access is positive and significant for most crops. The elasticity of output with respect to rain is significant in all cases and positive for all crops except sorghum. The result for sorghum is not entirely unexpected: it is customary for Ethiopian farmers to shift from sorghum towards high-yielding, short-cycle and less drought tolerant crops such as *teff* (a substitute and the crop most responsive to rain) in seasons of abundant and regular rains. The results confirm that nothing is as crucial for agriculture in this drought-prone region as rain and better quality land.

In most cases, incorporation of technical inefficiency has increased the magnitudes and statistical significance of elasticities of non-price factors. Once again, land size, rain and land quality are the most important factors. Interestingly, the incorporation of inefficiency has dramatically increased both the magnitude and the statistical significance of agricultural extension. For example, elasticity of teff with respect to extension has increased from 0.01 to 0.28. This variable has increased five-fold in the sorghum equation, and at least two-fold in all the others. In addition, in the model without inefficiency, this variable was statistically significant only in the fertilizer demand equation, but now it is significant in all equations except other crops and maize. Therefore, the impact of extension on output supply is likely to be seriously hampered by the presence of technical inefficiency. On the other hand, the magnitude and significance of farm capital have mostly worsened, having wrong signs in some cases. This may have to do with the fact that it is measured in value terms.

Specification Tests

To determine the impact of technical inefficiency on the supply response of the farmers, we compared the two models based on non-nested hypotheses tests and conformity to regularity conditions of symmetry, monotonicity and convexity. The two models are non-nested in that one cannot be expressed as a special case of the other by parametric restrictions. The traditional hypothesis tests cannot be applied in this case. To choose between the two models, we conducted two regression-based tests, known as J and JA, along the lines of Doran (1993).

This involves re-estimating the profit function and testing the relative performance of fitted values from each model in a composite model. The test statistics and associated t-values are reported in Table 5. The J-test does not discriminate between the two models. The JA-test however accepts Model 2 against Model 1 at 5%. Unfortunately, lack of conclusive evidence from tests of non-nested hypotheses is quite common (e.g., Frank *et al*, 1990; Doran, 1993; Arnade and Trueblood, 2002).

Table 5 Non-nested Hypotheses Tests

Null Hypothesis	Alternative Hypothesis	
	Model 1	Model 2
Model 1	--------	6.94
	--------	5.22**
Model 2	4.57	--------
	1.87	--------

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

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 wage rate, and hence cannot be tested. We first conducted a test for symmetry globally, subject to homogeniety. 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. The following symmetry restrictions are tested and imposed in the final estimation:

(18) $\gamma_{ij} = \gamma_{ji} (i, j = 1,...6, i \neq j)$

(19) $\gamma_{ri} = \gamma_{ir} (i = 1,...6; \quad r = 1,$ and stands for fertilizer)

A joint test of these symmetry restrictions cannot be accepted for both models. But when tested individually, it was accepted in 82 percent of the cases for Model 2 while it was accepted in only 64 percent of the cases for Model 1. 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.

Then we checked for monotonicity and convexity after estimation. Monotonicity requires that the fitted values of the output supply (input demand equations) are positive (negative). The necessary condition for convexity is that all terms on the leading diagonal of the Hessian of the normalized profit function must be positive, or alternatively the own-price elasticities should have the expected signs. The sufficient condition is that this Hessian must be positive definite. Monotonicity (at data mean points) cannot be rejected for both models. We can see from Tables 1 and 2 that Model 2 satisfies the necessary condition for convexity, but not Model 1 because of the wrong sign for the own price of barley. Failure to satisfy 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).

In general, therefore, based on theoretical consistency, Model 2 is clearly preferred to Model 1. Further, the coefficient on the one stand alone technical inefficiency variable, τ, is statistically significant in all the equations except in wheat and sorghum, implying that technical inefficiency does really matter.

5 Conclusions and Policy Implications

Increasing the efficiency and productivity of smallholder agriculture has been an important objective of the Ethiopian government in the 1990s. Market liberalisation, in particular price incentives, and encouraging fertilizer use have been the major policy instruments. There has been limited research on how farmers respond to these incentives. The purpose of this study is to assess the supply response of Ethiopian farmers in the presence of technical inefficiency. Two systems of output supply and input demand functions are estimated: one incorporating inefficiency and another without inefficiency. We compared the two models based on non-nested hypotheses tests and conformity to neo-classical assumptions of production theory.

A number of important conclusions emerge. First, while non-nested hypotheses tests provide no conclusive evidence, the model with technical inefficiency is clearly preferred to the other model based on theoretical consistency. Second, the results indicate that technical inefficiency restricts the parameter estimates of the traditional model. The effect of inefficiency may have been compounded into the parameter estimates of the standard model due to the exclusion of the inefficiency variable from the model; thus resulting in smaller elasticity estimates. Incorporation of inefficiency has generally increased the magnitudes and the statistical significance of own price elasticities, substantially so in the case of *teff* and fertilizer. In most cases, incorporation of technical inefficiency has increased the magnitudes and statistical significance of elasticities of non-price factors, particularly agricultural extension.

Third, peasant farmers in Ethiopia respond positively and significantly to price incentives. Forth, fertilizer usage appears to be more responsive to output prices, particularly of *teff*, barley and wheat, than to its own price. Policies directed at improving output prices may be the most effective way to encourage increased fertilizer use. Nevertheless, the response of output, especially that of *teff*, to fertilizer price is negligible. It is evident that education and extension services are required to ensure that fertilizer is used effectively.

Finally, 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. Therefore, 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 a direct effect on output, facilitating increased profitability, but equally important are the indirect effects by encouraging increased usage of fertilizer.

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Appendix A Definition of Variables

The output variables for individual crops are measured as total output produced, in kilograms. We used the actual market prices collected in each village by an independent price survey. In a very few cases where the price of a crop is not reported, we used unit values. For "other crops", a Laspeyer's quantity and price index was calculated by taking the share of the value of the output as a weight. Fertilizer is measured as total amount applied in kilograms. The price of fertilizer is calculated by dividing total expenditure by 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). Labour is defined as the number of person-days of traditional (share) and hired labour used in ploughing and harvesting. 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 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.

Land is total area of land cultivated in hectares. Land quality is defined as an index of the quality of cultivated land (1 being worst, 2 mediocre and 3 best). 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. 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. A proxy for access to land is measured by the share of the harvest paid in the form of rent for land. 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.[4] The rainfall variable is measured by multiplying the amount of rain in millimetres by the dummy for rain included in the questionnaire, in which the farmer is asked if rain was enough or on time. This way of measuring rainfall captures the seasonal and/or temporal variation of rain, as well as the amount, which is typically important in the case of Ethiopia. Extension is measured by the number of hours of extension services obtained.

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[4] We thank Bereket Kebede for bringing this variable to our attention.

Table A1 Average Output, Input use and Prices by Crop

Variable	*Teff*	Wheat	Barley	Maize	Sorghum	Other Crops
Land:						
Size (ha)	0.79	0.48	1.14	0.20	0.86	0.88
Share (%)	12.63	7.93	34.38	1.52	12.59	22.57
Quality	2.42	2.40	2.17	2.33	2.46	2.44
Output:						
Quantity(Kg)	255.58	210.42	518.00	67.43	252.93	190.07
Kg/ha	277.12	390.82	371.32	287.66	291.10	188.59
Share (%)	13.00	10.00	46.00	1.40	13.87	16.72
Surplus (%)	14.26	1.33	0.63	6.45	3.96	20.00
Fertilizer						
Quantity(Kg)	168.24	104.79	94.46	27.14	-	0.29
Kg/ha	83.71	115.30	38.05	11.71	-	1.20
Prices (*Birr*/Kg)	1.89	1.50	1.69	1.27	1.23	1.49

Table A2 Average Use of Inputs and Other Variables

Variable	Mean
Cultivated Land (ha)	2.17
Land Quality	2.30
Fertilizer	
Quantity(Kg)	98.53
Kg/ha	21.44
Prices (*Birr*/Kg)	1.49
Labour	
Man-days	31.96
Man-days/ha	8.54
Wage Rate (*Birr*/day)	2.84
Animal Power (numbers)	2.48
Farm Capital (*Birr*)	33.05
Land Access (*Birr*)	252.87
Market Access (Pop/Km)	3601.25
Rain (mm)	1241.00
Extension (hours)	3.27

Table A3 Summary Statistics on Technical Efficiency

Distribution	*Percent of Farmers*
≤0.9	15.6
0.10-0.19	6.0
0.20-0.29	7.0
0.30-0.39	9.1
0.40-0.49	9.2
0.50-0.59	7.2
0.60-0.69	6.6
0.70-0.79	6.8
0.80-0.89	5.8
0.90-0.99	5.9
1.0	20.8
Describtive Statistics	*Value*
Mean	0.55
St. Deviation	0.35
Minimum	0.00
Maximum	1.00

Appendix B Detailed Econometric Results

Table B1 Parameter Estimates: Model 1 (without technical inefficiency)

Variables	*Teff*	Wheat	Barley	Maize	Sorghum	Other Crops	Fertilizer
Price *Teff*	12.283	25.082	-44.309	6.315	25.074	-17.445	1.508
	(0.58)	(2.02)**	(2.43)**	(1.19)	(1.35)	(1.81)*	(0.26)
Price Wheat	25.082	40.011	-17.266	0.514	-47.988	-8.680	11.110
	(2.02)**	(2.66)***	(1.39)	(0.08)	(3.38)***	(1.08)	(2.58)***
Price Barley	-44.309	-17.266	-9.575	-6.839	78.142	11.035	-15.931
	(2.43)**	(1.39)	(0.36)	(1.50)	(4.28)***	(0.97)	(2.39)**
Price Maize	6.315	0.514	-6.839	5.360	-4.828	-2.021	-0.374
	(1.19)	(0.08)	(1.50)	(1.20)	(0.80)	(0.64)	(0.22)
Price Sorghum	25.074	-47.988	78.142	-4.828	63.184	5.893	12.231
	(1.35)	(3.38)***	(4.28)***	(0.80)	(2.27)**	(0.53)	(1.86)*
Price Other	-17.445	-8.680	11.035	-2.021	5.893	16.192	1.141
	(1.81)*	(1.08)	(0.97)	(0.64)	(0.53)	(1.72)*	(0.29)
Price Fertilizer	-1.508	-11.110	15.931	0.374	-12.231	-1.141	-1.795
	(0.26)	(2.58)***	(2.39)**	(0.22)	(1.86)*	(0.29)	(0.54)
Land Size	88.002	180.652	43.881	105.620	21.211	21.329	6.834
	(6.61)***	(10.45)***	(5.57)***	(5.81)***	(5.13)***	(5.48)***	(2.90)***
Animal Power	0.628	7.451	43.059	0.701	2.754	15.520	9.037
	(0.17)	(2.62)***	(5.67)***	(0.86)	(0.66)	(3.83)***	(4.28)***
Farm Capital	1.367	0.846	-0.084	0.108	0.382	0.374	0.194
	(7.02)***	(5.74)***	(0.22)	(2.46)**	(1.97)**	(1.85)*	(2.24)**
Land Quality	20.542	8.305	29.559	8.783	36.442	15.155	6.171
	(3.37)***	(1.72)*	(2.61)***	(4.18)***	(2.65)***	(3.02)***	(1.11)
Land Access	0.105	0.022	0.070	0.002	0.085	0.012	0.011
	(6.04)***	(1.71)*	(2.07)**	(0.48)	(4.67)***	(0.66)	(1.41)

Table B1 (contd.)

Variables	***Teff***	**Wheat**	**Barley**	**Maize**	**Sorghum**	**Other Crops**	**Fertilizer**
Market Access	-0.002	0.000	0.055	0.000	0.026	0.010	0.004
	(1.07)	(0.04)	(15.36)***	(0.66)	(14.33)***	(5.84)***	(3.31)***
Rainfall	0.316	0.144	0.081	0.023	-0.128	0.085	0.074
	(16.70)***	(9.77)***	(2.21)**	(5.27)***	(6.43)***	(4.39)***	(8.82)***
Extension	1.624	4.633	18.476	1.178	5.411	6.220	6.489
	(0.14)	(0.94)	(1.68)*	(0.44)	(0.74)	(0.50)	(2.16)**
DU12	2.942	-8.803	15.909	0.438	-118.558	14.252	4.474
	(0.19)	(0.81)	(0.50)	(0.13)	(6.39)***	(0.80)	(0.58)
Mill's Ratio							-11.399
							(1.26)
Constant	-26.472	-18.402	-161.554	-2.953	71.624	-78.116	-16.504
	(2.17)**	(2.28)**	(7.15)***	(1.19)	(2.01)**	(2.37)**	(0.83)

Notes: Absolute value of z-statistics in parentheses. *Significant at 10%; ** significant at 5%; *** significant at 1%.

Table B2 Parameter Estimates: Model 2 (With technical inefficiency)

Variables	*Teff*	Wheat	Barley	Maize	Sorghum	Other Crops	Fertilizer
Inefficiency (τ)	-98.075	-23.852	-299.615	-13.686	27.150	-170.953	-73.082
	(3.67)***	(1.43)	(6.42)***	(2.90)***	(0.55)	(3.78)***	(4.09)***
Price *Teff*	60.904	42.787	-80.318	5.678	-25.225	-15.987	3.945
	(1.40)	(1.46)	(2.52)**	(0.48)	(0.74)	(0.75)	(0.98)
Price Wheat	42.787	101.128	-26.036	-6.586	-55.480	-30.448	51.303
	(1.46)	(2.83)***	(1.03)	(0.58)	(2.02)**	(1.86)*	(3.28)***
Price Barley	-80.318	-26.036	10.989	-3.191	86.867	25.647	-24.330
	(2.52)**	(1.03)	(1.04)	(0.36)	(1.98)**	(0.99)	(1.66)*
Price Maize	5.678	-6.586	-3.191	1.387	-1.834	-1.678	-4.899
	(0.48)	(0.58)	(0.36)	(1.09)	(0.17)	(0.29)	(0.78)
Price Sorghum	-25.225	-55.480	86.867	-1.834	50.145	-26.615	14.692
	(0.74)	(2.02)**	(1.98)**	(0.17)	(3.13)***	(1.26)	(1.94)*
Price Other	-15.987	-30.448	25.647	-1.678	-26.615	29.550	0.246
	(0.75)	(1.86)*	(0.99)	(0.29)	(1.26)	(5.74)***	(0.03)
Price Fertilizer	-3.945	-51.303	24.330	4.899	-14.692	-0.246	-34.245
	(0.98)	(3.28)***	(1.66)*	(0.78)	(1.94)*	(0.03)	(2.74)***
Land Size	120.713	184.633	60.248	110.606	41.399	40.014	11.530
	(8.16)***	(10.58)***	(7.35)***	(6.17)***	(10.76)***	(4.55)***	(5.53)***
Animal Power	6.417	13.466	14.520	0.566	16.668	12.855	15.943
	(1.77)*	(5.64)***	(0.79)	(0.35)	(1.69)*	(1.30)	(4.15)***
Farm Capital	0.247	0.230	0.853	-0.012	0.607	0.422	0.315
	(0.53)	(0.78)	(2.09)**	(0.16)	(1.32)	(0.97)	(1.72)*
Land Quality	42.059	11.899	87.324	9.308	24.086	36.395	5.300
	(6.45)***	(2.68)***	(7.94)***	(4.66)***	(1.87)*	(2.27)**	(0.78)
Land Access	0.375	0.214	0.357	-0.002	-0.086	0.095	0.236
	(1.80)*	(1.62)	(0.93)	(0.05)	(0.40)	(0.47)	(2.76)***

Table B2 (contd.)

Variables	Teff	Wheat	Barley	Maize	Sorghum	Other Crops	Fertilizer
Market Access	0.001	0.009	0.035	0.001	0.029	0.004	0.007
	(0.16)	(3.35)***	(4.41)***	(0.93)	(6.39)***	(1.03)	(4.19)***
Rainfall	0.506	0.157	0.190	0.018	-0.071	0.041	0.115
	(5.84)***	(2.98)***	(4.82)***	(4.74)***	(0.86)	(2.23)**	(3.62)***
Extension	22.099	11.093	39.875	2.517	26.307	14.190	9.821
	(1.98)**	(2.06)**	(2.45)**	(0.91)	(1.99)**	(1.62)	(2.79)***
DU12	55.933	2.382	-12.693	9.237	-31.226	40.532	12.572
	(2.55)**	(0.18)	(0.30)	(2.50)**	(1.36)	(1.89)*	(1.36)
Mill's Ratio							5.793
							(1.66)*

Notes: Absolute value of z-statistics in parentheses. *Significant at 10%; ** significant at 5%; *** significant at 1%.