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Supply Response of Peasant Farmers in Ethiopia: A Farm –Level Profit Function Analysis

by

Suleiman Abrar, Oliver Morrissey and Tony Rayner

Centre for Research in Economic Development and International Trade, University of Nottingham

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The Authors

Sulieman Abrar is a Lecturer in Economics, Addis Ababa University, and research student in the School of Economics, University of Nottingham. Oliver Morrissey is Director of CREDIT and Reader in Development Economics, University of Nottingham. Tony Rayner is Emeritus Professor, School of Economics, University of Nottingham.

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Abstract
This study assesses the responsiveness of peasant farmers to price and non-price factors using a farm-level survey data from Ethiopia, and the extent to which responsiveness varies with agro-ecology and farming systems. Agro-climatic and farming system differences are explicitly taken into account by estimating the Northern and Central highlands of the grain-plough, as well as the Southern enset-hoe, systems separately. Peasant farmers in Ethiopia respond positively and significantly to price incentives, and responsiveness to prices is far greater in the more climatically favoured and commercially oriented regions of the Central and Southern highlands. This suggests that agro-climatic and farming system differences need to be taken into account in designing and implementing agricultural policy. Some important differences are also observed in the relative importance of non-price variables across zones, although the difference is not generally large compared to the effects of prices. The results underscore the need to strengthen market incentives through effective policies that will improve farmer's access to better quality land, credit and inputs, and public investment in roads and irrigation. Even more so in the Northern highlands where these factors are far more important in affecting production and resource use than price incentives.

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] Food grains (cereals, pulses and oilseeds) account for about 45 per cent of GDP, and contribute about 90 percent of the daily diet of households. Cereals make up for approximately 85 percent of the value added of food grains. Maize, which is the major consumption item in most of rural Ethiopia, accounts for 27 percent of total cereal output, followed by *teff*[2] with about 20 percent. *Teff* is the most dominant in terms of area cultivated and fertilizer consumption. Whereas cereals are predominantly produced for domestic consumption, significant proportions of pulses and oil seeds are exported. Other food crops, mainly *enset*[3] and other tubers, account for some 12 percent of agricultural value added, while cash crops such as coffee and *chat*[4] account for just less than 10 per cent.[5] Coffee is the major export product accounting for nearly 60 percent of foreign exchange earnings.

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. These essentially structural problems are magnified by the presence of institutional rigidities and policy constraints. These inter-linked factors have contributed to declining productivity and stagnating yields in the sector. 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.

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).

2 *Teff* is a cereal unique to Ethiopia, a non-exportable cash crop that is the single most important staple food in Northern and South Ethiopia.

3 *Enset* (false banana) is a perennial and the major staple for an estimated 15-20 percent of the population, mostly in the South.

4 *Chat* is a perennial cash crop and a strong stimulant which is widely used in the Southern and Eastern parts of the country. It is rapidly emerging as an export item. It is called Q'at in Djibouti, Yemen, Kenya and Somalia.

5 See Alem (2000) for a succint review of the agricultural sector in Ethiopia.

Direct (sector-specific) agricultural policies have been adopted that include early and rapid moves towards deregulating food grains markets (initiated in 1989 under the previous government) and price support for export crops. This was further strengthened by subsequent reforms in agricultural input markets, especially fertilizer. Most importantly, a new system of extension programmes was launched in 1994/95. In general, the reform measures of the 1990s mostly focused, directly or indirectly, on 'getting prices right'. 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).[6] Nevertheless, how much of this recovery is due to price incentives and how much due to non-price factors is not clear. It is therefore appropriate to try and determine how responsive farmers are to the resulting price changes.

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 1996). The only exception is Abebe (1998) who used aggregate time series data to estimate yield and area responses of aggregate as well as five major cereals. Based on the short and long-run elasticities, he found fairly inelastic responses to prices. Zerihun (1996) addresses similar concerns and argues that aggregate food grain production changes only slightly following price incentives.

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). 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

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

to estimate the level of technical efficiency[7], 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. Most importantly, all studies focused on a single farming system, grain-plough cereal system. Differences in agro-ecology and technology are ignored at worst, or captured by dummy variables at best. Even under the few occasions where technology was explicitly introduced in the analysis (e.g. Asmerom and David, 1994), the role of prices is ignored. In the African context, Savadogo *et al* (1995) is the only study which explicitly addresses the effficts of agro-ecology and technology on farm level supply response of peasant farmers in Burkina Faso.

This paper primarily aims at examining peasant responsiveness to price and non-price factors using farm-level survey of 1500 farmers from 18 villages of Ethiopia in 1994-1997. In an earlier paper, we carried out a farm-level cross-section analysis of aggregate supply response using the first wave of the same data (Abrar, 2001a, 2001b). In this study, we estimate supply responses for six major food crops (*teff*, wheat, barley, maize, sorghum, and *enset*) and three cash/export crops (coffee, *chat*, and an aggregate of other minor cash crops). As a secondary objective, we assess the extent to which responsiveness varies with farming systems and agro-ecology. To this end, all the study villages are first classified into two farming systems, grain-plough and *enset*-hoe. Agro-climatic differences are then explicitly taken into account by modelling the Northern and Central highlands of the grain-plough, as well as the Southern *enset*-hoe, systems separately.

The rest of the paper is organized as follows. The modelling approach is set out in Section 2. After a short description of the data (details are in Appendix A), Section 3 discusses the salient features of the farming systems and agro-climatic zones. Section 4 briefly presents the estimation procedures (with econometric detail provided in Appendix B) and discusses the results. The conclusions are in Section 5, which draws out the policy implications.

7 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.

II MODELLING FRAMEWORK

Suppose that the production transformation set is represented by:

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

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

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

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:

$$\mathbf{y}_i (\mathbf{p}, \mathbf{w}; \mathbf{z}) = \partial\pi(\mathbf{p}, \mathbf{w}; \mathbf{z})/\partial\mathbf{p}_i, \ \forall\ i = 1, \ldots, n \quad (3)$$

and

$$-\mathbf{x}_r(\mathbf{p}, \mathbf{w}; \mathbf{z}) = \partial\pi(\mathbf{p}, \mathbf{w}; \mathbf{z})/\partial\mathbf{w}_r, \ \forall\ r = 1, \ldots, m \quad (4)$$

where i and r index the outputs and variable inputs respectively. The econometric approach of the paper is to estimate a quadratic normalized restricted profit function, i.e. a fully specified version of (2), from which supply response can be identified by applying (3) and (4). Homogeneity is imposed through dividing profit and all prices by the wage rate; thus, the labour demand equation in (4) is excluded from estimation. Final estimation is carried out using iterative Seemingly Unrelated Regression, as discussed in Section 4 below.

III DATA AND CLASSIFICATION OF THE STUDY VILLAGES

The data we use is the Ethiopian Rural Household Survey (ERHS), a nationally representative survey of rural households conducted during 1994-2000. The survey was undertaken in 18 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.[8] 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.

The classification of farming systems ultimately depends on the purpose of the study. There are various considerations in this regard, such as allowing for administrative boundaries and agro-ecological or socio-economic variations. Some studies (e.g., Westphal, 1975) classified sedentary agriculture in Ethiopian highlands into plough based (or grain-plough) and hoe based (or *enset*-hoe) mixed farming complexes. Central and North Central highlands fall in the grain-plough system where ox-plough is the major technology, and most of sedentary agriculture in Southern Ethiopia falls under *enset-hoe* system. Accordingly, we first classify all the study villages into these two farming systems. The grain-plough system is again classified into two agro-climatic zones: Northern and Central highlands. Classifying the villages this way at once takes into account agro-climatic and geographic features, farming systems and technology, as well as economic considerations such as cropping patterns. Details of measurement and summary statistics on production, input use and prices are given in Appendix A.

The Northern zone consists of nine peasant associations (PAs) namely, Haresaw Tabia, Geblen Tabia, Dinki, Shumshaha, Yetmen, and the four PAs in Debre Birhan. All but two of the villages are located in region 3. For Geblen and Harasaw, both in region 1, a dummy is included (du12). This zone is characterized by an extreme form of climate (*dega* or *kola*), frequent failure of rain, as well as chronic drought and famine. Partly due to risk aversion in subsistence farming, mixed farming is common. Production is predominantly for subsistence and very low amounts of fertilizer are used, with the possible exception of Yetmen.

8 The final sample consists of fewer observations (1296 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. Further observations are excluded through a preliminary analysis of outliers based on the examination of residuals.

Production is highly skewed towards non-*teff* cereals like barley, wheat and sorghum, although a significant amount of maize and *teff* are produced in Dinki and Yetmen. Barley alone accounts for nearly 35 percent of the area cultivated and 46 percent of production (Table A1). Average land holding is 2.17 hectares, which is much higher than the other two zones. Nevertheless, most farms are too small and highly fragmented, with plots scattered and not easily accessible. Topography and soil quality are not good owing to high level of soil erosion and overgrazing. Consequently, the productivity of land is very low. Barley per hectare, for example, is only half as much as in the Central zone.

The Central zone consists of four surplus producing cereal areas namely, Sirbana Godeti, Turufe Kechema, Korodegaga, Adele Keke, all in region 4. This zone is characterised by a higher level of output and yield per hectare, higher use of fertilizer and other inputs, and higher level of market integration than the Northern zone. It is also the most favoured in terms of climate, terrain, and soil fertility. Some farms have access to irrigation and tractors. Cereals are dominant, accounting for over 70 percent of land cultivated (Table A2), although, unlike the North, farming is highly diversified. Tree crops such as *chat*, coffee, sugar cane, and other minor cash crops, such as potato, are produced. *Teff* is the major crop accounting for about 35 and 30 percent of area cultivated and production respectively, followed by maize (about 23 and 10 percent) and wheat (about 12 and 16 percent). In Kersa, which is located in the Eastern highlands, hoe based perennial cropping is very common and production of *teff* is virtually non-existent. We include a dummy (du8) to control for this effect.

The Southern zone consists of five PAs namely, Imdibir, Adado, Aze Deboa, Gara Godo, and Doma, all of which are found in the Southern Regional Administration. All the villages are in the temperate highlands where the soil is quite fertile. This zone is characterized by high population density, and hence high level of out migration. Production is more diversified than the other two zones. Farmers typically produce perennial cash crops such as coffee, *chat*, and fruit, and a perennial staple crop, *enset* (mainly for own consumption). They also produce significant amounts of cereals, root crops and vegetables. Maize is by far the most important cereal grown for both consumption and markets, while *teff* is predominantly produced for sale. In Gara godo and Doma, grain-plough is common and production is largely for subsitence, hence we include a dummy to capture this effect (du16).

Only a few farmers use fertilizer (less that 40 percent), and nearly all of them for maize and *teff*. Farmers here use less than half and one third the amount of fertilizer as farmers in the Northern and Central zones respectively (Table A3). Average land holding is only 0.77 hectares (Table A4), which is about half and one third as the size in the Central and Northern zones respectively. They use almost twice as much labour as farmers in the North. Labour per hectare is much higher than the other two zones (roughly more than twice and five times as much as the Central and Northern zones respectively).

IV ESTIMATION AND RESULTS

In each zone six crops, 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 three 'exogenous' controls - land access, market access, and rainfall. For the Northern and Central zones we include four major cereals - *teff*, wheat, barely and maize. While sorghum is also modelled in the former, an aggregate of perennial cash crops, largely composed of coffee and *chat*, labelled as 'tree crops', is added in the latter. In the South, separate equations are fitted for *teff,* coffee, *chat, enset* and maize.

A sixth crop variable is formed as 'other crops' for all three zones. This is an aggregate of three minor cash crops categories - legumes, root crops and tubers and vegetables. The relative importance and composition of these crops, however, vary across zones. Legumes (notably beans and linseed) and vegetables (notably onions) dominate the basket in the North, root crops (notably potato) in Central, and legumes (mainly beans) and vegetables (mainly selata) in the South. Note also that this aggregate includes a wider variety of crops and is more heterogeneous in Northern than the other two zones.

Supply response for each of the three zones is estimated separately using a quadratic normalized restricted profit function, with homogeneity imposed by dividing profit and prices by the wage rate. The system of six output supply equations and one input demand equation (fertilizer) is estimated using iterative Seemingly Unrelated Regression. To estimate the fertilizer demand equation consistently (that is to ensure zero expectation of the error terms), we followed the two-stage Heckman (1979) procedure. The fertilizer equation is not included for the Southern zone where fertilizer is rarely used. Instead, we used a dummy (duf2) to capture the effect of fertilizer. Details of the econometric methods are provided in Appendix B. Estimated parameters from the system of output supply and fertilizer demand equations for the Northern, Central and Southern zones, with symmetry imposed, are, respectively, in Tables B1 through B3.

The signs and magnitudes of the parameters are generally consistent with theory and the farming conditions of the three zones. All own price coefficients have expected signs except for barley in the North, which is insignificant suggesting a statistical lack of response. There are a few unexpected signs as well for non-price variables, all of which are insignificant with the exception of rainfall for sorghum and land size for *teff* in the Northern and Central zones respectively. Nearly half of the parameters are significant at five percent.

There are big differences in the importance of price and non-price variables among the three zones. In the North, about 75 and 60 percent of the non-price variables are significant at five and one percent respectively. On the other hand, only 29 percent of prices are significant at five percent. In the South, however, 50 percent of the price and only 40 percent of the non-price coefficients are significant at five percent, with only 26 percent of non-price variables significant at one percent. In the Central zone, only 50 and 60 percent, respectively, of price and non-price variables are significant at five percent.

Some differences are also observed in the relative importance of price and non-price variables across crops, apparently more so in the South. For example, the *chat* equation has only two non-price variables (29 percent) significant at one percent, but four of the six prices are significant at this level. This is generally the trend in the South except for *teff* and *enset.* The only other case where this trend applies is for tree crops in the Central zone, where four of seven prices are significant at one percent, and only one non-price variable is significant at five percent. In general, it appears to be the case that prices are at least as important for cash crops as non-price variables.

Own Price Elasticities

Price and non-price elasticities for the three zones, calculated at data mean points, are given in Tables 1 through 3, respectively. With the exception of *chat* in the South, price elasticities are all less than unity, often considerably so in the North. Further, all but two own price elasticities are significant at five percent in the climatically favoured and more commercially orientated zones of the Central and the South. Exceptions are barley in the Central (insignificant at all) and *enset* in the South (significant only at ten percent). With the exception of three cases (including the above two), all of these prices are significant at one percent. In the Northern zone, however, only wheat and sorghum have own price elasticities significant at five percent.

The own price elasticities in North are very low, the highest being for wheat and sorghum (0.20). In light of higher shares of marketed surplus for other crops and *teff*, compared to wheat and sorghum, such a significant response 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) rather than by commercial motives. Fertilizer has the lowest own price elasticity, 0.02. Own price elasticities in the Central and Southern zones are substantially higher.

In the Central zone, maize has the highest own price elasticity, 0.62, followed by *teff*, 0.44. In the Southern region as well, the own price elasticity of maize, 0.57, is the second highest, only next to *chat*. This is possibly because *teff* and maize markets are more integrated than those of wheat and barely (ADE, 1995, quoted in Alem, 2000). The higher response of maize may also be due to multiple cropping. Compared to other cereals, there is greater flexibility in the production of maize, as a significant amount is produced during *belg*. The data show that about 60 and 30 percent of maize is produced during *belg* in the Southern and Central zones, respectively.

The only elastic value is the own price elasticity of *chat* in the South, 1.08, and is considerably higher than that of coffee, which is only 0.35. This is not surprising for several reasons. First, *chat* is a rapidly emerging export item. Second, *chat* is becoming increasingly profitable owing partly to a steady rise in its price over the last decade. Furthermore, coffee production has been depressed by highly volatile international prices (FAO, 2002), and this might have resulted in fluctuations in the incomes of coffee farmers.

The own price elasticity of coffee is even lower compared to *teff* and maize. Thus, there is only a small, though statistically significant, response in the production of coffee to the series of devaluations aimed at boosting the production of coffee. Evidence from aggregate time series studies show a small and statistically insignificant export supply response to price incentives. 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 meaningful 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.

Meanwhile, the own price elasticity of tree crops in the Central zone is also low compared to *teff* and maize. Lower short run responses for permanent crops like coffee might be attributed to the inherent inflexibility in the use of land. Not only because it takes longer to shift land away from food grains, but also because they are important for survival and food self-sufficiency. It needs to be mentioned that, in the Ethiopian highlands, extensification is not an option for increasing the size of land holdings in response to price incentives.

The only feasible options are intensification (increasing yield through fertilizer) and crop mix shifts. All of these possibilities are, to some extent, practised in the Central zone. In the North, where fertilizer is not frequently used and land is of poor quality, farmers should be relying largely on crop mix shifts. In the South, the dominant role of permanent crops, coupled with high population density, have made short run output expansion by changing crop mix even more limited. This could be part of the reason why supply response of export/cash crops like coffee is relatively lower than cereals, particularly in the Southern zone.

Table 1 Estimated Elasticites: Northern Highlands[1]

With respect to:	*Teff*	Wheat	Barley	Maize	Sorghum	Other Crops	Fertilizer
Price *Teff*	0.06	0.14	0.11	0.11	0.12	-0.11	0.02
	(0.58)	(1.98)**	(2.46)**	(1.12)	(1.33)	(1.69)*	(0.22)
Price Wheat	0.11	0.20	-0.03	0.01	-0.21	-0.04	0.13
	(1.98)**	(2.61)***	(1.29)	(0.07)	(3.49)***	(0.94)	(2.63)***
Price Barley	-0.20	-0.04	-0.02	-0.11	0.35	0.05	-0.18
	(2.46)**	(1.29)	(0.26)	(1.46)	(4.28)***	(0.78)	(2.24)**
Price Maize	0.02	0.002	-0.01	0.08	-0.02	-0.01	-0.003
	(1.12)	(0.07)	(1.46)	(1.24)	(0.75)	(0.62)	(0.16)
Price Sorghum	0.08	-0.19	0.12	-0.05	0.20	0.03	0.10
	(1.33)	(3.49)***	(4.28)***	(0.75)	(2.27)**	(0.68)	(1.83)*
Price Other Crops	-0.07	-0.04	0.02	-0.03	0.03	0.08	0.01
	(1.69)*	(0.94)	(0.78)	(0.62)	(0.68)	(1.54)	(0.12)
Price Fertilizer	-0.01	-0.06	0.03	0.004	-0.05	-0.003	-0.02
	(0.22)	(2.63)***	(2.24)**	(0.16)	(1.83)*	(0.12)	(0.61)
Land Size	0.76	1.83	0.19	3.39	0.18	0.20	0.16
	(6.61)***	(10.32)***	(5.67)***	(5.81)***	(5.23)***	(4.55)***	(2.93)***
Animal Power	0.01	0.08	0.20	0.03	0.02	0.19	0.22
	(0.16)	(2.55)**	(5.55)***	(0.84)	(0.57)	(3.57)***	(4.01)***
Farm Capital	0.18	0.13	-0.003	0.05	0.05	0.07	0.07
	(7.07)***	(5.83)***	(0.11)	(2.53)**	(1.81)*	(1.99)**	(2.44)**
Land Quality	0.19	0.10	0.14	0.30	0.32	0.27	0.13
	(3.36)***	(1.86)*	(2.64)***	(4.20)***	(2.60)***	(4.31)***	(1.00)
Land Access	0.11	0.02	0.03	0.01	0.08	0.002	0.03
	(6.03)***	(1.72)*	(2.07)**	(0.48)	(4.66)***	(0.76)	(1.41)
Market Access	-0.03	0.00	0.39	0.00	0.43	0.15	0.15
	(1.08)	(0.13)	(15.64)***	(0.62)	(14.37)***	(4.38)***	(3.37)***
Rainfall	1.56	0.82	0.19	0.42	-0.63	0.52	0.94
	(16.72)***	(9.79)***	(2.21)**	(5.25)***	(6.42)***	(4.01)***	(8.72)***

1 Absolute values of z-statistics in parentheses. *significant at 10%; ** significant at 5%; *** significant at 1%.

Table 2 Estimated Elasticites: Central Highlands[1]

With respect to:	*Teff*	Wheat	Barley	Maize	Tree Crops	Other Crops	Fertilizer
Price *Teff*	0.44	-0.20	0.29	-0.89	-0.21	-0.03	0.43
	(3.09)***	(1.69)*	(2.21)**	(3.99)***	(3.33)***	(0.40)	(2.30)**
Price Wheat	-0.15	0.24	-0.26	0.46	0.03	-0.03	0.10
	(1.69)*	(2.11)**	(2.52)**	(2.79)***	(0.89)	(0.81)	(0.65)
Price Barley	0.13	-0.16	0.13	0.23	-0.06	-0.05	-0.41
	(2.21)**	(2.52)**	(1.21)	(1.82)*	(1.67)*	(1.93)*	(3.64)***
Price Maize	-0.28	0.19	-0.16	0.62	0.11	0.02	0.11
	(3.99)***	(2.79)***	(1.82)*	(3.80)***	(3.19)***	(0.53)	(0.95)
Price Tree Crops	-0.16	0.03	-0.10	0.06	0.35	0.10	0.11
	(3.33)***	(0.89)	(1.67)*	(3.19)***	(6.71)***	(2.81)***	(1.64)
Price Other Crops	-0.03	-0.04	-0.12	0.05	0.12	0.12	0.11
	(0.40)	(0.81)	(1.93)*	(0.53)	(2.81)***	(2.06)**	(1.40)
Price Fertilizer	-0.07	-0.02	0.15	-0.06	-0.02	-0.02	-0.35
	(2.30)**	(0.65)	(3.64)***	(0.95)	(1.64)	(1.40)	(4.21)***
Land Size	-0.20	1.45	-0.08	0.25	0.08	0.14	0.07
	(3.11)***	(8.20)***	(1.41)	(2.89)***	(1.35)	(2.27)**	(1.09)
Animal Power	0.59	0.14	0.12	0.13	-0.01	0.16	0.36
	(11.02)***	(4.17)***	(2.64)***	(1.80)*	(0.13)	(2.99)***	(4.78)***
Farm Capital	0.09	0.05	0.02	0.14	-0.004	0.02	0.13
	(2.83)***	(2.58)***	(0.90)	(3.55)***	(0.15)	(0.80)	(4.35)***
Land Quality	0.31	0.09	0.71	0.09	0.38	0.00	0.11
	(2.89)***	(1.59)	(11.31)***	(0.27)	(1.79)*	(0.00)	(0.48)
Land Access	0.14	0.12	0.05	0.19	0.02	0.32	0.32
	(2.67)***	(3.29)***	(1.32)	(2.78)***	(0.44)	(6.31)***	(6.80)***
Market Access	1.23	0.54	0.22	1.30	0.10	1.32	0.41
	(7.88)***	(6.09)***	(2.07)**	(6.76)***	(0.90)	(8.95)***	(2.88)***
Rainfall	1.08	0.10	0.09	0.34	0.22	-0.15	0.59
	(9.88)***	(1.48)	(1.05)	(2.34)**	(2.33)**	(1.34)	(5.50)***

1 Absolute values of z-statistics in parentheses. *significant at 10%; ** significant at 5%; *** significant at 1%.

Table 3 Estimated Elasticites: Southern Zone[1]

With respect to:	*Teff*	Coffee	*Chat*	*Enset*	Maize	Other Crops
Price *Teff*	0.35	-0.004	0.01	-0.08	-0.27	0.001
	(2.40)**	(0.16)	(0.97)	(1.69)*	(2.78)***	(0.14)
Price Coffee	-0.004	0.35	-0.17	0.07	-0.15	0.03
	(0.16)	(3.24)***	(3.40)***	(0.99)	(3.64)***	(1.31)
Price *Chat*	-0.02	-0.22	1.08	-0.02	-0.02	-0.10
	(0.97)	(3.40)***	(15.89)***	(3.05)***	(0.61)	(4.09)***
Price *Enset*	-0.08	0.06	-0.12	0.13	-0.05	0.04
	(1.69)*	(0.99)	(3.05)***	(1.69)*	(0.95)	(2.31)**
Price Maize	-0.29	-0.18	-0.01	-0.05	0.57	0.003
	(2.78)***	(3.64)***	(0.61)	(0.95)	(6.35)***	(0.34)
Price Other Crops	0.002	0.08	-0.23	0.12	0.01	0.17
	(0.14)	(1.31)	(4.09)***	(2.31)**	(0.34)	(3.78)***
Land Size	0.15	0.42	0.06	0.07	0.20	0.29
	(3.41)***	(4.96)***	(0.68)	(0.93)	(5.43)***	(4.29)***
Animal Power	0.08	0.35	0.07	0.23	0.12	0.09
	(2.47)**	(2.30)**	(0.42)	(1.81)*	(1.86)*	(0.79)
Farm Capital	0.004	0.05	0.21	0.18	-0.01	0.06
	(0.31)	(0.82)	(3.26)***	(3.44)***	(0.51)	(1.20)
Land Quality	0.69	-0.04	-0.43	0.27	0.21	0.35
	(11.50)***	(0.08)	(0.87)	(0.64)	(1.01)	(0.90)
Land Access	0.02	0.26	-0.02	0.29	0.41	-0.14
	(0.60)	(2.02)**	(0.13)	(2.49)**	(7.21)***	(1.23)
Market Access	-0.03	1.07	2.41	1.56	0.25	1.41
	(0.41)	(3.52)***	(9.89)***	(5.65)***	(1.90)*	(6.85)***
Rainfall	0.11	0.65	-0.22	0.51	0.19	0.01
	(2.07)**	(2.26)**	(0.91)	(3.01)***	(1.63)	(0.04)

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

Cross-Price Elasticities

To determine the role of inter-crop competition for land in explaining cross-price effects, we have computed a matrix of partial correlation coefficients among the areas cultivated in each crop for each zone. The results, which are reported in Appendix A, show that inter-crop competition for land is mainly the driving force behind the relationship of crops in the Northern zone, while it is rarely so in the Central zone. In the latter, the competition for fertilizer is quite important. In the South, the competition for land seems to be at least as important as for other resources. Other factors, such as inter-cropping and multiple cropping, are also important to explain cross-price effects.

Table 1 shows that for the Northern zone, unlike the other two zones (Tables 2 and 3), cross-price elasticities are more important determinants of supply and input demand decisions than own prices. *Teff* is a strong complement to wheat while it is a strong substitute with barley. Wheat is a strong substitute with sorghum. Both *teff* and wheat are also weak substitutes with other crops. On the other hand, barley and sorghum are strong complements to each other (with the highest cross-price elasticity of 0.35, significant at one percent), and both are very weak complements to other crops.

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. Thus, 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. The partial correlation coefficients of area cultivated (Table A5) show generally similar trends to the cross-price elasticities. Therefore, it is highly likely that the cross-price elasticities and the resulting relationships among the crops in the Northern highlands have been driven mostly by the apparent competition for scare land. The only exception is the relationship between barley and sorghum - the correlation coefficient in this case suggests that they are substitutes.

In the Central zone, *teff* is a strong substitute with maize and tree crops, significant at one percent, but it is a complement to barley at five percent. Maize is a strong complement to wheat and tree crops, significant at one percent, but a weaker substitute with barely. While wheat and barely are substitutes at five percent, tree crops is a complement to other crops at one percent. Unlike the North, correlation coefficients (Table A6) show that the relationship of crops is not simply the result of competition for land. Note that the highest price elasticity in the Central zone is the cross-price elasticity of maize with respect to the price of *teff*, -0.85.

This is because these two crops are the most important crops in terms of area cultivated, use of fertilizer and hired labour, and hence there is fierce competition for all resources, including land. The correlation coefficients show that there is significant competition for land between these two crops. On the other hand, the cross-price elasticity of *teff* with respect to the price of maize is only -0.28, confirming that resource share is in favour of *teff*. Also, maize, unlike *teff,* is a complement to most of the crops. This is because it is the most inter-cropped crop in the region. The data show that it is usually inter-cropped with sorghum, tree and other crops during *belg*, and sometimes with wheat during *meher*.

In the South, crops are mostly substitutes to one another. The only significant complementary relationship is between *enset* and other crops. The highest cross-price elasticity is that of *teff* with respect to the price of maize, -0.29, significant at one percent. The is not surprising as these are the only cereals produced and hence the competition for land and fertilizer is very high (mainly for fertilizer since the partial correlation coefficient between areas cultivated of the two crops is negative but not significant). Maize is also a strong substitute with coffee, a relationship largely driven by competition for land as the partial correlation coefficients are negative and highly significant.

Chat is a strong substitute with the other cash crops, coffee and other crops, at one percent. It is also a strong substitute with *enset*. Note however that the partial correlation coefficients between *chat* and these crops is positive (and significant in the case of *enset*). This indicates a rather different nature of the competition among these crops, possibly the result of competition for labour and manure. For example, *enset* and *chat* are usually grown in the garden near homes and female labour is mostly involved in the harvesting and processing. A larger proportion of manure appears to be used for coffee as the elasticity of animal power is the highest for coffee. Note that *enset* is mostly intercropped with coffee, and hence they are complements but not significant. However, the partial correlation coefficients show that they are strong complements when it comes to land (with the highest correlation coefficient of 0.81).

Non-Price Elasticities

Land size, rain and land quality seem to be most important in the Northern zone. Land elasticity is very high and significant at one percent for all crops, suggesting that land is a critical constraint. Output elasticities of land for maize and wheat are particularly high and elastic, 3.39 and 1.83 respectively. The elasticity of land quality is also significant at one percent for all crops except wheat, which is significant only at 10 percent. The benefits from more land of better quality is, therefore, high in this region. Rain is everywhere positive (except for sorghum) and significant at one percent (except for barely, significant at five percent). This confirms that nothing is as crucial for agriculture in this drought-prone region as rain is. The negative elasticity of rain for sorghum (significant at one percent) is unexpected. As sorghum is drought resistant, farmers may tend to shift towards less drought tolerant crops such as *teff* and wheat that will bring higher returns during high rainfall years.

In the Central zone, market access, animal power and land access are most binding constraints. Animal power is significant at one percent in all but two cases. The two exceptions are maize (significant at 10 percent) and tree crops (negative and insignificant). The highest response for animal power comes from *teff* which has elasticity of 0.59. In the Southern zone, however, animal power is significant at five percent only for *teff* and coffee, the latter having the highest elasticity of 0.35. This might be due to the higher use of manure for coffee. With the exception of barley and tree crops, land access is significant at one percent, with the highest elasticity in other crops and maize. In the Northern zone where land renting opportunities are limited, the elasticity of land access is far lower and is significant at five percent only for *teff*, barely and sorghum.

The most important non-price element in both the Central and Southern regions is market access. In the South, with the exception of *teff* and maize, this elasticity exceeds one, all significant at one percent, with *chat* having the highest value of 2.41. Similarly, the supply response of market access is quite high in the Central region. Output elasticities of market access are all significant at one percent, with the exception of barley (significant at five percent) and tree crops (insignificant). T*eff*, maize and other crops have elasticities greater than one. In contrast, the variable for market access is mostly insignificant in the North, suggesting the subsistence nature of production in this zone.

The results show that land size, rain, and land quality are also important in the Central and Southern zones, if not as severely binding as in the North. With the exception of wheat and maize (in the Central) and coffee and other crops (in the South), the magnitude of output elasticity of land size is no greater than 0.20. But the response of wheat and coffee to additional land is quite high, with elasticities of 1.45 and 0.42 respectively. This shows that an increase in land will lead to a proportionately larger increase in the output of these crops. The elasticity of land for *teff* in the Central zone is negative and significant at one percent. It is possible that additional land is not allocated to *teff*, and that farmers substitute out of *teff* as acreage expands. In the Central region, land quality is significant only for barley and *teff*, with elasticities of 0.71 and 0.31, respectively. In the Southern zone, the only significant value of land quality is calculated for *teff*. The elasticity of rain is significant at one percent only for *teff* in the Central (with an elasticity of 1.08) and maize in the South (with an elasticity of 0.51). Rain is also an important factor for coffee in the South and for tree crops in the Central region.

Fertilizer Demand

In the Northern zone, own price of fertilizer is very low and highly insignificant. The own price of fertilizer in the Central zone, 0.35, is more than ten times higher, and is significant at one percent. In the North, prices of output and non-price factors appear to be more important than own price. The largest output price effect on fertilizer demand comes from the price of barely, with an elasticity of -0.18 (significant at five percent), followed by the price of wheat (significant at one percent) but with an opposite sign. In the Central zone, the largest price effect comes from the price of *teff*, with an elasticity of 0.43, significant at one percent, followed by the price of barley but with an opposite sign.

Higher response of fertilizer demand to the price of *teff* in the Central zone is not surprising as *teff* is the major crop on which fertilizer is applied. However, the results show that the responsiveness of output to fertilizer price is negligible and, except for teff and barley, insignificant. For instance, output elasticity of *teff* with respect to *teff* is only –0.07. This is surprising but is likely to reflect the low usage of chemical fertilizer on a per hectare basis and the inefficiency associated with its delivery and application. Ethiopian farmers often use considerably less fertilizer than the recommended level.[9] The response of maize to fertilizer price is about the same as that of *teff*, but a far lower amount of fertilizer is applied for maize. This confirms the fact that maize has the highest return to fertilizer use. The negative response of fertilizer demand to the price of barley in both the Central and Northern zones is not entirely unexpected in light of the low level of fertilizer used for barley. Moreover, in the North, farmers substitute out of barley to produce fertilizer intensive crops like *teff* and wheat. Therefore, lower barley prices could result in more land for, and higher production of, *teff* and wheat and hence higher demand for fertilizer.

In the North, the highest response of fertilizer demand comes from rain, with an elasticity of 0.94, followed by animal power, with an elasticity of 0.22, both significant at one percent. Note that the only elastic value for rain, 1.56, is registered for *teff.* This again confirms intensive use of fertilizer for *teff* during high rainfall years. Moreover, the largest elasticity for animal power is for fertilizer demand. 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.

Land size and market acess/infrastructure are also important factors affecting fertilizer use, with elasticities of 0.16 and 0.15 respectively, both significant at one percent. Such a significant response 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). The significant elasticity of land in the fertilizer equation indicates that increased acreage is associated with higher use of fertilizer for *teff* and wheat.

Once again, fertilizer is most responsive to rain, market access and animal power in the Central zone, with elasticities, respectively, of 0.59, 0.41 and 0.36, all significant at one percent. Also, the impact of rain and animal power on fertilizer demand is relatively high, next only to *teff*. But fertilizer seems to be unresponsive to land size as the land

9 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.

elasticity is very low and insignificant. This is because, unlike the Northern zone, increased acreage does not increase the use of fertilizer as farmers substitute other less fertilizer intensive crops for *teff*. Note however that fertilizer is responsive to land access, unlike the North, and land access has the highest impact on fertilizer demand equation.

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, has been a major policy instrument. Recognizing the crucial role fertilizer plays in the drive for enhancing agricultural productivity, the government has, from the outset, placed fertilizer at the centre of agricultural development strategy. However, little attention has been given to the diversity of farming systems and agro-climatic conditions prevailing in Ethiopia. We analyse survey data on almost 1500 peasant households during 1994-1997 to assess how responsive are Ethiopian farmers to price incentives and to identify the major constraints to expanding output. As a secondary objective, we try to assess the extent to which this responsiveness varies due to agro-ecology and farming systems. The sample is first stratified by farming systems into grain-plough and *enset*-hoe. Agro-climatic differences are then explicitly taken into account by estimating the Northern and Central highlands of the grain-plough system separately.

The results are generally consistent with theory and the farming conditions of the three zones. A number of important conclusions emerge. First, peasant farmers in Ethiopia respond positively and significantly to price incentives, and responsiveness to prices is far greater in the more climatically favoured and commercially oriented regions of the Central and Southern highlands. With one exception, own and cross-price elasticities are all less than unity, often considerably so for the Northern zone. The only elastic estimate is the own price elasticity of *chat* in the South, 1.08. This is because *chat* is a rapidly emerging export item the price of which has been continuously rising over the last decade. Among cereals, own price elasticities are highest for maize (except in the Northern zone where it is the second highest), and lowest for barley. Moreover, maize has the highest own price elasticity in the Central zone, and the second highest in the Southern zone.

Second, the results show marked differences in the size, significance and relative importance of estimated price elasticities among the three zones under study. Magnitudes of own price elasticities range from 0.12 for 'other crops' to 0.62 for maize in the Central zone, and from 0.13 for enset to 1.08 for chat in the Southern zone. Own price elasticities in the North are substantially lower ranging from 0.02 for barley and fertilizer to 0.20 for wheat and sorghum. All but three of these are significant in the Central and Southern zones. In the Northern zone, however, only wheat and sorghum have significant own price elasticities. Further, the own price elasticity of fertilizer in the Central zone is more than ten times higher. This suggests that agro-climatic and farming system differences need to be taken into account in designing and implementing agricultural policy.

Third, prices of other related products have a statistically significant impact on output levels. This is particularly the case in the Northern zone where inter-crop competition for better quality land is rather high. Here, cross-price elasticities are higher in absolute terms than own price elasticities for all crops. This suggests that, in designing price policies, a comprehensive approach should be taken to properly account for interrelationships among various products.

Forth, fertilizer demand appears to be more responsive to output prices, particularly to prices of barley and *teff*, than to its own price. This implies that policies directed at improving output prices are more likely to have appreciable effects on fertilizer use. Nevertheless, the response of output, especially that of *teff*, to fertilizer price is negligible, and mostly insignificant. This is surprising but is likely to reflect the low usage of chemical fertilizer on a per hectare basis and the inefficiency associated with its delivery and application.

Fifth, some important differences are also observed in the relative importance of non-price variables across zones, although the difference is not generally large compared to the effects of prices. Differences in the magnitude and significance of these factors are particularly large when comparing output elasticities of land quality, rain and infrastructure. Of particular importance, elasticities of rain are large and highly significant in the North, unlike the other two zones. The combined effect of more land of better quality is also quite enormous in this region. The most important non-price element in both the Central and Southern regions is market access, with elasticities exceeding one for a number of crops. In contrast, the variable for market access is very low and mostly insignificant in the North, suggesting the subsistence nature of production in this zone.

The non-price factor to which fertilizer is most responsive is rain, perhaps because farming is more commercial in seasons of good rainfall. Furthermore, fertilizer seems to be land-augmenting in the Northern zone, although increased acreage in the North is associated with higher use of fertilizer for *teff*. Fertilizer might even be land-saving in the Central zone as farmers appear to be substituting out of *teff* as acreage expands. The responsiveness of fertilizer to animal power and infrastructure is also quite high.

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. This is most apparent in the Northern highlands where these factors are far more important in affecting production and resource use than price incentives. 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 crop aggregates, "other crops" and "tree crops", implicit quantity index was calculated by dividing total value of output by the price index. The price index is defined as the Laspeyer's price index calculated from the components of these aggregates using the value share of each crop as a weight. The output and price indices are similar to those used by Croppenstedt and Mulat (1997). 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 farm-related work other than their own). The data also show that weeding constitute a very low component of hired labour. Excluding it is justified as we derive the wage rate from hired labour and off-farm income. Second, weeding is least important in the Southern zone producing perennial crops. 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). 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 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. 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.[10] 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 helps to capture the seasonal and/or temporal variation of rain, as well as the amount, which is typically important in the case of Ethiopia. Some other variables, such as education, age, household size, area of land inter-cropped, area of land share-cropped, number of plots, access to credit, and non-farm income, included in the preliminary estimation are left out due to multicollinearity.

10 We thank Bereket Kebede for bringing this variable to our attention.

Table A1 Average Output, Input use and Prices by Crop: Northern Highlands

Variable	*Teff*	Wheat	Barely	Maize	Sorghum	Other Crops
Land:						
Area (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 Output, Input use and Prices by Crop: Central Highlands

Variable	*Teff*	Wheat	Barely	Maize	Tree Crops	Other Crops
Land:						
Area (ha)	1.02	0.47	0.38	0.58	0.27	0.39
Share (%)	35.20	11.90	7.44	23.22	4.11	10.05
Quality	2.68	2.63	2.57	2.63	2.37	2.58
Output:						
Quantity(Kg)	535.22	505.35	306.15	267.44	65.76	673.04
Kg/ha	534.02	1043.25	724.70	415.72	145.97	1488.99
Share (%)	30.00	16.32	5.48	9.95	6.90	20.92
Surplus (%)	35.29	25.17	14.61	10.12	89.30	53.00
Fertilizer						
Quantity(Kg)	145.79	141.89	147.76	148.22	-	144.35
Kg/ha	124.51	399.55	196.37	91.68	-	186.54
Prices (*Birr*/Kg)	2.14	1.67	1.58	1.23	12.84	1.49

Table A3 Average Output, Input use and Prices by Crop: Southern Zone

Variable	*Teff*	Coffee	*Chat*	*Enset*	Maize	Other Crops
Land:						
Area (ha)	0.32	0.18	0.15	0.19	0.52	0.26
Share (%)	10.15	17.61	4.59	19.28	36.66	16.35
Quality	2.52	2.46	2.41	2.47	2.64	2.53
Output:						
Quantity(Kg)	98.87	48.76	43.24	306.49	163.95	626.53
Kg/ha	276.82	360.76	1226.32	1598.88	372.60	1816.61
Share (%)	3.00	34.67	33.58	5.91	14.82	3.63
Surplus (%)	69.21	75.08	88.42	2.33	9.94	65.00
Fertilizer						
Quantity(Kg)	57.86	-	-	-	70.55	-
Kg/ha	121.87	-	-	-	53.15	-
Prices (*Birr*/Kg)	2.16	5.44	6.41	0.52	1.58	1.35

Table A4 Average Use of Inputs and Other Variables by Zone

Variable	North	Central	South
Cultivated Land (ha)	2.17	1.86	0.77
Land Quality	2.30	2.61	2.50
Fertilizer			
Quantity(Kg)	98.53	116.06	42.74
Kg/ha	21.44	53.60	22.29
Prices (*Birr*/Kg)	1.49	1.50	1.58
Labour			
Man-days	31.96	44.91	57.82
Man-days/ha	8.54	21.24	46.07
Wage Rate (*Birr*/day)	2.84	2.99	2.47
Animal Power (numbers)	2.48	3.22	1.65
Farm Capital (*Birr*)	33.05	31.77	18.11
Land Access (*Birr*)	252.87	727.31	424.77
Market Access (Pop/Km)	3601.25	6756.96	1040.36
Rain (mm)	1241.00	747.61	1584.33

Appendix B Econometric Method

For empirical estimation, we use the quadratic functional form, which has the advantageous feature of self-duality.[11] The quadratic normalised restricted profit function is given by:

$$\Pi^* = \alpha_o + \sum_i^6 \alpha_i P_i^* + \sum_r^2 \alpha_r W_r^* + \sum_k^7 \beta_k Z_k + \frac{1}{2}\left(\sum_i^6 \sum_j^6 \gamma_{ij} P_i^* P_j^* + \sum_r^2 \sum_q^2 \gamma_{rq} W_r^* W_q^* + \sum_k^7 \sum_h^7 \delta_{kh} Z_k Z_h \right) \quad \text{(B1)}$$
$$+ \sum_i^6 \sum_r^2 \gamma_{ir} P_i^* W_r^* + \sum_i^6 \sum_k^7 \phi_{ik} P_i^* Z_k + \sum_r^2 \sum_k^7 \phi_{rk} W_r^* Z_k + \varepsilon.$$

where, Π^* is the normalised restricted profit; P_i^* is the normalized price of output *i*, subscripts 1 and 6 indicate prices of *teff* and "other crops" for all zones; for the Northern and Central zones, subscripts 2 through 4 indicate the prices of wheat, barely and maize respectively; subscript 5 indicates prices of sorghum and "tree crops" for the Northern and the Central zones respectively; subscripts 2 through 5 indicate the prices of coffee, *chat*, *enset* and maize, respectively, for the Southern zone; W_r* is the normalised price of input *r*, subscript 1 indicates the fertilizer price and subscript 2 the wage rate; Z_k 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 market access, and 7 for rainfall). 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 expressed, respectively, as:

$$Y_i = \alpha_i + \sum_j^6 \gamma_{ij} P_j^* + \sum_r^2 \gamma_{ir} W_r^* + \sum_k^7 \phi_{ik} Z_k + v_i, i = 1,...6$$
$$-X_r = \alpha_r + \sum_i^6 \gamma_{ri} P_j^* + \sum_q^2 \gamma_{rq} W_q^* + \sum_k^7 \phi_{rk} Z_k + v_r, r = 1,..2. \quad \text{(B2)}$$

where Y_i and X_r denote the quantities of output and variable inputs, respectively, and ν is the error term. Homogeniety is imposed by dividing profit and all prices by the wage rate. So the labour demand equation is excluded from estimation. The final estimation is for the system of six output supply equations and one input demand

11 We compared two other commonly used flexible forms (the generalised Leontief and translog), as well as Cobb-Douglas, with the quadratic form. Based on various statistical criteria and consistency with theoretical restrictions, the quadratic and Cobb-Douglas forms are found to best approximate the underlying data. Full details are available in Abrar (2001a).

equation (fertilizer). The fertilizer equation is not included for the Southern zone where fertilizer is rarely used. Instead, we used a dummy (duf2) to capture the effect of fertilizer use. The cross-equation (symmetry) restrictions and the possibility of error correlation among the system of equations could make the OLS estimator inefficient. For efficient estimation we used iterative Seemingly Unrelated Regression. The following symmetry restrictions are tested and imposed in estimation:

$$\gamma_{ij} = \gamma_{ji} (i, j = 1,...6, i \neq j)$$
$$\gamma_{rq} = \gamma_{qr} (r, q = 1,...2, r \neq q) \quad \text{(B3)}$$

In countries like Ethiopia, where there is low level of market integration and other forms of input market imperfection prevail, lower use of fertilizer by some farmers could be the result of these external factors rather than rational decision based on prices. Therefore, to estimate the fertilizer demand equation consistently (that is to ensure zero expectation of the error terms), we followed the two-stage Heckman (1979) procedure. First, the probability of using fertilizer is estimated by probit maximum likelihood using the following binary choice model:

F*=HΘ+u (B4)

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

F=**1** (F*>0, i.e., users)

=**0**, otherwise (i.e.,F*≤ 0, non-users) (B5)

Then, the resulting values of the vector Θ are used to compute the vectors of inverse Mills ratios, M_1=Φ/Φ and M_2= -Φ /1- Φ, 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 HΘ). 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 users and non-users sub-sample respectively. Once this correction is made, all observations, including zero observations, can be used to estimate the fertilizer demand equation.

Table B1Parameter Estimates, Symmetry imposed: Northern Highlands[1]

Variables	*Teff*	Wheat	Barley	Maize	Sorghum	Other Crops	Fertilizer
Price *Teff*	12.367	24.663	-44.881	5.930	24.710	-16.247	-1.277
	(0.58)	(1.98)**	(2.46)**	(1.12)	(1.33)	(1.69)*	(0.22)
Price Wheat	24.663	39.256	-15.939	0.443	-49.468	-7.585	-11.278
	(1.98)**	(2.61)***	(1.29)	(0.07)	(3.49)***	(0.94)	(2.63)***
Price Barley	-44.881	-15.939	-6.924	-6.657	78.044	8.758	14.872
	(2.46)**	(1.29)	(0.26)	(1.46)	(4.28)***	(0.78)	(2.24)**
Price Maize	5.930	0.443	-6.657	5.532	-4.504	-1.966	0.266
	(1.12)	(0.07)	(1.46)	(1.24)	(0.75)	(0.62)	(0.16)
Price Sorghum	24.710	-49.468	78.044	-4.504	63.480	7.527	-12.009
	(1.33)	(3.49)***	(4.28)***	(0.75)	(2.27)**	(0.68)	(1.83)*
Price Other Crops	-16.247	-7.585	8.758	-1.966	7.527	14.310	-0.485
	(1.69)*	(0.94)	(0.78)	(0.62)	(0.68)	(1.54)	(0.12)
Price Fertilizer	-1.277	-11.278	14.872	0.266	-12.009	-0.485	2.030
	(0.22)	(2.63)***	(2.24)**	(0.16)	(1.83)*	(0.12)	(0.61)
Land Size	88.139	178.438	44.405	105.564	21.552	17.845	-6.930
	(6.61)***	(10.32)***	(5.67)***	(5.81)***	(5.23)***	(4.55)***	(2.93)***
Animal Power	0.588	7.229	41.914	0.684	2.371	14.223	-8.432
	(0.16)	(2.55)**	(5.55)***	(0.84)	(0.57)	(3.57)***	(4.01)***
Farm Capital	1.369	0.856	-0.040	0.110	0.370	0.394	-0.210
	(7.07)***	(5.83)***	(0.11)	(2.53)**	(1.81)*	(1.99)**	(2.44)**
Land Quality	20.505	8.943	31.190	8.813	35.672	22.157	-5.530
	(3.36)***	(1.86)*	(2.64)***	(4.20)***	(2.60)***	(4.31)***	(1.00)

Table B1 (contd.)

Variables	***Teff***	**Wheat**	**Barley**	**Maize**	**Sorghum**	**Other Crops**	**Fertilizer**
Land Access	0.105	0.022	0.069	0.002	0.085	0.014	-0.011
	(6.03)***	(1.72)*	(2.07)**	(0.48)	(4.66)***	(0.76)	(1.41)
Market Access	-0.002	0.000	0.056	0.000	0.026	0.008	-0.004
	(1.08)	(0.13)	(15.64)***	(0.62)	(14.37)***	(4.38)***	(3.37)***
Rainfall	0.316	0.144	0.082	0.023	-0.128	0.077	-0.073
	(16.72)***	(9.79)***	(2.21)**	(5.25)***	(6.42)***	(4.01)***	(8.72)***
DU12	3.440	-8.523	15.150	0.498	-118.198	20.791	-4.232
	(0.22)	(0.78)	(0.47)	(0.14)	(6.37)***	(1.30)	(0.55)
Mill's Ratio							13.200
							(1.45)
Constant	-26.338	-18.153	-162.940	-2.999	73.426	-56.559	12.093
	(2.16)**	(2.25)**	(7.20)***	(1.21)	(2.06)**	(4.63)***	(0.61)
R squared	0.688	0.632	0.707	0.442	0.476	0.410	0.493
	(1139.09)***	(885.73)***	(1266.29)***	(404.70)***	(466.77)***	(374.27)***	(510.48)***

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

Table B2 Parameter Estimates, Symmetry imposed: Central Highlands[1]

Variables	*Teff*	Wheat	Barley	Maize	Tree Crops	Other Crops	Fertilizer
Price *Teff*	184.399	-78.904	69.185	-185.492	-10.816	-14.070	-38.298
	(3.09)***	(1.69)*	(2.21)**	(3.99)***	(3.33)***	(0.40)	(2.30)**
Price Wheat	-78.904	121.919	-78.427	122.588	2.133	-18.063	-11.883
	(1.69)*	(2.11)**	(2.52)**	(2.79)***	(0.89)	(0.81)	(0.65)
Price Barley	69.185	-78.427	39.584	-61.596	-3.857	-36.411	46.864
	(2.21)**	(2.52)**	(1.21)	(1.82)*	(1.67)*	(1.93)*	(3.64)***
Price Maize	-185.492	122.588	-61.596	208.147	9.325	13.900	-15.796
	(3.99)***	(2.79)***	(1.82)*	(3.80)***	(3.19)***	(0.53)	(0.95)
Price Tree Crops	-10.816	2.133	-3.857	9.325	2.948	8.279	-1.633
	(3.33)***	(0.89)	(1.67)*	(3.19)***	(6.71)***	(2.81)***	(1.64)
Price Other	-14.070	-18.063	-36.411	13.900	8.279	81.088	-12.842
	(0.40)	(0.81)	(1.93)*	(0.53)	(2.81)***	(2.06)**	(1.40)
Price Fertilizer	-38.298	-11.883	46.864	-15.796	-1.633	-12.842	41.115
	(2.30)**	(0.65)	(3.64)***	(0.95)	(1.64)	(1.40)	(4.21)***
Land Size	-58.188	397.017	-13.303	36.660	2.777	51.072	-4.052
	(3.11)***	(8.20)***	(1.41)	(2.89)***	(1.35)	(2.27)**	(1.09)
Animal Power	99.407	21.749	11.649	10.798	-0.130	33.983	-12.902
	(11.02)***	(4.17)***	(2.64)***	(1.80)*	(0.13)	(2.99)***	(4.78)***
Farm Capital	1.462	0.794	0.227	1.222	-0.008	0.526	-0.457
	(2.83)***	(2.58)***	(0.90)	(3.55)***	(0.15)	(0.80)	(4.35)***

Table B2 (contd.)

Variables	*Teff*	Wheat	Barley	Maize	Tree Crops	Other Crops	Fertilizer
Land Quality	62.900	18.032	82.810	8.793	9.527	0.215	-4.695
	(2.89)***	(1.59)	(11.31)***	(0.27)	(1.79)*	(0.00)	(0.48)
Land Access	0.097	0.076	0.023	0.066	0.002	0.288	-0.050
	(2.67)***	(3.29)***	(1.32)	(2.78)***	(0.44)	(6.31)***	(6.80)***
Market Access	0.097	0.039	0.011	0.051	0.001	0.126	-0.007
	(7.88)***	(6.09)***	(2.07)**	(6.76)***	(0.90)	(8.95)***	(2.88)***
Rainfall	0.768	0.069	0.040	0.122	0.019	-0.131	-0.086
	(9.88)***	(1.48)	(1.05)	(2.34)**	(2.33)**	(1.34)	(5.50)***
DU8	-609.142	69.230	29.100	252.578	30.608	358.856	43.922
	(6.12)***	(1.56)	(0.78)	(4.77)***	(3.64)***	(3.73)***	(2.71)***
Mill's Ratio							-9.458
							(0.24)
Constant	449.973	-299.071	-100.016	-325.751	-29.746	-840.575	-41.942
	(3.64)***	(6.62)***	(2.14)**	(2.81)***	(1.57)	(4.08)***	(0.87)
R squared	0.649	0.681	0.389	0.242	0.306	0.434	0.523
	(686.41)***	(773.88)***	(253.43)***	(132.58)***	(171.71)***	(287.42)***	(394.83)***

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

Table B3 Parameter Estimates, Symmetry imposed: Southern Zone[1]

Variables	*Teff*	Coffee	*Chat*	*Enset*	Maize	Other Crops
Price *Teff*	17.597	-0.093	-0.238	-12.573	-22.184	0.210
	(2.40)**	(0.16)	(0.97)	(1.69)*	(2.78)***	(0.14)
Price Coffee	-0.093	3.855	-1.612	4.878	-6.736	3.808
	(0.16)	(3.24)***	(3.40)***	(0.99)	(3.64)***	(1.31)
Price *Chat*	-0.238	-1.612	6.952	-8.198	-0.489	-9.690
	(0.97)	(3.40)***	(15.89)***	(3.05)***	(0.61)	(4.09)***
Price *Enset*	-12.573	4.878	-8.198	62.214	-12.266	36.233
	(1.69)*	(0.99)	(3.05)***	(1.69)*	(0.95)	(2.31)**
Price Maize	-22.184	-6.736	-0.489	-12.266	71.805	1.660
	(2.78)***	(3.64)***	(0.61)	(0.95)	(6.35)***	(0.34)
Price Other Crops	0.210	3.808	-9.690	36.233	1.660	104.719
	(0.14)	(1.31)	(4.09)***	(2.31)**	(0.34)	(3.78)***
Land Size	19.586	26.515	3.300	27.016	42.176	233.053
	(3.41)***	(4.96)***	(0.68)	(0.93)	(5.43)***	(4.29)***
Animal Power	4.626	10.226	1.710	43.529	11.917	35.939
	(2.47)**	(2.30)**	(0.42)	(1.81)*	(1.86)*	(0.79)
Farm Capital	0.021	0.135	0.490	3.065	-0.120	2.021
	(0.31)	(0.82)	(3.26)***	(3.44)***	(0.51)	(1.20)
Land Quality	27.453	-0.790	-7.501	32.591	13.804	87.132
	(11.50)***	(0.08)	(0.87)	(0.64)	(1.01)	(0.90)

Table B3 (contd.)

Variables	***Teff***	**Coffee**	***Chat***	***Enset***	**Maize**	**Other Crops**
Land Access	0.004	0.031	-0.002	0.208	0.160	-0.196
	(0.60)	(2.02)**	(0.13)	(2.49)**	(7.21)***	(1.23)
Market Access	-0.003	0.051	0.120	0.459	0.043	0.854
	(0.41)	(3.52)***	(9.89)***	(5.65)***	(1.90)*	(6.85)***
Rainfall	0.007	0.016	-0.006	0.112	0.016	0.003
	(2.07)**	(2.26)**	(0.91)	(3.01)***	(1.63)	(0.04)
DU16	-16.148	-34.815	-156.709	111.172	179.076	-861.167
	(1.65)*	(1.67)*	(8.39)***	(0.95)	(5.62)***	(4.32)***
DUF2	-2.442	-10.723	-78.714	72.848	15.777	-715.646
	(0.40)	(0.80)	(6.55)***	(1.00)	(0.81)	(5.51)***
Constant	14.299	-46.603	213.033	-616.884	1.602	1,231.123
	(1.15)	(1.30)	(6.58)***	(3.13)***	(0.03)	(3.53)***
R-squared	0.537	0.257	0.692	0.221	0.615	0.215
	(485.00)***	(165.98)***	(929.12)***	(138.25)***	(679.61)***	(155.02)***

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

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