The Effects of Education on Farmer Productivity in Rural Ethiopia

SHARADA WEIR

WPS99-7

Centre for the Study of African Economies
Department of Economics, University of Oxford

St. Cross Building, Manor Road, Oxford OX1 3UL, United Kingdom

Office: +44 1865 274 555
Fax: +44 1865 274 558

sharada.weir@Economics.ox.ac.uk

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Abstract The Ethiopian education system is characterised by extremely low participation rates, particularly in rural areas. This paper challenges the hypothesis that demand for schooling in rural Ethiopia is constrained by the traditional nature of farm technology and lack of visible benefits of schooling in terms of farmer productivity. The effects of schooling upon farmer productivity and efficiency are examined employing both average production functions and two-stage stochastic frontier production functions. Data drawn from a large household survey conducted in 1994 were used to estimate internal and external benefits of schooling in 14 cereal-producing villages. Empirical analyses reveal substantial internal (private) benefits of schooling for farmer productivity, particularly in terms of efficiency gains. However, a threshold effect is identified: at least four years of primary schooling are required to have a significant effect upon farm productivity. Evidence of strong external (social) benefits of schooling was also uncovered, suggesting that there may be considerable opportunities to take advantage of external benefits of schooling in terms of increased farm productivity if school enrolments in rural areas are increased.

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1. Introduction

Economic benefits of schooling include the potential to obtain paid employment or to generate income through self-employment using skills learned in school. These anticipated benefits of schooling may represent an important determinant of enrolment in rural Ethiopia. The purpose of this paper is two-fold: first, to examine the hypothesis that demand for schooling in rural Ethiopia is constrained by the traditional nature of farm technology and lack of visible benefits of schooling in terms of farmer productivity; and second, to understand better the potential consequences of low levels of investment in schooling in terms of missed opportunities to improve agricultural output in rural Ethiopia by raising farmer efficiency and by increasing the propensity successfully to adopt innovations.

The first objective is to illuminate a potentially crucial determinant of school enrolment - the benefits (or lack thereof) of schooling to the rural economy. Parents may see the benefits of secondary schooling for their children in terms of the possibility for urban employment, and view primary education as a necessary input into secondary schooling. Thus, demand for both levels of schooling may be constrained by a perceived lack of job opportunities for secondary school graduates. However, farm households may still value schooling for their children if there is a perception that primary education generates cognitive skills (e.g., basic literacy and numeracy) which are useful in agriculture. If this is not the case in Ethiopia, it may explain why there is such low school enrolment in rural areas.

The second objective is important for policy-makers concerned about narrowing the gap between actual and universal primary enrolments in rural Ethiopia. There is a prevalent view that given the traditional character of Ethiopian agriculture, education has no economic value to the country, and the benefits of schooling are primarily non-economic in nature. This assumption probably underlies (and constrains) policy-makers' views on the expansion of education. If education is found to have a significant impact upon agricultural productivity, this will provide an economic rationale for policy interventions to increase access to schooling in rural areas.

There are several avenues by which schooling may create economic benefits in rural areas. Households receive income in cash and in kind from farming and off-farm activities, wage employment, and remittances from migrants. Education may increase the probability of success in each of these endeavours and, in so doing, diversify household income sources to reduce risk and improve economic security. Since farming is the primary activity of most households in rural Ethiopia, this paper will focus on the part played by schooling in agricultural production.

Education may enhance farm productivity directly by improving the quality of labour, by increasing the ability to adjust to disequilibria, and through its effect upon the propensity to successfully adopt innovations. Education is thought to be most important to farm production in a rapidly changing technological or economic environment (Shultz 1964; 1975). Since farming methods in Ethiopia are largely traditional, there appears to be little economic justification for Ethiopian farm households to invest in education. However, new, higher-yield crop varieties are available in some areas, and some farmers in many areas have adopted certain modern inputs, primarily chemical fertilisers. As technological innovations spread more widely within the country, the importance of formal schooling to farm production ought to become more apparent.

Admassie and Asfaw (1997) note that Ethiopian farmers have faced frequently changing input and output prices under the new government. In addition, unpredictable weather, pests and crop disease all contribute to an environment in which farmers must adapt frequently in order to survive. As a result, there may be an efficiency advantage for farmers who are better prepared to anticipate and cope with disequilibria. Thus, even in the absence of innovation, farm productivity may be enhanced by investments in education.

The aim of this paper is to identify the possible benefits of schooling for households engaged in agricultural production and to quantify the effects of education upon farm output in rural Ethiopia. Section 2 surveys the literature on returns to schooling in agriculture. Section 3 covers the availability and suitability of data on rural Ethiopia. The empirical methodology is set out in Section 4. Results are presented in Section 5. Section 6 concludes the paper with a summary of the main findings and the implications for enrolment in rural areas.

2. Literature Review

2.1. Empirical Evidence on the Effects of Education in Agriculture

Since wage data is seldom available in the context of agricultural production in the developing world, most studies on the effects of schooling in rural areas employ production function methodology. An advantage of the production function approach is that it provides evidence on the marginal product of the farmer in terms of real output, whereas wages may be subject to institutional constraints and not reflect accurately marginal productivity.

2.1.a. Developing World Evidence

The production function approach has produced evidence of a link between education and agricultural output in the developing world literature. Hussain and Byerlee (1995) note that evidence is mounting (for Asia at least) that returns to schooling in agriculture may be as high as for urban wage earners. Lockheed, Jamison and Lau (1980) reviewed 18 studies representing 37 data sets (primarily in Asia) and found that most reported a significant positive effect of education upon output, though the results were mixed. They noted that a significant positive relationship was more likely to be found in areas where farmers are modernising. On average for the studies considered, the increase in production associated with having four years of schooling was 8.7 percent. However, for the group of studies concerned with the effects of education in traditional agriculture, the increase in output owing to four years of schooling was only 1.3 percent on average, as compared with a mean increase of 9.5 percent for studies of modernising regions.

Phillips (1994) reviewed an additional 12 studies using 22 data sets (with more recent data and greater representation of Latin America), and was able to confirm the general trends noted above. The average increase in output owing to an additional four years of schooling in the studies he considers is 10.5 percent, with the relevant figures for traditional versus modern farming systems at 7.6 and 11.4 percent, respectively. However, his survey was sufficiently geographically diverse to show that (under certain conditions) the effects of schooling are stronger in Asia than in Latin America, irrespective of the degree of modernisation. This may have implications for the assumed applicability of Asian findings to Africa, though too few studies using African data were included to draw strong conclusions.

Appleton and Balihuta (1996) point out that these surveys included only two African studies (both on Kenya) and that education was not found to be significant in either. They review several additional African studies and find that the effect of schooling on agricultural output is usually not significant, though in some cases it can be large, indicating that there is substantial variation in returns to schooling both within and between the areas surveyed. The authors suggest several possible reasons for the lack of significance of education in the African studies, including small sample sizes (for a few of the studies), errors in measurement of farm production, and wide variation in the actual effects of education on agricultural output in different areas and under different farming systems. These reviews illustrate the need for further investigation of the effects of education on farm productivity in Africa.

2.1.b. Ethiopian Evidence

Until recently, very little empirical evidence was available to illuminate the effects of education in Ethiopian agriculture. Much of the recent research may be criticised on the grounds of poor measurement of education variables and small sample size. However, a variety of data sets and methods have been used in this context, providing some insight into the effects of education on productivity and efficiency in Ethiopia.

Mirotchie (1994) investigates technical efficiency in cereal crop production in Ethiopia using aggregate data for the period 1980-86. The data on education are weak. Although conclusions must be drawn with caution, he reports that primary schooling tends to increase productivity, while secondary schooling has no effect.

Croppenstedt and Muller (1998) examine the effects of various forms of human capital upon agricultural productivity using data from the first round of the Ethiopia Rural Household Survey (ERHS), but do not find a relationship between their measure of education[1] and agricultural output.

Croppenstedt, Demeke and Meschi (1998), using data from a 1994 USAID fertiliser marketing survey, find that literate farmers are more likely to adopt use of fertiliser than those who are illiterate, though the quantity of fertiliser demanded does not depend upon literacy.

Croppenstedt and Demeke (1997) use data from the ERHS, selecting eight sites dominated by oxen-plough cultivation, to estimate efficiency using a mixed fixed-random coefficients regression model. They include four alternative education variables: a dummy indicating that the household head has the adult literacy programme certificate; a dummy indicating that another household member can read and write a letter (self-report); a dummy indicating that the household head has completed primary school; and an estimator of the number of years of schooling attained by the household head, calculated based on the highest education level

[1] Note that the measure of education used was possession of an Adult Literacy Programme certificate. This is not an ideal proxy for education, since literacy skills may have completely deteriorated by the time of the survey and because no account is taken of numeracy, which may be equally important.

attained. They find that literacy has a positive effect upon productivity, and that education is weakly correlated with farm efficiency.

Admassie and Asfaw (1997) estimate a stochastic frontier profit function to investigate technical and allocative efficiency of farmers. Their data are also drawn from the ERHS. However, only four of the 15 sites are considered, and within those four sites, only those households who used fertiliser and hired labour were included (120 households in total). Education is measured in two ways: (1) a dummy variable equal to one if at least one household member reports being able to read and write or has the ALP certificate; and (2) a dummy variable set equal to one if at least one household member has completed primary school. They estimate average inefficiency over their sample of 46 percent. Educated farmers were found to be relatively and absolutely more efficient than those without education. However, their sample selection methodology is unsatisfactory and casts doubt upon the reliability and generalisability of their findings.

Finally, Dercon and Krishnan (1998), using panel data on six sites covered by both the ERHS and a 1989 IFPRI survey, found that the decline in poverty between 1989 and 1994 was greater for household heads who had completed primary schooling than for those who had less (or no) education. Poverty reduction is defined by a headcount measure in terms of greater consumption per adult equivalent across the two periods. The decomposition results suggest that the educated were able to take better advantage of opportunities to increase consumption over this period.

In sum, this body of research is suggestive of the possible benefits of schooling in agricultural areas in terms of increasing efficiency and the adoption of innovations as well as in reducing poverty. However, there is at present no convincing direct evidence to quantify the magnitude of the effect of education upon crop output in rural Ethiopia. That is the aim of this paper.

2.2. The Role of Schooling in Farm Production: A Few Fundamentals

2.2.a. From Schooling to Education

Education may have both cognitive and non-cognitive effects upon labour productivity. Cognitive outputs of schooling include the transmission of specific information as well as the formation of general skills and proficiencies. Education also produces non-cognitive changes in attitudes, beliefs and habits. Increasing literacy and numeracy may help farmers to acquire and understand information and to calculate appropriate input quantities in a modernizing or rapidly changing environment. Improved attitudes, beliefs and habits may lead to greater willingness to accept risk, adopt innovations, save for investment and generally to embrace productive practices (Appleton and Balihuta 1996; Cotlear 1990). Education may either increase prior access to external sources of information or enhance the ability to acquire information through experience with new technology. That is, it may be a substitute for or a complement to farm experience in agricultural production. Schooling enables farmers to learn on the job more efficiently (Rosenzweig 1995).

Education may directly influence agricultural productivity via one or more of the routes described above. Education may also indirectly increase output through its interaction with other institutional variables. For example, schooling may substitute for access to credit by providing the skills necessary to obtain waged employment, thereby generating cash to finance agricultural investments (Appleton and Balihuta 1996). Collier and Lal (1986) note the importance of non-agricultural income for farm productivity. Remittances from migrants educated by the household may also serve this function. Furthermore, Phillips and Marble (1986) note that educated farmers are able to interact more effectively with credit agencies, because they can understand financial transactions and keep records, increasing the likelihood of obtaining credit.

2.2.b. Types of Education

Cotlear (1990) describes three different types of education: formal, non-formal and informal. Formal schooling is what is usually meant by the term education. Non-formal education includes agricultural extension contacts and apprenticeships as well as adult literacy training. Informal education may refer to a wide range of experiences, including ‘learning by doing’ and migration or other activities which provide exposure to new ideas and facilitate learning.

Formal education tends to promote formation of cognitive skills and abstract reasoning ability as well as changes in attitudes. Non-formal education most often serves to transmit specific information needed for a particular task or type of work. Informal education may serve mainly to shape attitudes, beliefs and habits.

2.2.c. Internal versus External Returns to Schooling

Benefits of investment in schooling may accrue not only to the person who has acquired the education, but also to other members of that person’s household or village. Internal (or private) benefits of schooling include enhanced income-generation capacity as well as other quality of life improvements. External (or social) effects of schooling include the diffusion of new farm inputs and productivity-enhancing techniques.

Ironically, the presence of externalities may obscure evidence that education affects productivity at the household level (Phillips and Marble 1986). Jamison and Lau (1982) suggest that external effects of education upon farmer productivity may not be apparent when the household is the unit of analysis, since less educated farmers may copy the agricultural practices of their more educated (more productive) neighbours. As well as presenting an empirical consideration, this point is highly relevant from a policy perspective, since the presence of externalities may reduce the private demand for schooling, while at the same time raising its social value.

2.3. Decomposing Productivity Gains: Efficiency and Technical Change

There are two important ways in which education may increase farm output: (1) general skills acquired in school reduce technical and allocative inefficiencies in production; and (2) attitudes acquired in school encourage the adoption of new technologies which cause the production frontier to shift outward (Hussain and Byerlee 1995). Education may cause movement toward the production frontier, in the case of technical inefficiency, or movement along the frontier to a profit maximising point, in the case of allocative inefficiency, or an outward shift in the production frontier in the case of inefficiency caused by failure immediately to adopt new techniques or inputs, a special type of allocative inefficiency.

This distinction is shown in Figure 1. The farmer operating at point B is neither technically nor allocatively efficient. Movement to point T on the production frontier represents achievement of technical efficiency. Movement along the frontier to point A occurs when the producer becomes allocatively efficient. A shift in the production frontier is shown by the movement from A to I, where new technology allows the already efficient producer to further increase output and profits.

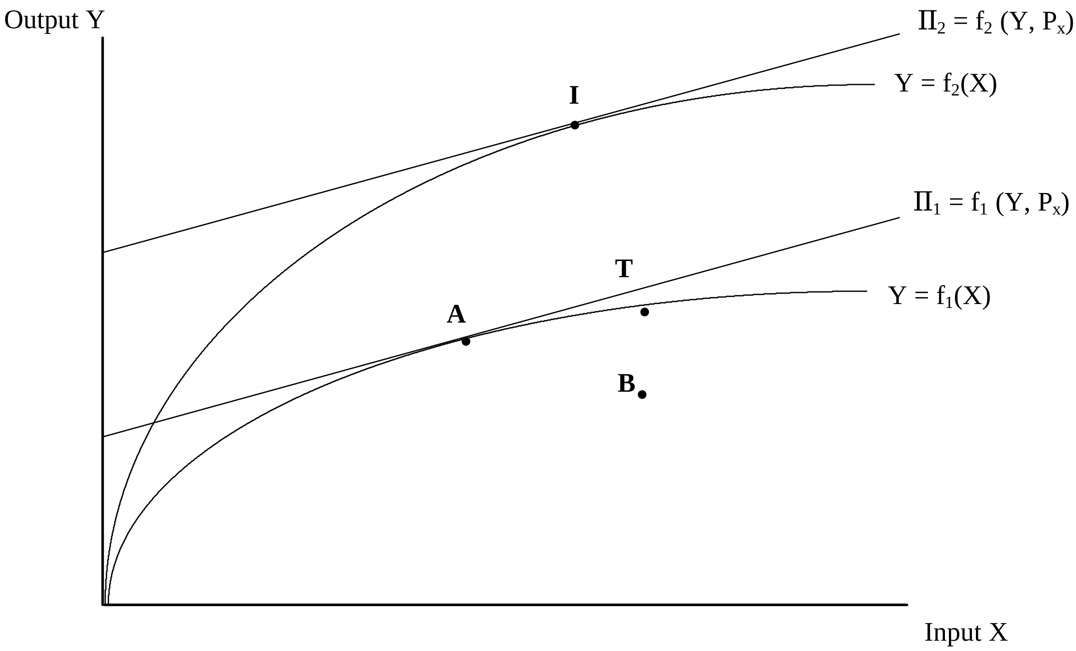

Figure 1: Production vis-à-vis the Production Frontier (single input/single output case)

When two farmers are observed using similar amounts of inputs to produce very different quantities of output, it does not necessarily follow that one is more efficient than the other. Both may be equally efficient at using their chosen technology, but one may be using a more effective production technology and operating on a higher production frontier (Jamison and Lau 1982).

2.3.a. Economic Efficiency

A farmer is technically efficient if it is impossible to raise farm output without increasing use of at least one input. Technical inefficiency may arise because of inappropriate timing or method of input application, which is often caused by a lack of information but may also reflect problems of input supply (Ali and Byerlee 1991).

Allocative (or price) efficiency is achieved when the cost of producing a given output is minimised, as evidenced by the equality of the ratio of the marginal products of inputs to the input price ratio. Farmers are allocatively inefficient if the chosen input-output combination does not minimise costs (to maximise profits), given prevailing prices (i.e., production occurs off the farm's expansion path). Causes of allocative inefficiency include failure to choose the most cost-efficient combination of inputs, and may be attributed to lack of information as well as unreliable input supply, sub-optimal tenancy arrangements, risk aversion, and other institutional constraints (Ali and Byerlee 1991).

Further inefficiency may exist when there are fixed factors of production or economies of scale. Farmers may fail to take advantage of profit-maximising opportunities to move up along the expansion path. Often, this may be primarily explained by limited availability of cultivable land, constraints in the credit market or risk aversion, rather than lack of information (Ali and Byerlee 1991). However, where schooling reduces risk aversion and removes credit constraints, education may also play a role in increasing productivity through greater scale efficiency. In the short run, education may affect the quantities of variable inputs used, while in the long run it may influence the optimal scale of operation (Wu 1977).

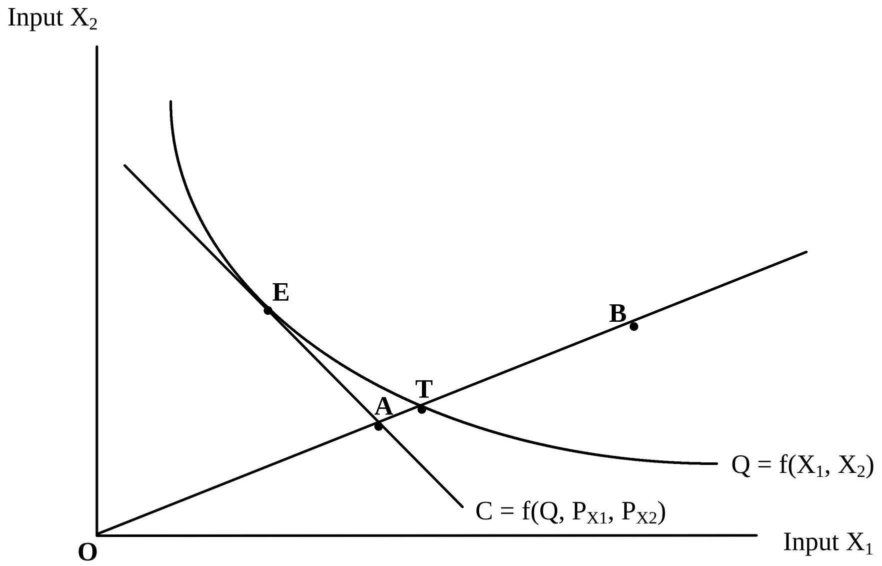

Figure 2: Farrell Measures of Technical and Allocative Efficiency

Efficiency measures provide an indicator of performance. Farrell (1957) originated the concept of measuring the extent of technical and allocative inefficiency in terms of deviation from a unit isoquant representing best practice or frontier production (see Figure 2). Taking the special case of a one-product firm, the extent of technical inefficiency is measured as the ratio of the distance from the production point to a point on the unit isoquant along the same ray from the origin (TB) to the distance from the origin to the production point (OB). Allocative inefficiency is measured as the ratio of the distance between a point on the unit isoquant and the lowest cost factor combination for a given set of input prices along the same ray from the origin (AT) to the distance from the origin to the point on the unit isoquant (OT).

Ali and Byerlee (1991) maintain that observed inefficiency must be considered in a dynamic context. Farmers who adopt a new technique or input may initially be technically inefficient as they learn how to use the innovation and allocatively inefficient as they experiment with appropriate amounts of new inputs for their enterprise, given farm-specific environmental factors, such as soil quality, which may affect use of the new input. Inefficiency ought to fall as farmers gain experience in using the new input. Thus, measures of inefficiency at any one point in time may not reflect the equilibrium situation, but rather indicate deliberate trial and error on the part of farmers (Welch 1978). Schmidt and Lovell (1980) agree that statically measured technical or allocative inefficiency may be consistent with dynamic efficiency. Nonetheless, higher initial levels of information (for example, through schooling) should reduce measured inefficiency at all stages in the adoption process. Schooling may speed the adjustment in use of new technologies (see Huffman 1974).

2.3.b. Technological Change

Technical progress of farmers in a particular area may be measured by the proportion of the population to take up new innovations or by the quantities of modern inputs, such as fertiliser, which are used. Ideally, panel data are required to fully document the process of innovation.

Psacharopoulos and Woodhall (1985) adapt Heyneman's (1983) framework to describe the four stages of agricultural technology adoption and the role education may play in each stage. Stage 1: Traditional farming. Information is passed from father to son, and little or no schooling is needed. Stage 2: Single input adoption (e.g., fertiliser). Basic literacy and numeracy are very useful to farmers for understanding instructions and adjusting quantities of the new input. Stage 3: Adoption of multiple inputs simultaneously. Here, more than literacy and numeracy are necessary. Some basic science knowledge is helpful. Stage 4: Irrigation-based farming. The farmer must make complex calculations of effects of changes in crops and weather. More education is needed for efficient production at this stage.

Schooling is not only useful after new technologies have been adopted. Education may also help to determine whether a farmer decides to be an early adopter of innovations and the extent to which the new innovation will be used. There are at least three reasons for this: firstly, those with schooling tend to be more affluent and are in less danger of starvation if a prospective innovation is unsuccessful; secondly, educated farmers may be more likely to be contacted by agricultural extension workers looking for model farmers to test innovations; and thirdly, literate farmers are better able to acquire information about potential innovations and to make rational evaluations of the risks involved in trying new inputs, crops or methods.

2.4. Effects of Schooling on Productivity: Competing Methodologies

The literature on the effects of education on agricultural productivity is divided into two major camps: frontier versus non-frontier (direct) methods for estimating the production function. Whether frontier or non-frontier techniques are chosen depends in part on the research question. If the researcher is interested mainly in the estimated coefficient on schooling in the production function, non-frontier techniques will suffice. However, if the researcher wishes to investigate the magnitude and causes of inefficiency, consideration of the production frontier (and deviations from that frontier) become more interesting. Figure 3 illustrates the difference between frontier and non-frontier estimation.

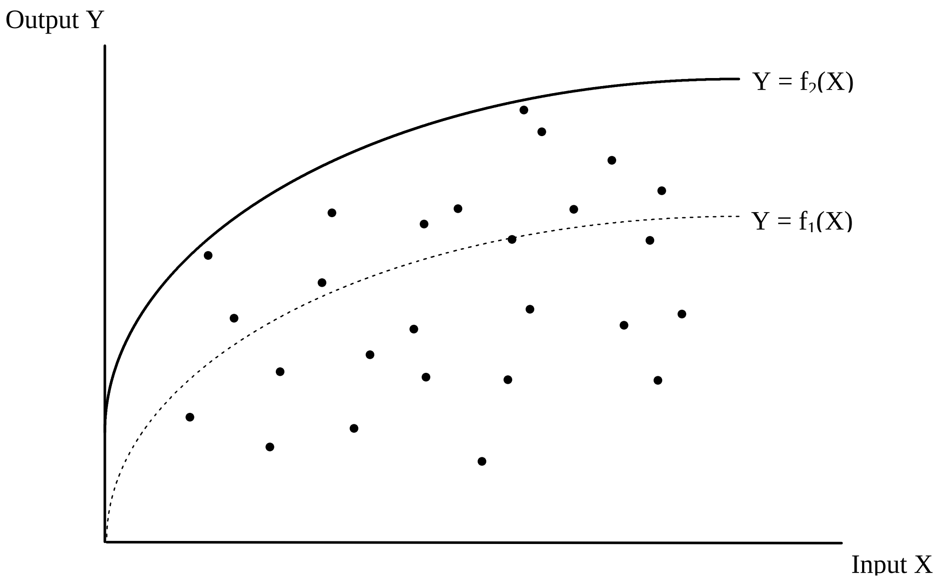

Figure 3: Frontier and Average Production Functions

In Figure 3, the dotted line which passes through the data is the average production function. The solid line which envelopes the data is the frontier production function. The frontier is estimated either by shifting the constant term up until all outliers are included or by adjusting the slope and constant term to fit the best practice farm data. The magnitude of inefficiency of each farm is measured by comparing farm production with the relevant point on the frontier.

Estimation of the average (non-frontier) function permits efficiency ranking of firms, but gives no indication of the magnitude of inefficiency. If the frontier is a neutrally scaled transformation of the average function, estimation of the average function provides information on the shape of the frontier, but not its placement. If not, estimation of the average function provides no information about the frontier (Schmidt and Lovell 1979).

Some literature pertaining to each of the major methodologies outlined above will be described in the remainder of this section. While not an exhaustive review of the extensive literature of production functions and frontiers, a number of key developments are highlighted.

2.4.a. Non-frontier (Direct) Production Function Approach

Estimation of the effects of eduction upon productivity using direct, non-frontier methods dates back to the 1960s. Griliches (1964) was the first to use a production function to estimate the effect of education on agricultural output. His method was replicated by Kislev in 1967 using the same data differently aggregated, but the results did not confirm the earlier findings. Chaudhri (1979) described this apparent paradox, claiming that the reason for the discrepancy is that different levels of aggregation reveal different effects of schooling. The higher the level of aggregation, the more effects are captured, and therefore, the stronger the estimated relationship between education and productivity in farming.

Chaudhri (1979) discussed four possible effects of schooling: the worker effect, the allocative effect, the innovative effect and the external effect. Based upon his own empirical work, he concluded that an examination of data at the household level will reveal only direct (worker) effects of schooling on output. As the level of aggregation is increased up to the state level, more of the allocative, innovative and external effects will be picked up, and eventually a level of aggregation will be reached at which all external effects are internalised.

Welch (1970) built upon Chaudhri's work, suggesting methodology to describe direct, allocative (including innovative), and input-selection effects of schooling using disaggregated data. Estimating a production function with physical output of one product as the dependent variable and education plus other inputs as explanatory variables discloses only the worker (direct) effect of education. Using gross output sales of two or more products as the dependent variable reveals both the worker and the allocative effects of schooling, as the role of education in allocating inputs across different outputs can be captured. Estimating a value-added (or profit) production function makes it possible to examine the worker, allocative and input-selection effects of education, if education is included in the specification and other purchased inputs are excluded.

Ram and Singh (1988) provide a straightforward application of this methodology, examining the allocative effect of schooling in Burkina Faso. They estimate alternative Mincer/Chiswick-style earnings (income) functions to estimate the effect of education upon income: one with education plus other farming inputs as the explanatory variables, and one including only education. The coefficient on education in the first equation captures only the worker effect of schooling, while in the second equation it captures both the worker and allocative effects because other inputs are no longer held constant. The difference between the coefficients on schooling in the two equations provides an indication of the size of the allocative effect.

One potential problem with this approach to studying the allocative effect is that it assumes causality between the amount of education attained by the farmer and the quantity of other inputs used. This is inappropriate if education and other inputs are simply correlated, and levels of all production inputs are caused by a third, unobserved, factor.

To establish causality from education to input choice, Appleton and Balihuta (1996) run regressions with each input as the dependent variable and education and other regressors as explanatory variables in their research on Ugandan agricultural productivity. Since they find that education does have a strong positive effect upon use of capital and other purchased inputs, they conclude that the usual Cobb-Douglas production function which includes other inputs explicitly (i.e., holding other inputs constant) understates the importance of education in explaining output. They then estimate the production function without these inputs, as suggested by Welch (1970), to capture more fully the effect of schooling.
When there is adequate information about input and output prices, it is possible to investigate the full effects of schooling without omitting other inputs from the production function. Wu (1977) estimated the worker, allocative and scale effects of schooling for small-scale farmers in Taiwan using a model of profit maximisation. Farm profits are a function of fixed and variable inputs plus education less costs. Optimal input demand functions are specified as functions of fixed inputs and education to give an expression for optimal profits. Totally differentiating the actual and optimal profit functions with respect to education provides information on the allocative, worker and scale effects of education.

2.4.b. Frontier Production Function Approach

A production frontier is estimated based on the most efficient observed use of inputs to produce each level of output. The extent to which farm production differs from the frontier provides a measure of technical inefficiency for the sample as a whole or for each firm individually. The causes of technical inefficiency can be investigated by regressing inefficiency on education and other explanatory variables (Ali and Byerlee 1991).

One explanation behind recent interest in frontier methods for estimating production efficiency is that in post-green revolution agriculture, which characterises much of Asia, it has become apparent that opportunities to increase output through innovations are becoming more scarce, and that in order to increase production, it is necessary for farmers to move closer to their production frontier. This represents a reverse in the view that farmers are 'poor but efficient' (Shultz 1964), and that education has a limited role to play in increasing output without the introduction of new inputs and technologies (Hussain and Byerlee 1995; Idachaba 1995). Phillips and Marble (1986) contend that the frontier production function may be more relevant to the study of the effects of education upon farm productivity than the conventionally used average function because it focuses attention upon the best-practice farmers in the sample, highlighting the role of schooling.

Statistical estimation of production frontiers has had two incarnations: stochastic and non-stochastic (deterministic). The deterministic frontier takes the following general form:

$$Y = f(X)e^{-u} ,$$

where Y is output, X a vector of production inputs and $-u$ a non-negative error component representing technical inefficiency. The deterministic frontier is estimated without consideration of the possibility of measurement error, statistical noise or random exogenous variations. This method permits ready calculation of the degree of inefficiency for each farm in terms of the divergence of output from the production frontier. However, it is unsatisfactory from an econometric point of view. Random variations in output across farms, and even measurement error, will be wrongly attributed to inefficiency within the firm's control (Ali and Byerlee 1991).

In response to the inadequacies of deterministic frontier estimation, three sets of researchers simultaneously and independently developed the stochastic production frontier methodology: Aigner, Lovell and Schmidt (1977), Meeusen and van den Broeck (1977) and Battese and Corra (1977). Stochastic frontier estimation involves specification of a two-part error term:

$$Y = f(X)e^{v-u} ,$$

where v represents random shocks, such as measurement error or factors which are external to the firm (e.g., weather), and is symmetric and distributed normally. The second component, u, is a one-sided, strictly non-negative, error representing technical inefficiency.

Jondrow et al. (1982) show how to decompose the $v-u$ term to provide estimates of technical inefficiency by calculating the expected level of inefficiency for each farm, $E(u_i)$, conditional on the random component, v_i (Ali and Byerlee 1991). Battese and Coelli (1988) provide a formula to estimate farm-specific efficiency in the case of a logged dependent variable.

Ordinary Least Squares produces estimates of the average production function. To estimate the production frontier, there are several alternatives including: Corrected OLS, Modified OLS and MLE. (1) COLS - attributed to Winsten (1957) and Gabrielsen (1975) - shifts up the OLS intercept to encompass all outliers so that estimated technical efficiency is always above 0 and less than 1. However, this technique can only be used if a deterministic frontier is estimated, not a stochastic frontier. (2) MOLS - attributed to Richmond (1974) - also shifts up OLS intercept but some outliers may be above the frontier, so estimated technical efficiency can be greater than 1 in the case of a deterministic frontier. Since the stochastic frontier includes noise, all observations will be below the frontier and TE will fall between 0 and 1. (3) MLE - suggested by Afriat (1972) and first used by Greene (1980) and Stevenson (1980) - permits modification of the slope as well as the intercept of the average function to estimate the frontier. MLE estimates of the production frontier encompass all observations, so that estimated TE lies between 0 and 1, as expected (Lovell 1993).

The first two methods implicitly assume that the most efficient farmers employ the same structure of production technology as inefficient farmers, ignoring the possibility that farmers may become more efficient by taking advantage of possible economies of scale and substitution. By contrast, MLE estimates permit a change in the slope of the frontier as compared with the OLS function, allowing the production frontier estimated by MLE to be structurally different from the average production function estimated by OLS. Empirical evidence using both frontier and non-frontier techniques seems to suggest that this possibility may be highly relevant (Lovell 1993).

One weakness of the frontier approach is that empirical results are very sensitive to the number of inputs included, the degree of aggregation of the data, and whether or not environmental factors, such as soil quality, are included (Hussain and Byerlee 1995). If environmental variables are omitted from the production function specification, then variations in productivity between farms owing to differences in soil quality or other environmental factors between farms will be erroneously regarded as resulting from inefficiency under the control of the farmer. Production frontiers should be estimated on geographically small, homogenous regions to reduce variability in environmental factors. Furthermore, if any of the factors of production are fixed in the short term, this will lead to upward bias in measurement of technical inefficiency (Ali and Byerlee 1991).

Lovell (1993) notes that the Cobb-Douglas function is the most commonly used functional form to estimate the production frontier. It has the advantage of ease of estimation and interpretation of the coefficient, u. However, since it assumes constant elasticity of scale and unitary elasticity of substitution, variations in elasticity of scale or substitution may be erroneously attributed to inefficiency. Hence, functional form is a relevant consideration when estimating the production frontier. Results are also highly sensitive to the assumed distribution of u, the component of the error term attributed to inefficiency.[2] Commonly assumed distributions include: half-normal, truncated normal, exponential, and gamma (Greene 1993).

[2] See, for example, Croppenstedt and Muller (1998) for empirical evidence that the estimation of inefficiency is sensitive to choice of distribution.

Once the frontier has been estimated and reasonable estimates of *u* have been obtained, it is possible to examine the determinants of inefficiency in production. Lovell (1993) advises that the first stage (estimation of efficiency scores) should include variables under the control of the farmer, while the second stage (explanation of the efficiency scores) should include variables not under the control of the farmer, such as site variables, demographic variables, socio-economic variables, environmental variables, and any quasi-fixed factors. This appears to contradict the advice of Ali and Byerlee (1991) that environmental factors should be included in stage one to avoid attributing to inefficiency productivity shortfalls which are owing to the environment.

Ultimately, the research question of interest will determine which variables are included in the first stage and which are reserved for the second stage. For example, if the researcher wishes to measure the inefficiency which remains after considering all factors under control of the farmer, then any variables which are exogenous to the farmer (such as land quality and rainfall) should be included in the second stage to explain the remaining inefficiency, as Lovell (1993) suggests. However, if the researcher wishes to explain the causes of inefficiency which cannot be attributed to environmental or similar factors, then all production and environmental variables should be included in stage one to avoid attributing to inefficiency problems such as inadequate rainfall. Then the variables which are hypothesised to explain inefficiency under the control of the farmer, such as years of schooling, may be included in the second stage of estimation.

Lovell (1993) notes that this two-stage procedure rests on the assumption that factors such as education affect the efficiency of the farmer in transforming inputs into output but do not affect the process by which production occurs. If the variables used in estimating efficiency are correlated with the variables used to explain efficiency, the coefficients on the variables used in the first stage to estimate efficiency will be biased. A one-stage model in which all variables, including education, appear in a single equation to estimate efficiency may alternatively be specified. This reduces the problem of omitted variable bias, but may lead to multicollinearity. There is an important difference between the two-stage and one-stage model: in the one-stage model, efficiency is measured controlling for variables such as education; in the two-stage model, efficiency is measured without controlling for variations in education in the first stage, and regressors such as education are used to explain variations in efficiency in the second stage (Lovell 1993).

Ali and Byerlee (1991) survey 12 frontier production function studies, of which approximately half investigate the sources of measured inefficiency, and note that variables related to managerial ability of farmers, including education and technical know-how, were found to be significant in every case, whereas mixed results were found for other potential sources of inefficiency.

3. Data

The basic economic and demographic data for this study are drawn from the first round of the Ethiopia Rural Household Survey (ERHS). The initial round of this large panel survey was funded by the Swedish International Development Agency and conducted by the Department of Economics, Addis Ababa University, in collaboration with the Centre for the Study of

African Economies, Oxford, and the International Food Policy Research Institute (IFPRI), Washington, in 1994.

The survey covered 1477 households in 18 Peasant Associations (villages) spanning 15 *woredas* (districts) in six regions. Six of the sites, primarily located in drought-prone areas, had previously been surveyed by the IFPRI in 1989. The remaining nine were chosen by the Department of Economics with the assistance of Ministry of Agriculture officials in 1993 to reflect most of the important agro-economic variations found in rural Ethiopia. Together, the 15 sites provide a realistic mix of cultivation categories and standard of living strata. Brief site descriptions are given in Croppenstedt and Demeke (1997). Bevan and Pankhurst (1996) provide more detailed information.

The Peasant Association (PA) office in each site was consulted to determine the number of households in the PA, and the proportion headed by women. The number of households surveyed in each site reflects the size of the PA in relation to the total size of all PA's surveyed. Households were selected randomly using the PA registers, with female-headed households proportionally represented.

Each household was surveyed three times within approximately twelve months (early 1994, later in 1994 and early in 1995), providing a picture of both current activities and the household's historical background. Questions were asked on a wide range of issues affecting rural Ethiopian households, including production (crop output, land, labour and other inputs, and prices), consumption, assets, credit, migration, anthropometric measures and health. The first round also included a few key questions on educational status and attainment. Further information on education, as well as historical recall on agricultural innovations, was provided in the second round of the survey (conducted in 1994/95).

Since the three rounds were conducted at short intervals, and the educational investment and innovation questions involved historical recall, data on education and innovation from the second round may be used to illuminate production and output from the first round. Similarly, data from the third-round village-level questionnaires should be representative of school resources and enrolments at the time of the first round.

Data availability will ultimately determine which effects of schooling may be captured and how they are described. Jamison and Lau (1982) maintain that the most appropriate data set for the purposes of investigating the effects of education upon agricultural productivity should include household data drawn from a number of regions, and the ERHS data fulfil this criterion. Although it would be desirable to estimate a profit function to capture as many of the effects of schooling (worker, allocative and input-selection) as possible, data on input costs from the first round of the ERHS are inadequate for this purpose. Hence, a straightforward production function will be employed.

4. Methodology

In this section, methods are proposed to measure different effects of schooling upon agricultural output. In addition, variable specifications are considered, and interpretations of the education variable coefficients in differing equation specifications are suggested.

4.1. Non-frontier Production Function Estimation of the Effects of Schooling on Production

4.1.a. Worker Effect of Schooling

The worker effect of schooling refers to the increase in farm output that is owing directly to education, holding other inputs constant (Chaudhri 1979; Welch 1970). If a farm is not technically efficient, it will produce at a point inside its production possibilities frontier. Hence, more output could be produced for a given set of inputs if technical efficiency were increased. One reason for technical inefficiency may be ignorance of best practices. Cognitive and non-cognitive skills imparted by education (formal or non-formal) may increase technical efficiency. Therefore, more schooling is expected to be associated with higher output, *ceteris paribus*. However, it is possible that attitudes imparted in school, particularly at higher levels, may undermine technical efficiency if the farmer comes to view farming as inferior to urban wage employment and to believe that he has failed by remaining in a rural occupation (Appleton and Balihuta 1996).

To measure the worker effect of schooling, Cobb-Douglas[3] (C-D) production functions may be specified in semi-log linear form as follows:

$$(1) \qquad \ln Q_i = \alpha_0 + \alpha_1 \ln L_i + \alpha_2 \ln N_i + \alpha_3 \ln K_i + \alpha_4 \ln F_i + \alpha_5 \ln IN_i + \alpha_6 \ln OX_i + \beta S_i + \Sigma\, \gamma_{ji}\, Z_{ji} + \Sigma\, \phi_{ki}\, X_{ki} + \varepsilon_I\ ,$$

where: $\ln Q_i$ is the natural logarithm of farm output for household i; $\ln L_i$ is the natural logarithm of available cultivable land for household i; $\ln N_i$ is the natural logarithm of the number of adult household members who work on the farm in household i; $\ln K_i$ is the natural logarithm of the value of capital goods (hoes and ploughs) used by household i; $\ln F_I$ is the natural logarithm of the quantity of fertiliser used by household i; $\ln IN_i$ is the natural logarithm of expenditure on other purchased inputs (seeds, plants, tools, transport, etc.) by household i; $\ln OX_i$ is the natural logarithm of the number of bulls and oxen owned by household i; S_i is a variable(s) representing education for household i; Z_{ji} is other household characteristics for household i; X_{ki} is other farm characteristics, such as land quality, for household i; and ε_i is a stochastic error term.

There are many possible variants of this equation, particularly involving different specifications of the dependent variable and the education variables. Output may be measured as the physical output of one crop (for Ethiopia, cereals may be aggregated for use as the dependent variable, since most crops produced are cereals), or as the gross value of sales of all crops produced, where different crops are aggregated using price weights. The first measure is the simplest, but if households produce several different crops, its usefulness to describe the effects of schooling on farm output in general is limited. Note that when the second measure of output is used, an aspect of crop selection is incorporated in the dependent

[3] Chaudhri (1979) reports that most researchers use an unrestricted Cobb-Douglas production function because, conveniently, it is linear and homogenous. He notes that Griliches compared the Cobb-Douglas specification to some alternatives and decided that it provides efficient enough results and has the advantage of being easily interpreted economically. However, the translog function is more flexible, and if the coefficients on the interaction terms are jointly significant, use of the simpler Cobb-Douglas form may represent mis-specification.

variable and the effect of education measured will include the effect of education on crop choice, rather than the worker effect of schooling alone.

Labour is generally measured as the number of productive adults (aged 16 to 60) in the household or as person days of labour spent on ploughing, weeding and harvesting. An advantage of the first measure is that it allows distinction between different types of labour (e.g., male versus female, and by age cohort). An advantage of the second method is that it counts actual time spent on farm activities, rather than just potential effort.

Several different measures of education may be used, and different categories of labour may be considered (e.g., the household head versus all non-head adults in the household). If education is measured as the number of years of schooling attained, the estimated coefficient represents the percentage increase in output for one extra year in school. Here, several possibilities exist, including: years of schooling of the household head alone; average years of schooling of all adult household members or all non-head adult household members; and total years of schooling of the most educated adult household member. Interpretation of the education coefficient depends upon the specification chosen. For example, the coefficient on average years of schooling of all household members (not logged) in a C-D specification represents the percentage increase in farm output for a one year increase in the average education of all household members.

To account for the possibility that different levels of schooling have differing effects upon output, years of primary schooling may be included separately from years of secondary schooling, or a set of dummy variables representing different levels of schooling may be used, or a set of additive categorical variables, specifying the number of adults with each level of education, may be considered. The coefficient on a 0-1 dummy variable represents the percentage increase in output due to having that level of schooling, as compared with the base case (assuming a Cobb-Douglas specification of the production function). The coefficients on the additive categorical variables represent the marginal product associated with having one more household member with that level of education.

Different production functions apply to different farming systems. Use of the entire pooled sample of farm households in rural Ethiopia constrains the coefficients on each explanatory variable to be the same across different farming systems, which may represent a misspecification and result in biased estimated coefficients (Jamison and Lau 1982). Thus, it may be necessary to estimate different production functions for different regions or different farming systems (see Appleton and Balihuta 1996). Indeed, Cotlear (1990) found that education had differing effects in different farming systems, in his study of farmers using traditional versus modern technologies in Peru.

4.1.b. Allocative (Including Innovative) Effect of Schooling

The allocative effect of schooling refers to the benefits that education may confer in terms of an increased ability to deal with disequilibria (Shultz 1975). Cognitive skills, such as literacy and numeracy, help farmers to read instructions and calculate treatment amounts for new inputs. More positive attitudes toward modernisation and risk-taking, along with other non-cognitive consequences of schooling, encourage farmers to innovate. The allocative effect of schooling also may become apparent under circumstances of changing prices or weather patterns and novel cases of pest infestation or crop disease.

In the previous section, all other inputs were held constant to estimate the worker effect of education, and no consideration was given to the role of education in helping to allocate other production inputs. Hence, the coefficient on education in equation (1) may be considered a lower bound of the estimated effect of education upon farm production.

In measuring the allocative effect of schooling, the dependent variable must be total farm output aggregated over at least two crops, since no account is taken of allocation of inputs across competing uses in the case of only one output. In the simplest specification, explicit account must not be taken of the other inputs into production over which education is expected to play an allocative role. Note that omitting other inputs which are correlated with education is justified only if education is known to play a causal role in determining the quantities of other inputs used. This may be tested by estimating each input as a function of education and other variables (Appleton and Balihuta 1996). If the coefficient on education is positive and significant, including schooling in an equation without variable inputs, as follows, is reasonable:

$$\ln Q_i = \alpha_0 + \beta S_i + \Sigma\, \gamma_{ji} Z_{ji} + \mu_I\,, \quad (2)$$

where: $\ln Q_i$ is the natural logarithm of farm output for household i; S_i is a variable(s) representing education for household i; Z_{ji} are other household characteristics for household i; and μ_I is a stochastic error term.

Now, the coefficient on schooling incorporates the worker effect of education plus the increase in output owing to the allocative effect. The difference between the coefficients on schooling in Equation 2 and in Equation 1 gives the allocative effect of schooling.

A special case of the allocative effect of schooling, the innovative effect, may be investigated separately. A complete consideration of this effect is beyond the scope of this research. However, it is useful to examine the role of education in facilitating the use of innovations. Cotlear (1990) claims that when new technologies are introduced, formal education may be an important ingredient for successful adoption, as education decreases the costs of obtaining new information and learning to apply new techniques. A simple way to investigate this is to include cross-product terms interacting years of schooling with variables representing adoption or usage of new inputs or crops. If the coefficient on the interaction between education and a dummy for having adopted fertiliser (or another new input) is positive and significant, it indicates that education is complementary to the adoption of the input. Interacting site dummy variables with education will indicate whether there are significant differences in the effects of schooling upon output by locality, if the regions differ in terms of the degree of modernisation of production technology used (Cotlear 1990).

4.1.c. External Effect of Schooling

While the previous two sections have been concerned primarily with private benefits of schooling in terms of increased output by individual households engaged in agricultural production, an aspect of the allocative effect of schooling may not be fully captured by examining household-level data. Educated farmers may tend to be early innovators in a particular area. However, once an innovation has been tried and the results are obvious to others in the village, a farmer need not himself be educated in order to appreciate the possible advantages of new inputs or farming techniques. Social learning may occur. If it is uneducated farmers who are learning from the experiences of educated farmers, then part of the effect of schooling includes the external benefits in terms of increased opportunities for social learning in the village.

There are alternative ways to capture the external effect of schooling upon production. One is to estimate an aggregate village-level production function. However, since the ERHS data are drawn from a small number of villages, there are few degrees of freedom and the results would not be highly robust.

Appleton and Balihuta (1996) suggest that Equations (1) or (2) be re-estimated with a village-level aggregate education variable to capture the external effects of schooling as follows:

(3) $$\ln Q_i = \alpha_0 + \Sigma\, \alpha_j \ln X_{ji} + \beta S_i + \Sigma\, \gamma_k Z_{ki} + ED_v + \phi_i$$

where: $\ln Q_i$ is the natural logarithm of farm output for household i; $\ln X_{ji}$ is the natural logarithm of other inputs j for household i; S_i is a variable(s) representing average education for household i; Z_{ki} = other household characteristics for household i; ED_v is average education for village v; and ϕ_i is a stochastic error term. The coefficient on the village-level education variable may be interpreted as the increase in household output for an additional year of schooling, on average, in the village.

A potential disadvantage of this specification is that the village-level education variable may be correlated with other unobserved village-level variables, and the coefficient on this variable may incorporate not only the effects of average levels of schooling in the village but also other community fixed effects on farm output not caused by schooling. In particular, it is possible that villages which have historically been prosperous have made large investments both in education and in other productivity-enhancing inputs. An observed link between education and agricultural productivity may be owing to a third factor. This problem can be reduced by inclusion of several other community-level variables. However, it is difficult to be certain that it has been eliminated, particularly without data on a large number of villages.

4.2. Frontier Production Function Estimation of the Effects of Schooling on Efficiency

Two approaches have been described to study the effects of schooling upon productive efficiency using frontier production function analyses. The first approach is to estimate the production frontier with all relevant inputs, including education, in one stage as follows:

(4) $$Y = f_1(X,Z,H)e^{v-u}$$

where: X are direct inputs under the control of the farm manager; Z are environmental variables; and H are other exogenous variables specific to the household, including education. Farm-level inefficiency is estimated using methods developed by Jondrow, et al. (1982) and further derived for the case of a logged dependent variable by Battese and Coelli (1988).

The coefficient on education in the production frontier indicates the effect of education on the productivity of the most efficient farm operators, and does not provide information on the effect of education upon typical farms in the sample.

In the two-stage approach described earlier, a stochastic frontier production function is estimated using only inputs under the direct control of the farmer and exogenous environmental factors in the first stage in order to obtain estimates of inefficiency. Measured inefficiency is explained in the second stage using exogenous characteristics of the household and productive environment, including education. The coefficient on years of schooling in the second stage is expected to be negative and represents the reduction in inefficiency owing to an extra year of education. A general two-stage model is as follows:

$$Y = f_1(X,Z)e^{v-u} \qquad (5)$$

$$u = f_2(H) \qquad (6)$$

where: X are direct inputs under the control of the farm manager; Z are environmental variables; and H are other exogenous variables specific to the household, including education.

Since the role of education in reducing farmer inefficiency is of primary interest, rather than an exhaustive consideration of the sources of inefficiency, only the education policy variable will be included in the second stage, while other exogenous household characteristics will be controlled for in the first stage.

4.3. Estimation Issues

4.3.a. How Much Education is Needed?

Jamison and Moock (1984) discover a threshold effect in Nepal: farmers with one to six years of schooling are not significantly more productive than those who have never been to school, whereas those with seven or more years of schooling are more productive than those with less education. Appleton and Balihuta (1996) also find that at least four years of schooling are needed for education to affect farm output in Uganda. They note that this is commonly thought to be approximately the amount of schooling needed for literacy and numeracy to be functionally attained (see Lockheed, Jamison and Lau 1980; and Moock 1981).

It is usually assumed that formal schooling is most useful in an innovative environment where farmers face rapid technology changes and must acquire new information and make appropriate choices over inputs and outputs in order to continue to maximise profits (see Chaudhri 1979; Rosenzweig 1995; and Nelson and Phelps 1966). Schultz (1964; 1975) suggests that farmers operate more efficiently in steady state traditional agriculture than under the conditions of modernisation, and that education may help farmers cope with 'disequilibria.' If this is true, more schooling is needed in a rapidly changing environment.

Cotlear (1990) tested the Shultz hypothesis using data from three regions in the Peruvian sierra which were similar in their ecology and other salient characteristics, but which differed in terms of the degree of modernity of agricultural production. His estimates of agricultural production functions in each region show that education raises farm output. However, the relevant level of education depends on the farming technology employed. In areas which have just begun to modernise, basic literacy and numeracy are sufficient to foster growth. To ensure continued technological advancement, higher levels of education are required.

4.3.b. Whose Education Matters?

Another issue which arises is: whose education matters to agricultural productivity? Most studies include information on years of schooling of the household head, or average years of schooling of all adult household members, or average years of schooling of only those household members engaged in farming. Occasionally, average years of schooling attained by all household members is used. However, this proxy for household education is not ideal, since some household members, such as young children and the elderly, participate less in agricultural production and decision-making than others.

Basu and Foster (1998) argue that only one person need be educated in the household for the entire household to benefit from the cognitive skills acquired in school. Hence, it may be years of schooling of the most educated household member which matters, rather than average years of schooling attained by all household members (Foster and Rosenzweig 1996). This is particularly likely to be the case in terms of the allocative benefits of schooling, such as may be derived from adopting the use of modern farm inputs (Green, Rich and Nesman 1985). Certainly, households with an uneducated household head need not necessarily be less productive than those where the household head has been to school, if some other member of the household, or even a neighbour, has some schooling. Thus, children who have been to school may contribute to farm output by providing cognitive skills which compensate for lack of education of the head. However, owing to the possibility of confounding the empirical results with endogeneity, the education of children should not be included in average or maximum years of schooling in the household. This is discussed further below.

4.3.c. Establishing Causation

The relationship between education and agricultural productivity may be bi-directional. Areas which have more education enjoy higher farm output, and areas which are prosperous invest in greater levels of education (Tilak 1993; Bowman 1980). An analogous situation might exist at the household level. For example, a farm household may be very poor because of high levels of agricultural inefficiency. Bad farm management may reflect inadequate schooling of the household decision makers. As a result of their poverty, the household invests in low levels of education for its younger members. In this case, farm inefficiency and educational investments are correlated, but the true relationship between the two is not apparent.

This problem is less relevant with respect to adult years of schooling alone because the education of adult household members is based upon decisions made, and circumstances prevailing, a number of years ago, and not upon current levels of productivity. However, Strauss and Thomas (1995) point out that although adult educational attainment is a pre-determined variable, endogeneity may exist if investments in education made many years ago were correlated with unobserved variables which affect productivity today, such as ability and motivation. They call the problem one of 'unobserved, time-persistent heterogeneity,' as opposed to 'true' simultaneity bias. This issue is also relevant to the relationship between education and productivity at the village level, since historically favourable, and unobservable, agro-economic conditions in the site may have led to increased investment in education as well as in other productivity-enhancing agricultural inputs. ‘In a cross-section, predetermined variables can rarely be legitimately treated as exogenous’ (Deaton 1997, 99).

In a household production function, such information as the score on Raven’s Progressive Matrices test of non-verbal reasoning ability or family background variables could be used to proxy unobserved ability of the farm decision maker, ameliorating, however imperfectly, this empirical problem in the household production function. Unfortunately, there is little such data available for the ERHS. However, there is evidence of low income elasticity of demand for schooling in the sites surveyed (see Weir 1997). This indicates that the link between productivity and investments in schooling in the past is probably weak in rural Ethiopia, and the issue of causality is a less serious concern than would be the case if demand for education were found to be highly responsive to changes in household income.

In an aggregate production function, controlling for village-level sources of spurious correlation between education and agricultural productivity is a necessary, though not a sufficient, condition for establishing causality. Historical information on the institutional responsiveness of school provision to local demand for schooling may provide evidence that the direction of causation is from education to productivity.

4.3.d. Unobserved Heterogeneity

A frequent criticism of findings based on cross-sectional data involves the problem of unobserved omitted variables bias. Fane (1975) cautions that omission of pre-school (innate) ability and measures of the quality of schooling may lead to upward bias in the coefficient on schooling in the production function. However, he notes that previous studies for the United States on the relationship between education and income, including ability, did not find that this bias was large (see Griliches 1970; Gintis 1971; and Griliches and Mason 1972). A more recent study of the effect of schooling on wage income using data on twins in the United States showed that omission of ability did not cause upward bias in returns to education (Ashenfelter and Krueger 1994).

There is also some research in a developing world context to suggest that bias from omission of unobserved ability and motivation may not be large. Jamison and Moock (1984) include Raven’s score as well as two measures of family background (father’s education and father’s land-holding) in their production function to determine whether the relationship between education and productivity in Nepal is spuriously caused by the relationships between family background and education and between family background and productivity. They conclude that this is not the case. Family background does influence education but does not affect productivity by itself. Inclusion of family background variables in the production function does not change the coefficients on education, and the family background coefficients are not themselves significant when education variables are included in the equation. Furthermore, Krishnan (1996) investigated the role of family background and schooling in occupational choice and earnings in urban Ethiopia. She found that family background was a significant determinant of both occupation and earnings. However, returns to schooling were high even after controlling for family background.

5. Results

Table 1 describes the data to be used in both frontier and non-frontier production function estimation. Means are presented for the sub-sample of observations used in the econometric analysis. Data to estimate the relationship between education and farm productivity are drawn from the first round of the ERHS. The full sample for the ERHS contains 1477 households. However, the final sample employed for the present analysis includes only 616 households.

Observations with missing or inconsistent information were omitted. To ensure that the estimated production function represented a single farming system and production technology, only those sites where cereals are cultivated primarily using oxen-plough technology were chosen.[4] In addition, the following outliers were omitted from the sample: households using less than 0.2 ha of land; households using less than six or more than 800 person days of labour in total; households using less than two person days of labour for ploughing, or less than one person day of labour on weeding or harvesting; households which recorded cereal productivity per person day of labour ploughing of greater than 750, production of more than 620 per person day of weeding or in excess of 780 per person day of harvesting; and households which reported that the value of their capital assets exceeded 990 Birr. The lower bounds ensure that only households who are primarily engaged in farming were included, and the upper bounds were set to exclude data which is likely to have been erroneously recorded.

The dependent variable is the natural log of the value of cereal production deflated by a Laspeyre's price index. Cereal value is given by the sum of *tef*, wheat, maize, millet, barley and sorghum produced each multiplied by its price. An average price index is constructed for each household by weighting the price of each output by its share in total cereal production for that household (see Croppenstedt and Muller 1998).

Several of the farm variables are presented in logarithmic form. Input values of zero were transformed by adding the constant one to facilitate taking logs, as is common practice (see for example: Jacoby 1992; and MaCurdy and Pencavel 1986). Jacoby (1992) notes that the choice of constant is arbitrary, but should be small relative to the average value of the input for the whole sample. He cautions that use of different arbitrary constants to adjust inputs results in very different coefficient estimates for some variables. Johnson and Rausser (1971) find that adding an arbitrary constant produces biased parameter estimates. Bias increases with the size of the constant added, but modifying only the sub-sample of zero values results in less bias than modifying the entire sample. They note that omitting zero values does not result in bias, if the omitted observations are considered outliers, but the estimates produced will be less efficient than those obtained from the full sample.

For the purposes of this analysis, land is considered to be fixed in the long run, since buying or selling of land is prohibited. Labour, capital, oxen, and trees are fixed in the short run. Although not commonly practised, labour may be hired in by households during busy periods,

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[4] Education does not seem to increase the likelihood of employing oxen-plough cereal production technology. In fact, households in villages which primarily produced *enset* were found to have significantly higher average investments in schooling than those in the oxen-plough cereal growing areas. Thus, by omitting the enset growing region from the sample, no upward bias is expected in the results on the effects of schooling upon farm production.

and various types of work party arrangements are found in most villages. Use of commercial fertiliser, manure and other inputs are treated as variable in the short run.

Land quality and slope are proxies for environmental conditions. Other possible environment proxies, such as dummy variables indicating self-reports that the farmer's crops suffered from disease, unfavourable weather, animals or other pests, are considered to be potentially endogenous, and have been excluded from the analysis. Site dummy variables are included to capture site-specific fixed effects, such as problems of inadequate rainfall or widespread pests. The site dummy variables also capture variations by site in infrastructure quality and the timely availability of inputs, such as fertiliser, among other site characteristics.

Several different variables are available to proxy education. Information on years of schooling by type and recipient are included. These will be compared and contrasted to determine whether some types of schooling add more to farm productivity than others and whose education matters most to the farm.

Years of schooling of the household head is treated separately from years of schooling of other adults in the household. While every household has a head, not all households have any other adult household members. For these households, average years of schooling of other adult household members is set to zero, but average years of schooling of all adults is equal to years of schooling of the household head alone. Mean years of schooling of all adults is higher than either years of schooling of the head or average years of schooling of other adults, because average education of other adults is calculated including zeros for households with no other adults, while average years of schooling for all adults does not include these zero observations.

In the tables which follow, significant coefficients are flagged using stars according to significance on two-tailed t-tests. However, it may be argued that a one-tailed test is more appropriate where the hypothesis is that the coefficient on a particular variable will be greater than or equal to zero, but not negative (or vice versa). That is, under certain hypotheses, only the upper (or lower) tail of the distribution is relevant (Maddala 1992; Pindyck and Rubinfeld 1991; Larsen and Marx 1986). Education is usually expected to have a positive effect upon farm output and efficiency. However, it may also be argued that exposure to education can reduce farm productivity by creating negative attitudes toward farm labour or by reducing time spent in 'on the job training,' leading to a negative coefficient. This is more likely to be the case with respect to secondary schooling than primary. Since the appropriate form of the hypothesis to test may vary according to particular circumstances, and since it is desirable to perform the most stringent possible tests of hypotheses in any case, two-tailed t-tests have been used. However, to provide greater information, coefficients which are significant at the ten percent level on a one-tailed t-test (equivalent to the twenty percent level on a two-tailed test) have also been flagged using a check (✓).

Table 1: Variable Definitions and Mean Values

Variable Name	Definition	Mean
Dependent Variable:		
LN_CEREAL	Natural log of the value of cereal crops (deflated)	5.76
Farm and Household Variables ǂ*:*		
LN_LAND	Natural log of land cultivated - cereals (hectares)	0.19
LN_LABOUR	Natural log of person days worked (ploughing/harvesting)	4.27
LN_CAPITAL	Natural log of the value of hoes/ploughs (Birr)	2.57
LN_INPUTS	Natural log of value of other inputs (Birr)	1.93
OXEN	Dummy: 1 if household owns at least 2 oxen	0.27
BANANA	Dummy: 1 if number of banana trees>=10	0.08
COFFEE	Dummy: 1 if number of coffee plants>=5	0.12
CHAT	Dummy: 1 if number of *chat* plants>=50	0.11
EUCALYPTUS	Dummy: 1 if number of eucalyptus trees>=5	0.32
ENSET	Dummy: 1 if number of *enset* plants>=12	0.10
GESHU	Dummy: 1 if number of *geshu* plants>=12	0.05
LN_FERT	Natural log of quantity of fertiliser used (kg)	2.08
MANURE	Dummy: 1 if manure used on fields	0.49
LN_QUALITY	Natural log of cereal land quality (fertile - - - infertile)	0.45
LN_STEEPNESS	Natural log of cereal land slope (flat - - - steep)	0.19
AGE_HHH	Age of household head (years)	45.26
AGESQ_HHH	Square of age of household head (years)	2277.0
FEM_HEAD	Dummy: 1 if household head is female	0.17
NONAGR_HHH	Dummy: 1 if household head is not primarily a farmer	0.05
NO_ADULTS	Dummy: 1 if head is only adult in household	0.05
Education Variables		
ED_HHH_F	Years of schooling of household head - farmers	1.14
ED_HHH_NF	Years of schooling of household head - non-farmers	0.07
ED_ADO_F	Avg. years of school of other adults - farmers	0.66
ED_ADO_NF	Avg. years of school of other adults - non-farmers	0.78
ED_AD_F	Avg. years of schooling of all adults in hh - farmers	1.45
ED_AD_NF	Avg. years of schooling of all adults in hh - non-farmers	0.93
1T3_HHH_F	Dummy: 1 if head has between grades 1 to 3 - farmers	0.25
4T6_HHH_F	Dummy: 1 if head has between grades 4 to 6 - farmers	0.08
7UP_HHH_F	Dummy: 1 if head has grade 7 or higher - farmers	0.04
1T3_HHH_NF	Dummy: 1 if head has between grades 1 to 3 - non-farm	0.04
4T6_HHH_NF	Dummy: 1 if head has between grades 4 to 6 - non-farm	0.00
7UP_HHH_NF	Dummy: 1 if head has grade 7 or higher - non-farm	0.00
1T3_ADO_F	Dummy: 1 if others have grades 1 to 3, avg - farmers	0.13
4T6_ADO_F	Dummy: 1 if others have grades 4 to 6, avg - farmers	0.05
7UP_ADO_F	Dummy: 1 if others have grade 7 or higher, on avg - farm	0.02
1T3_ADO_NF	Dummy: 1 if others have grades 1 to 3, avg - non-farmers	0.21
4T6_ADO_NF	Dummy: 1 if others have grades 4 to 6, avg - non-farmers	0.04
7UP_ADO_NF	Dummy: 1 if others have gr. 7 or higher, avg - non-farm	0.02
1T3_AD_F	Dummy: 1 if adults have grades 1 to 3, avg - farmers	0.33
4T6_AD_F	Dummy: 1 if adults have grades 4 to 6, avg - farmers	0.09
7UP_AD_F	Dummy: 1 if adults have gr. 7 or higher, avg - farmers	0.04
1T3_AD_NF	Dummy: 1 if adults have grades 1 to 3, avg - non-farmers	0.23
4T6_AD_NF	Dummy: 1 if adults have grades 4 to 6, avg - non-farmers	0.04
7UP_AD_NF	Dummy: 1 if adults have gr. 7 or higher, avg - non-farm	0.02
NOEDUC_F	Number of farmers with no schooling	0.77
UPTOGR3_F	Number of farmers with pre-school to third grade	0.42
GR4TO6_F	Number of farmers with grade four to six	0.16
GR7UP_F	Number of farmers with grade seven or above	0.07
NOEDUC_NF	Number of non-farmers with no schooling	1.22
UPTOGR3_NF	Number of non-farmers with pre-school to third grade	0.29
GR4TO6_NF	Number of non-farmers with grade four to six	0.06
GR7UP_NF	Number of non-farmers with grade seven or above	0.07
AVED_VILLAGE	Average years of schooling in village (excl. students)	1.12

Note: Means are based on the 616 observations (out of 1477 observations in total) used in the analysis.
ǂ The author is grateful to Dr. Andre Croppenstedt for providing his set of farm and household variables for use in the econometric analysis.

5.1. Non-frontier Production Functions: Effects on Productivity

5.1.a. Basic Production Function Results

Results of the estimation of standard Cobb-Douglas production functions (without education variables) are presented in Table 2. The dependent variable is the natural log of the value of cereal crops produced deflated by a Laspeyre's price index. The first equation incorporates all basic regressors, including site dummy variables intended to capture unobserved effects of site on productivity. Land, labour and capital are each positive and significant.[5] The sum of their coefficients is 0.70, which suggests decreasing returns to scale. The dummy variable indicating that the household has at least two oxen is also found to have positive and significant effect upon output. However, the value of other inputs, such as improved seeds and transportation, is not significant.

Of the tree/plant dummy variables, only banana and *chat* significantly affect the value of cereal crops produced. This is perhaps not surprising since sites which rely primarily on cereals, rather than fruit or root crops, were selected. There appear to be minor site-specific aspects of the productive value of tree crops, since omitting site dummies in Equation 2 changes the significance of the tree dummy variables slightly.

Fertiliser usage is found to have a positive and significant effect upon output, whether or not site dummies are included. However, the effect is larger when sites are omitted, indicating that use of chemical fertiliser is partly correlated with site. Controlling for site fixed effects, the dummy for use of manure as fertiliser is found to have a significant impact upon the value of crops produced. Omission of site variables results in a negative (but insignificant) coefficient, suggesting that manure use is more prevalent in sites with lower crop output. It may be that these are sites where more cattle are raised, and there is less land available to grow cereal crops.

The environment variables, land quality and gradient, are not found significantly to affect output. While still insignificant, the effects of land quality and slope are stronger and both of the expected sign when site dummies are omitted. Presumably, environment characteristics are closely related to site, and vary less within sites.

Age of the household head is used to proxy farmer managerial experience as well as attitudes toward modernisation and risk-taking in agriculture. A quadratic specification is employed. The negative coefficient on age suggests that farmers are less productive as they age, but the positive coefficient on the square of age indicates that productivity declines at a falling rate as the head gets older. This is surprising if the household head acts primarily as a farm manager, and younger and fitter household members provide the main work power. However, household heads in rural Ethiopia provide much of the farm labour. Older farmers are not physically able to produce as much as younger household heads because farm experience is countered by declining physical strength and perhaps by negative attitudes toward innovation.

[5] An alternative specification of the labour variable, natural log of the number of adults aged 16 to 60, was tested. The coefficient was virtually identical to that given in Table 2, but insignificant.

Table 2: OLS Estimation of the Average Production Function
Dependent Variable: Natural Log of Cereal Crops Produced (LN_CEREAL)

	Eqn. 1	Eqn. 2	Eqn. 3	Eqn. 4
CONSTANT	5.22 ***	4.66 ***	5.10 ***	6.01 ***
LN_LAND	0.39 ***	0.30 **	0.42 ***	0.64 ***
LN_LABOUR	0.17 ***	0.36 ***	0.19 ***	
LN_CAPITAL	0.14 ***	0.20 ***	0.15 ***	
LN_INPUTS	-0.01	-0.00		
OXEN	0.23 ***	0.17 **	0.27 ***	
BANANA	0.27 ***	0.34 *	0.29 ***	
COFFEE	-0.10	-1.24 ***	-0.08	
CHAT	0.42 ***	0.78 ***	0.51 ***	
EUCALPTUS	0.18	0.20 ✓	0.20	
ENSET	0.40 ✓	-0.14	0.42 ✓	
GESHU	-0.02	-0.06	0.03	
LN_FERT	0.06 **	0.12 ***		
MANURE	0.24 *	-0.12		
LN_QUALITY	-0.09	-0.17	-0.10	-0.13
LN_STEEPNESS	0.01	-0.16	-0.01	-0.01
AGE_HHH	-0.03 *	-0.04 *	-0.03 ✓	-0.02
AGESQ_HHH	0.00 ✓	0.00	0.00 ✓	0.00
FEM_HEAD	-0.24	-0.30 ✓	-0.25	-0.35 ✓
NO_ADULTS	-0.20	-0.19	-0.20	-0.39 ✓
NONAGR_HHH	-0.56 *	-0.35	-0.56 *	-0.67 **
SITE_2	-0.83 ***		-0.62 ***	-0.44 ***
SITE_3	-0.61 ***		-0.48 ***	-0.52 ***
SITE_4	0.11		0.20	0.72 ***
SITE_5	0.24 *		0.40 ***	0.91 ***
SITE_7	0.88 ***		1.12 ***	1.48 ***
SITE_8	0.17		0.35 **	0.87 ***
SITE_9	-0.76 ***		-0.62 ***	-0.65 ***
SITE_10	0.76 ***		1.01 ***	1.52 ***
SITE_15	-2.26 ***		-1.96 ***	-1.67 ***
SITE_16	0.41 ***		0.39 ***	0.49 ***
R^2	0.55	0.45	0.55	0.51
NUMBER OBS.	616	616	616	616

Note: Standard errors have been adjusted to account for the clustered nature of the data. Stars indicate significance using a two tailed t-test as follows: *** = 0.01; ** = 0.05; * = 0.10; ✓ = 0.20.

Households headed by a woman suffer a productive disadvantage (though not significantly in the fixed effects specification). This may be because female-headed households have fewer adults available for farm production, or because they receive less attention from agricultural extension agents. Households in which the head is the only adult produce lower output than households with more than one adult present, whether the head is male or female, though this effect is not significant. Finally, households where the household head is not primarily engaged in agriculture produce significantly less cereals than households in which the head's main activity is farming.

Equations 3 and 4 are included to illustrate the effect on the estimates of omitting inputs which are variable in the short and long run, as will become relevant in later specifications when education variables are introduced. Omitting the short run variable inputs, representing fertiliser and manure use and expenditure on other inputs, results in slight changes to the other farm and household variables (see Equation 3). When all variable inputs (short and long run) are excluded, the coefficient on land used rises to 0.64, as land picks up most of the effects of labour and capital upon output (see Equation 4).

Exclusion of the variable and short-run fixed inputs is justified if the quantities used of these inputs are found to depend partly upon education of household members. To test this, OLS regressions were run with each input as the dependent variable (probit techniques were used in the case of dummy dependent variables) and several farm and household regressors, the site dummy variables, and average household education as explanatory variables. Education is found to have a positive and significant impact upon input use in the case of labour, capital, other inputs,[6] fertiliser, oxen, coffee, eucalyptus, and *enset*, and a significant negative impact upon whether *chat* is planted. Education has no significant effect upon use of manure or investment in banana or geshu plants. Overall, education does tend to influence use of most variable and short-run fixed inputs. Thus, omitting these inputs from the production function permits the full effect of education upon cereal production to be estimated.

Overall, the Cobb-Douglas production functions estimated are able to explain 53 percent of variation in cereal production when all variables are included and 43 percent when sites are omitted. This performance is good, partcularly given that production is influenced by a number of unobservable variables, such as farmer motivation and access to credit, which could not be considered in this specification.

A restricted translog specification was also estimated to determine whether the assumption of unitary elasticity of substitution inherent in the Cobb-Douglas production function is too restrictive. However, it was not possible to reject the null hypothesis that extra variables included in the translog function are jointly equal to zero at the five percent level, suggesting that the Cobb-Douglas specification is sufficient to represent cereal output in the rural Ethiopian villages surveyed.

Finally, although production function regressors are often assumed to be endogenous, it was not possible to reject the null hypothesis that the explanatory variables are weakly exogenous using a Hausman test. Furthermore, estimation of the production function using instrumental variables in place of the potentially endogenous regressors yielded insignificant coefficients on the IV parameters. Therefore, weak exogeneity of the parameters was assumed and no corrections for endogeneity were made. However, in a separate specification (not shown), it was possible to reject the weak exogeneity hypothesis for the number of adults aged 16-60 in the household (an alternative proxy variable for labour input). Replacing this endogenous variable with predicted values of the regressor caused the coefficient to rise, suggesting that, if endogenous, estimates of the effect of labour upon production may be understated.

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[6] 'Other inputs' is an aggregated variable including expenditure on improved seeds and transportation as well as other miscellaneous farming expenditures.

5.1.b. Internal Effect of Education upon Cereal Crop Production

Educational attainment variables may now be introduced to consider the effect of education upon productivity. Years of schooling of the household head, other adults in the household, and all adults (aged 15 and over) are included in Tables 3a and 3b.[7] In each case, years of schooling of farmers is considered separately from years of schooling of non-farmers, since it is primarily farmers' education which is expected to influence agricultural productivity directly.[8] Household members who earn off-farm income may contribute to farm production indirectly by providing capital in a credit-constrained environment or by reducing risk aversion toward the adoption of innovations. As well as providing additional farm labour during busy periods, other household members may also contribute information and advice when allocative farm decisions are taken. To the extent that schooling of non-farmers increases the likelihood of such indirect effects or reduces wastage when direct farming assistance is provided by non-farmers, it may be important to productivity. Students are excluded from the category of non-farm household members, since the effect of their schooling is expected to be endogenous in a farm production function.

The 'worker effect' of schooling is measured by the coefficient on schooling in the first equation of each table, where all other inputs are included. The worker effect of an additional year of schooling for household heads who are farmers is unexpectedly negative, but insignificant. However, raising school attainment by one year on average for all non-head farmers significantly increases production of cereals by five percent. Not surprisingly, there is no significant worker effect for non-farmers in the household. When years of schooling of the head and other adults are aggregated, education of neither farmers nor non-farmers has a significant effect at the ten percent level on a two-tailed test. The worker effect of schooling may be considered the lower bound for the full effect of schooling on farm productivity, since part of the effect of education is its role in the allocation of other inputs into production and these inputs have been controlled for *a priori* in Equations 5a and 5b.

Equations 7a and 7b each examine the effect of schooling when short-run variable inputs (fertiliser, manure and other inputs) are omitted from the specification. Here the coefficient on years of schooling may pick up the effects of using more fertiliser or other inputs upon productivity, to the extent that these decisions are affected by skills acquired in school. That is, part of the allocative effect of schooling may be captured by omitting variable inputs. The allocative effect is calculated by subtracting the 'worker effect' coefficient on schooling from the coefficient on schooling in the 'allocative plus worker effect' equation. Since the coefficients on years of schooling of both categories of farmers are identical when fertiliser and other short-run variable inputs are omitted, there is no allocative effect of schooling for farmers evident in this specification. However, there is a small (one percent) difference for other adults who are not farmers. This suggests that the off-farm activities of these household members may contribute to use of fertiliser and other inputs on the farm.

[7] Every household has a head. Households with no other adults are assigned a value of zero for average years of schooling of other adults, while mean years of schooling of all adults is set equal to years of schooling of the household head in these households.

[8] The dummy signifying that the household head is not a farmer consequently is omitted.

Table 3a: OLS PF - Schooling, Head vs. Other Adults & Farmers vs. Others
Dependent Variable: Natural Log of Cereal Crops Produced (LN_CEREAL)

	Eqn. 5a	Eqn. 6a	Eqn. 7a	Eqn. 8a	Eqn.9a	Eqn. 10a
ED_HHH_F	-0.01	0.03	-0.01	0.04	-0.01	0.01
ED_HHH_NF	0.06	0.03	0.04	-0.02	0.07	0.06
ED_ADO_F	0.05 ***	0.03 **	0.05 ***	0.03 ✔	0.07 ***	0.03
ED_ADO_NF	0.02	0.07 **	0.03 ✔	0.07 ***	0.03	0.11 ***
FIXED LR	YES	YES	YES	YES	YES	YES
FIXED SR	YES	YES	YES	YES	NO	NO
VARIABLE	YES	YES	NO	NO	NO	NO
ENVIRON	YES	YES	YES	YES	YES	YES
HH-VARS	YES	YES	YES	YES	YES	YES
SITES	YES	NO	YES	NO	YES	NO
R^2	0.55	0.45	0.55	0.44	0.51	0.21
NUM. OBS.	616	616	616	616	616	616

Note: Standard errors have been adjusted to account for the clustered nature of the data. Stars indicate significance using a two tailed t-test as follows: *** = 0.01; ** = 0.05; * = 0.10; ✔ = 0.20.

Table 3b: OLS PF - Schooling, All Adults, Farmers vs. Others
Dependent Variable: Natural Log of Cereal Crops Produced (LN_CEREAL)

	Eqn. 5b	Eqn. 6b	Eqn. 7b	Eqn. 8b	Eqn.9b	Eqn. 10b
ED_AD_F	0.01	0.05 **	0.02	0.06 *	0.02	0.03
ED_AD_NF	0.03 ✔	0.05 **	0.04 ✔	0.07 ***	0.03 ✔	0.11 ***
FIXED LR	YES	YES	YES	YES	YES	YES
FIXED SR	YES	YES	YES	YES	NO	NO
VARIABLE	YES	YES	NO	NO	NO	NO
ENVIRON	YES	YES	YES	YES	YES	YES
HH-VARS	YES	YES	YES	YES	YES	YES
SITES	YES	NO	YES	NO	YES	NO
R^2	0.55	0.46	0.54	0.44	0.51	0.21
NUM. OBS.	616	616	616	616	616	616

Note: Standard errors have been adjusted to account for the clustered nature of the data. Stars indicate significance using a two tailed t-test as follows: *** = 0.01; ** = 0.05; * = 0.10; ✔ = 0.20.

When inputs which are fixed in the short run but variable in the long run (such as labour inputs, capital, oxen and trees) are also excluded, the coefficients on years of schooling of non-farming household heads and other adult farmers both increase slightly, though the former is still not significant (see Equations 9a and 9b). These findings suggest that households which have invested in human capital may be allocatively more efficient in production even if the educated person is not the primary farm decision-maker nor even primarily a farmer. These estimates provide an outer bound on the effects of schooling which may be observed, as both the worker and allocative effects are captured.

For each specification, omitting site variables causes more noticeable changes the coefficients on years of schooling (see Equations 6a and 6b, 8a and 8b, 10a and 10b). For household heads who are farmers, omission of site dummies tend to increase the effect of schooling upon productivity. However, for heads who do not farm the coefficient on years of schooling tends to fall when sites are omitted. The opposite pattern is observed for other adults in the household. This indicates that the effects of schooling are correlated with unobserved site attributes and that the role of sites differs for different types of household member. If the benefits of schooling are greater in some sites than in others, it may be appropriate to omit site dummy variables when considering the full effects of education upon farm output. This will be considered at the end of this section.

The allocative effects of schooling were found to be fairly low in Tables 3a and 3b. Since allocative decisions are made by the primary farm decision maker, perhaps in consultation with other members of the household, allocative effects may be sensitive more to the highest level of education attained by a member of the household than to the average education of all farmers in the household. This was investigated by including in the farm production function maximum years of schooling attained in the household along with mean years of schooling of all adults (results not shown).[9] As expected, the dispersion of years of schooling in the household was found to be important when all variable inputs were omitted (so that the maximum allocative effect was visible). The allocative effect attributable to the dispersion of schooling in the household is to increase production of cereals by two percent per additional year of schooling of the most educated household member. This effect is significant at the ten percent level on a two-tailed t-test.

An implicit assumption in Tables 3a and 3b was that each year of schooling attained has an equal effect upon agricultural productivity. This is unlikely to be the case. Given that most farmers use fairly traditional technology in a relatively static environment, primary schooling is expected to be more productive than secondary schooling. Furthermore, Phillips and Marble (1986) suggest that the coefficient on years of schooling may be smaller and less significant than is expected because having less than four years of schooling is unlikely to affect farm productivity. Since most farmers who have been to school have fewer than four years of schooling, the insignificant effect of low levels of schooling may obscure any benefits to be obtained from more years of education in the equations reported above.

There are several possible ways to investigate whether the effects of education upon the value of farm output are non-linear and vary by level of schooling. First, mean years of primary schooling and mean years of secondary schooling of adults may be included as separate variables. However, preliminary regressions which specified years of primary versus years of secondary schooling separately for the household head versus other adults showed no significant effects, perhaps owing to collinearity of the variables (results not shown).

Alternatively, non-linearity in the effects of education upon farm production may also be captured using a quadratic specification of years of education in the production function. However, when the square of years of schooling was included in the production function, the coefficient on years of education fell, and neither the linear nor the quadratic term was significant (results not shown). This indicates that it is not appropriate to represent the

[9] In this case, years of schooling of all adults in the household was considered, since non-farmers (and even students) may be consulted when allocative decisions are made.

relationship between education and farm output as being a smooth inverted U-shaped curve. Given the low average educational attainment in rural Ethiopia, this is unsurprising.

Table 4a: OLS PF - Highest Schooling Indicators, Head vs. Other Adults
Dependent Variable: Natural Log of Cereal Crops Produced (LN_CEREAL)

	Eqn. 11a	Eqn. 12a	Eqn. 13a	Eqn. 14a	Eqn. 15a	Eqn. 16a
1T3_HHH_F	-0.06	-0.07	-0.06	-0.08	-0.05	0.05
4T6_HHH_F	0.12 *	0.22 **	0.13 *	0.23 **	0.11 ✓	0.06
7UP_HHH_F	-0.33	0.04	-0.32	0.08	-0.26	0.02
1T3_HHH_NF	0.21	0.02	0.20	-0.05	0.27 ✓	0.09
4T6_HHH_NF ‡						
7UP_HHH_NF	0.05	0.15	-0.16	-0.21	-0.08	0.29
1T3_ADO_F	0.11	-0.01	0.12	0.03	0.20 **	0.09
4T6_ADO_F	0.29 ***	0.25 **	0.28 **	0.27 **	0.39 ***	0.14
7UP_ADO_F	0.47 ***	0.16	0.46 ***	0.12	0.64 ***	0.14
1T3_ADO_NF	0.09	0.17 ✓	0.11	0.18 ✓	0.15 ✓	0.30 *
4T6_ADO_NF	0.12	0.46 ***	0.11	0.59 ***	0.12	0.73 ***
7UP_ADO_NF	0.14	0.16	0.25	0.36	0.14	0.64 *
FIXED LR	YES	YES	YES	YES	YES	YES
FIXED SR	YES	YES	YES	YES	NO	NO
VARIABLE	YES	YES	NO	NO	NO	NO
ENVIRON	YES	YES	YES	YES	YES	YES
HH-VARS	YES	YES	YES	YES	YES	YES
SITES	YES	NO	YES	NO	YES	NO
R^2	0.56	0.46	0.55	0.44	0.52	0.21
NUM. OBS.	616	616	616	616	616	616

Note: Standard errors have been adjusted to account for the clustered nature of the data. Stars indicate significance using a two tailed t-test as follows: *** = 0.01; ** = 0.05; * = 0.10; ✓ = 0.20.
‡ There were no non-farmer/non-student household heads with between grades 4 to 6 complete.

Finally, a set of threshold dummy variables were created to better understand the relative importance of different levels of schooling. Each indicates that the household head (or other non-head adult household members or all adults, on average, as the case may be) has attained the specified category of schooling. The results are revealing. See Tables 4a and 4b.

Table 4a provides strong evidence of a threshold effect for schooling. The effect of education for household heads who are farmers is only positive and significant for those with between four and six years of schooling complete. Thus, it is not surprising that years of schooling of farming heads appears to be insignificant in Table 3a. For adult farmers other than the head, at least four years of schooling again are needed to affect production. However, in contrast to the findings for the household head, secondary schooling of other adults is associated with greater cereal output. When site fixed effects are taken into consideration, there are no significant effects of schooling upon production for any category of educated non-farmer.

Table 4b: OLS PF - Highest Schooling Indicators, All Adults
Dependent Variable: Natural Log of Cereal Crops Produced (LN_CEREAL)

	Eqn. 11b	Eqn. 12b	Eqn. 13b	Eqn. 14b	Eqn. 15b	Eqn. 16b
1T3_AD_F	0.05	0.08	0.05	0.10	0.05	0.08
4T6_AD_F	0.18 *	0.25 ***	0.21 **	0.29 ***	0.25 **	0.13
7UP_AD_F	-0.14	0.31	-0.12	0.36	-0.12	0.20
1T3_AD_NF	0.14 ✔	0.15 ✔	0.15 ✔	0.14	0.20 ✔	0.31 *
4T6_AD_NF	0.14	0.42 ***	0.12	0.52 ***	0.14	0.72 ***
7UP_AD_NF	0.20	0.15	0.31	0.36	0.22	0.57 ✔
FIXED LR	YES	YES	YES	YES	YES	YES
FIXED SR	YES	YES	YES	YES	NO	NO
VARIABLE	YES	YES	NO	NO	NO	NO
ENVIRON	YES	YES	YES	YES	YES	YES
HH-VARS	YES	YES	YES	YES	YES	YES
SITES	YES	NO	YES	NO	YES	NO
R^2	0.55	0.45	0.55	0.44	0.51	0.21
NUM. OBS.	616	616	616	616	616	616

Note: Standard errors have been adjusted to account for the clustered nature of the data. Stars indicate significance using a two tailed t-test as follows: *** = 0.01; ** = 0.05; * = 0.10; ✔ = 0.20.

Given the traditional nature of farm technology in rural Ethiopia, it is not surprising that secondary schooling adds nothing to the productivity of household heads who are farmers, as noted above. Indeed, the negative (though insignificant) coefficients on the dummy for having grade seven or above complete are not unexpected, since those who spend more years in school will have spent less time in the fields learning traditional farm methods from their fathers and may have developed negative attitudes toward farm labour. However, the strong positive effect of secondary schooling for other adult farmers is difficult to explain.

One possibility is that other adults who farm tend to be younger than the group of household heads and that the quality of schooling has deteriorated as access to schooling spread during the past 30 years. This is a testable hypothesis. Interacting years of schooling with age of the farm manager may reveal a cohort effect. If the coefficient on the interaction term is positive, it suggests that school quality was sacrificed as education expanded (Appleton and Balihuta 1996). Hence, more schooling is needed to impart the same basic literacy and numeracy skills to younger farmers than was required for functional literacy and numeracy for the older group of household heads. The coefficient on the interaction between age and years of schooling in the production function was found to be positive and significant, supporting the hypothesis that the quality of education in rural Ethiopia has fallen in recent years as access to schooling has expanded (results not shown).

Table 4b shows that for all adult farmers taken together, having an average of between four to six years of schooling attained is the only significant category. Non-farmers with pre-school up to grade three may contribute more to farm production than those with no education, but the effect is not quite significant.

These findings illustrate the non-linear relationship between level of education and farm output. Although on average, an additional year of schooling for farmers raises output by only one percent, the actual effect on productivity depends on the level of schooling which has been augmented. Providing farmers with between grades four and six (basic education) will add 18 percent to farm production in terms of the worker effect of schooling alone.

Table 5a: OLS PF - Number of Adults by Category of Education
Dependent Variable: Natural Log of Cereal Crops Produced (LN_CEREAL)

	Eqn. 17	Eqn. 18	Eqn. 19	Eqn. 20	Eqn. 21	Eqn. 22
NOEDUC_F	-0.00	-0.04	0.01	0.02	0.02	0.07
UPTOGR3_F	0.06	-0.01	0.08	0.05	0.11 ✔	0.18 **
GR4TO6_F	0.21 ***	0.20 ***	0.23 ***	0.27 ***	0.23 ***	0.10
GR7UP_F	-0.08	0.07	-0.07	0.16	-0.02	0.06
NOEDUC_NF	0.05	-0.02	0.04	-0.04	0.09 ✔	-0.10 ✔
UPTOGR3_NF	0.05	0.02	0.03	-0.03	0.12 **	-0.00
GR4TO6_NF	0.19	0.27 **	0.17	0.29 *	0.18	0.30 ✔
GR7UP_NF	0.27 **	0.38 ***	0.29 **	0.49 ***	0.29 **	0.47 ***
FIXED LR	YES	YES	YES	YES	YES	YES
FIXED SR	YES	YES	YES	YES	NO	NO
VARIABLE	YES	YES	NO	NO	NO	NO
ENVIRON	YES	YES	YES	YES	YES	YES
HH-VARS	YES	YES	YES	YES	YES	YES
SITES	YES	NO	YES	NO	YES	NO
R^2	0.55	0.44	0.55	0.41	0.52	0.21
NUM_OBS	616	616	616	616	616	616

Note: Standard errors have been adjusted to account for the clustered nature of the data. Stars indicate significance using a two tailed t-test as follows: *** = 0.01; ** = 0.05; * = 0.10; ✔ = 0.20.

To measure the importance of the quality of farm labour to production, the number of household members with each level of schooling have been included as a series of variables in Table 5a to facilitate calculation of the marginal products of each type of farm worker. In most specifications of the production function, a farmer with less than four years or more than six years of schooling complete has no greater effect upon farm output than one who has never been to school. This reinforces the threshold findings noted above. For non-farmers, secondary schooling or above is the most important category. This confirms the hypothesis that the effect of non-farmers' schooling upon farm output operates through access to off-farm sources of income, which generally requires at least some secondary schooling.

The marginal product of each type of education may be calculated by subtracting the coefficient on a particular level of education from the coefficient on the level of education which precedes it. The marginal products of each type of farm labour are reported in Table 5b. When all variables are included in the specification, so that the education variables capture only the worker effect of schooling, having one more farmer with pre-school up to third grade completed increases output by six percent as compared with having an additional farmer with no education. Non-farmers enjoy no increase in marginal product associated with pre-school to grade three (see MP_{ED}[17]).

Table 5b: Marginal Product of Education by Category

	MP_{ED}[17]	MP_{ED}[18]	MP_{ED}[19]	MP_{ED}[20]	MP_{ED}[21]	MP_{ED}[22]
NOEDUC_F						
UPTOGR3_F	0.06	0.03	0.07	0.03	0.09	0.11
GR4TO6_F	0.15	0.21	0.15	0.22	0.12	-0.08
GR7UP_F	-0.29	-0.13	-0.30	0.11	-0.25	-0.04
NOEDUC_NF						
UPTOGR3_NF	0.00	0.04	-0.01	0.01	0.03	0.10
GR4TO6_NF	0.14	0.25	0.14	0.32	0.06	0.30
GR7UP_NF	0.08	0.11	0.12	0.20	0.11	0.17

An additional farmer with between grades four to six increases farm product by 15 percent, as compared to one with pre-school to third grade. This is slightly greater than the increase in marginal product for a non-farmer with upper primary school. However, having an additional farmer with some secondary schooling decreases output by 29 percent in relation to a person having completed between fourth and sixth grades. By contrast, marginal product for a non-farmer with secondary or above is positive, adding an additional eight percent to output as compared with one who has attained only some upper primary schooling. The marginal product of secondary education exceeds that of upper primary for non-farmers in Equation 21, when the full allocative effect of schooling is apparent.

To determine whether the effects of schooling differ by site, interaction terms (site*average years of schooling) are included in the first column of Table 6. The effect of education in each site is calculated by adding the coefficient on the interaction variable to the coefficient on years of education in the omitted site. These range from a six percent fall in farm production in Site 6 to a rise in the value of output of ten percent in Site 7.

The effects of education by site with variable short-run fixed inputs omitted are presented in Equation 24. The effect of education is subsequently higher in Sites 3, 4, 6, 7, 8 and 9, suggesting that education is positively correlated with variable and short-run fixed inputs in these sites, and lower in Sites 5, 10, 15 and 16, suggesting that they are negatively correlated in these sites, and unchanged in Site 2, suggesting there is no relationship between them there. These results provide further evidence that the effect of education does vary by site, justifying analysis of the effects of education with sites omitted.

Beyond its role in determining the type and quantities of inputs used, education may also interact with other variables to influence cereal productivity. To test this, interaction terms between years of schooling of farmers and other inputs and years of schooling of non-farmers (excluding students) and other inputs were included in the production function. For both farmers and other adults, education was found to be substitute for labour in production. While for farmers, schooling was also a substitute for capital inputs, for non-farmers it was complementary. The education of non-farmers was also found to complement use of other inputs in production, such as improved seeds, as well as to the use of fertiliser. This indicates that the schooling of non-farmers may provide a buffer against risk, either by increasing information needed to use fertiliser and other inputs effectively or by increasing the diversity of income sources available to the household. Education of farmers was found to aid production in households with a female head or where there are no other adults apart from the head. There were also some significant interactions between schooling and the tree dummy variables for both farmers and other adults (results not shown).

Table 6: OLS PF - Years of Education * Site Interaction
Dependent Variable: Natural Log of Cereal Crops Produced (LN_CEREAL)

	Eqn. 23	Effect of Education	Eqn. 24	Effect of Education
ED_AD_F (Site 6)	-0.06 **	-0.06	-0.04*	-0.04
ED_AD_F*SITE 2	0.12 *	0.06	0.10 ***	0.06
ED_AD_F*SITE 3	0.12 ***	0.06	0.12 ***	0.08
ED_AD_F*SITE 4	0.06 *	0.00	0.07 **	0.03
ED_AD_F*SITE 5	0.05 **	-0.01	0.01	-0.03
ED_AD_F*SITE 7	0.16 ***	0.10	0.18 ***	0.14
ED_AD_F*SITE 8	0.13 ***	0.07	0.12 ***	0.08
ED_AD_F*SITE 9	0.11 ***	0.05	0.11 ***	0.07
ED_AD_F*SITE 10	0.08 ***	0.02	0.05 *	0.01
ED_AD_F*SITE 15	0.03	0.03	0.03	-0.01
ED_AD_F*SITE 16	-0.00	-0.06	-0.06 ✔	-0.10
FIXED LR	YES		YES	
FIXED SR	YES		NO	
VARIABLE	YES		NO	
ENVIRON	YES		YES	
HH-VARS	YES		YES	
SITES	YES		YES	
R^2	0.55		0.51	
NUM_OBS	616		616	

Note: Standard errors have been adjusted to account for the clustered nature of the data. Stars indicate significance using a two tailed t-test as follows: *** = 0.01; ** = 0.05; * = 0.10; ✔ = 0.20.

Strangely, education appears to play a non-complementary role in the use of innovative farm inputs, such as fertiliser. The usual production function (without the fertiliser use variable or the tree dummy variables) was estimated with average years of schooling of farmers, one or more dummy variables indicating that the farmer has innovated, and cross product terms between years of schooling and the input innovation dummy variable(s). The results (not shown) indicate that the innovation dummy variables have positive, though sometimes insignificant, effects upon cereal production. However, the interaction between years of schooling and innovation behaviour tends to be significantly negative.

It is implausible to suggest that education has a negative effect on the productivity of innovative inputs, since we expect farmers with schooling to be better able to make use of new inputs. A more reasonable explanation is that it is the most able and highly motivated farmers who innovate, irrespective of education. Since even able and motivated individuals are unlikely to have obtained much, if any, schooling in rural Ethiopia, years of education may not be a good proxy for ability and motivation of farmers. Indeed, having been to school for a number of years may reduce ability and motivation in traditional agriculture. Hence, self-selection of able and motivated farmers into the group of those who have innovated is probably responsible for the negative coefficient on the interaction between schooling and innovative behaviour.

A caveat to the discussion of private benefits of schooling is that the education years variable may be merely a proxy for the status of the household in the village, and that farmers with higher status were able to keep control of their good quality land during the land reform and redistribution that occurred repeatedly during the Derg regime. There is a slight negative correlation between years of schooling of farmers and a dummy variable indicating that the household lost land during the land reform/redistribution process. However, including this dummy variable in the production function does not affect the coefficient on years of schooling of either farmers or other adults, and it is not itself significant.

5.1.c. External Effect of Education upon Cereal Crop Production

Table 7 illustrates the external effects of schooling. Estimation of an aggregate production function shows that an extra year of education on average of all adult village members (excluding students) is found to increase aggregate household farm production by 50 percent (see Equation 26). By comparison, an additional year of schooling on average at the household level increases farm output by five percent for farmers and 12 percent for non-farmers in a comparable specification (see Equation 25). Note that the aggregate production function did not perform well when many variables were included, and only land was included with education in the final specification.

Including average education in the village in a household production function with average years of schooling within the household shows that the effect of education at the village level (the external effect) is considerably greater than the internal effects of education acquired by household members (see Equation 27).

To control for some additional site-specific effects, a set of village-level variables, including average rainfall, distance to an all-weather road, the proportion of female headed households, the percentage of households who use manure to increase land quality and average use of commercial fertiliser in the village (which may proxy extension service activities), are incorporated in Equation 28. The decrease in the coefficient on average education between Equations 27 and 28 indicates that the coefficient on average education may pick up the effects of other site level variables, such as distance to markets or average soil fertility.

To a certain extent, these variables may even explain average school attainment in the village (if present farm output is correlated with past farm output and levels of farm output in the past help to explain investments in human capital evident today). However, if villages with more education are more likely to take initiative in building better roads to transport goods to and from markets and if they are more likely to invest in land quality improvements, then it is reasonable to omit these variables and estimate the effect of average schooling without their inclusion in the equation. Note that, in any event, it is difficult to control for all important site-level characteristics owing to the small number of villages surveyed and consequent lack of degrees of freedom.

Table 7: OLS PF - External versus Internal Effect of Schooling, All Adults
Dependent Variable: Natural Log of Cereal Crops Produced (LN_CEREAL)

	Eqn. 25	Eqn. 26	Eqn. 27	Eqn. 28
ED_AD_F	0.05		0.02 *	0.02
ED_AD_NF	0.12 ***		0.02	0.03
AVED_VILLAGE		0.50 **	0.56 ***	0.17 *
FIXED_LR	YES	YES	YES	YES
FIXED_SR	NO	NO	YES	YES
VARIABLE	NO	NO	YES	YES
ENVIRONMENT	NO	NO	YES	YES
HH_VARS	NO	NO	YES	YES
SITES	NO	NO	NO	NO
VILLAGE VARS	NO	NO	NO	YES
R^2	0.18	0.44	0.48	0.54
NUMBER OBSERVATIONS	616	14	616	616

Note: Standard errors have been adjusted to account for the clustered nature of the data. Stars indicate significance using a two tailed t-test as follows: *** = 0.01; ** = 0.05; * = 0.10; ✔ = 0.20.

Including average rainfall in the village and the interaction between average education of farmers and average rainfall (not shown) results in a negative coefficient on the interaction term, indicating that education at the site level is a substitute for rainfall. The implication for sites where rainfall is low is that increasing average levels of education may enable farmers to cope better in a challenging environment.

External returns to schooling may vary by site. Controlling for site-level variations in internal returns to schooling and other farm and household variables, the effect of average education in the village upon production by site may be simulated. Taking the percentage change in output in a given site compared to the mean for all sites provides information on external returns to schooling by site (see Table 8). External benefits of schooling may vary by site because of differences in the state of technology used in each site.

External benefits of schooling are found to be positively correlated with average production per hectare cultivated and per person day worked. Sites with higher external returns to schooling are those where households are more productive, on average. External benefits are also correlated positively with the presence of an all-weather road in the area and negatively correlated with the distance to travel to reach an all-weather road and to reach the nearest town. This indicates that sites which have better access to markets enjoy greater external benefits of schooling. Higher externalities are found in sites where a greater proportion of households have adopted the use of modern inputs. In particular, usage of fertiliser is positively correlated with external benefits of schooling. This is to be expected, since villages where farmers have moved into more modern farming practices will be those where the skills taught in school are most needed for agriculture. However, every farmer who wishes to adopt a new input need not have completed several years of schooling to benefit from the innovation. Successful early adopters are expected to be those who have acquired some schooling. Farmers with little or no education may copy the productive practices of more highly skilled farmers.

Table 8: OLS PF Simulation - Effect of Education in the Village, by Site
Dependent Variable: Natural Log of Cereal Crops Produced (LN_CEREAL)

	Average Education in the Village (Years per Adult)	Effect of Education in Village (Predicted Log of Farm Output)	Percentage Change: Predicted Farm Output vs. Mean LN_CEREAL
SITE 2	0.17	5.35	-6.98
SITE 3	0.32	5.42	-5.84
SITE 4 - VILLAGE 1	1.23	5.80	+0.79
SITE 4 - VILLAGE 2	1.31	5.84	+1.39
SITE 4 - VILLAGE 3	1.97	6.11	+6.24
SITE 4 - VILLAGE 4	1.61	5.96	+3.61
SITE 5	1.13	5.76	+0.08
SITE 6	0.72	5.59	-2.90
SITE 7	1.94	6.10	+6.01
SITE 8	0.37	5.44	-5.50
SITE 9	1.11	5.75	-0.04
SITE 10	3.16	6.61	+14.93
SITE 15	1.30	5.83	+1.34
SITE 16	1.23	5.80	+0.84
SIM: AVED_VILLAGE = 0	0	5.28	-8.20
SIM: AVED_VILLAGE = 6	6	7.81	+35.72
Coeff. on AVED_VILLAGE	0.42 *		
Mean AVED_VILLAGE	1.12		
Mean LN_CEREAL	5.76		
FIXED LR	YES		
FIXED SR	YES		
VARIABLE	YES		
ENVIRON	YES		
HH-VARS	YES		
SITES	NO		
SITE*EDYRS_AD	YES		
ED_AD (F and NF)	YES		

Note: Standard errors have been adjusted to account for the clustered nature of the data. Stars indicate significance using a two tailed t-test as follows: *** = 0.01; ** = 0.05; * = 0.10; ✓ = 0.20.

Simulated external returns by site are significantly correlated with gross enrolment ratios by site for boys at the primary and secondary levels. This indicates that where external benefits of schooling in terms of agricultural production are high, parents are sending more of their male children to school. This is a remarkable and encouraging finding from a policy point of view. However, proving simple bivariate correlation says nothing about the direction of causation. It may be that in sites where external returns are high, constraints on enrolment are (coincidentally or causally) also lower, so that a greater percentage of children participate in schooling. For instance, external returns may be higher because of the availability of innovative inputs to production, and sites with access to new inputs may also have better access to schooling than sites which have less access to modern farm inputs.

5.1.d. Summary of Non-Frontier Results

To summarise, there are positive and significant returns to formal schooling in agriculture in rural Ethiopia. However, in the case of the household heads who farm, these returns are greatest for those who have attained some upper primary schooling (grades four to six) and no more. While secondary schooling may provide skills which are useful in terms of the allocation of inputs, it tends to have an inhibiting effect upon output overall. For other adult farmers, again at least four years of schooling is needed to affect farm production, but farm productivity increases further if some secondary schooling has been acquired. This difference in the effect of secondary schooling for the household head compared with other adults appears to be owing to a cohort effect whereby the quality of schooling has fallen as access to school places expanded over the past 20-30 years. Given the traditional nature of farming in Ethiopia, it is not necessary for the primary farm decision maker to have acquired more than basic literacy and numeracy. Non-farmers may contribute to agricultural productivity indirectly by providing external sources of income to overcome credit constraints and reduce risk aversion. Secondary schooling is particularly useful in this regard.

Private benefits of schooling pale in comparison to social benefits. An additional year of formal schooling on average in the village has a much larger impact upon farm productivity than an additional year of schooling on average within the household. Findings on both internal and external benefits of schooling may be location-sensitive. There appear to be very different returns to education in different sites. It has been possible to correlate external benefits of schooling by site with various site-specific characteristics, such as distance to an all-weather road, productivity of farmers in the village and the percentage of farmers who have adopted innovations.

Findings on internal returns to schooling in Ethiopia may be compared with similar research in other areas. Lockheed, Jamison and Lau (1980) surveyed findings on the effects of education from 37 data sets world-wide and compared their results by computing the percentage increase in output for a one year increase in education above the mean reported for each study. The results presented here may be compared with those reviewed by Lockheed, Jamison and Lau (1980) using their method of computing the percentage increase in output due to adding one extra year of schooling by calculating the ratio of cereal crop production when education is 0.5 years higher than average to cereal crop production when education is 0.5 years below average:

% increase in output for one year increase in schooling above mean

$$= [e^{\beta (\bar{E}+0.5)} / e^{\beta (\bar{E}-0.5)} - 1]*100$$
$$= [e^{\beta} - 1]*100 ,$$

where β is the coefficient on education from the production function, and $\bar{E}$ is mean education in the sample (Lockheed, Jamison and Lau 1980). This transformation results in slight changes to the approximated effects of schooling described earlier.

The effect of an additional year of schooling for the household head is to decrease output by one percent (insignificantly), when sites fixed effects are included. For other adult farmers, the effect ranges from 5.1 to 7.3 percent (significant), depending on which effects of schooling are considered (worker alone versus full worker plus allocative effects). For non-farmers, an additional year of schooling increases farm output by between 6.2 and 7.3 percent for the household head and between 2.0 and 3.0 percent for other adults (though neither is significant). Overall, the effect of one extra year of schooling for a farmer is to increase output by between 1.0 and 2.0 percent, while for non-farmers an additional year in school raises farm production by between 3.0 and 4.1 percent.

In general, Lockheed, Jamison and Lau (1980) found that the effects of schooling were strongest in the most modern regions and were often negative in traditional areas. The results reported here compare quite favourably with those of Lockheed, Jamison and Lau (1980), which range from -3.3 percent to 6.5 percent, and those discussed in an updated survey of the literature by Phillips (1994), which ranged from -3.1 percent to 8.4 percent. The present findings compare particularly well with the two African studies (both on Kenya) considered by Lockheed, Jamison and Lau (1980) and Phillips (1994), which found small or negative effects of an additional year of schooling.

5.2. Frontier Production Functions: Effects on Efficiency

Stochastic production frontiers were estimated to illuminate more clearly the effects of schooling upon cereal production for the most efficient farmers as compared with typical farmers in the sample (Phillips and Marble 1986). The FRONTIER estimation package was chosen for this task because it is programmed to compute firm-specific inefficiency using the Battese and Coelli (1988) method, which accounts for the logged specification of the dependent variable, rather than the method originally suggested by Jondrow, et al. (1982), which is better suited to the case of a non-logged dependent variable.

5.2.a. Basic Frontier Production Function Results

Table 9 presents the results of estimating the stochastic production frontier. Equations 30 and 31 are one-stage production frontiers without education included. They are identical, except that in the first equation the distribution of the one-sided error term is assumed to be normal-half-normal, while the second was estimated assuming a truncated normal distribution of the one-sided component of the error term. Greene (1993) notes that the latter assumption is less restrictive than the former. However, it is not commonly employed in the applied literature. A likelihood ratio test of the restrictive normal-half-normal distribution versus the truncated normal distribution leads to rejection of the null-hypothesis that the normal-half-normal distributional form assumed in Equation 30 is appropriate.

The coefficients on land, labour and capital in Equation 31 sum to 0.58, indicating decreasing returns to scale in production. This is consistent with expectations, since minimum efficient scale in rural agriculture in developing countries is usually found to be rather low. This may be partly explained in terms of increased direct and opportunity costs of transportation faced by larger scale farmers (Croppenstedt and Muller 1998, using the same data set as this thesis). It may also reflect increased costs of monitoring labour when farms become large enough to need to hire in labour.

Although few apart from the basic inputs are significant in the production frontier, likelihood ratio tests of the contribution of each set of regressors argue against omitting any one group of variables (e.g., variable farm inputs, trees, environmental proxies, household characteristics, and sites) from the frontier specification. Furthermore, likelihood ratio tests of the one-sided error term suggest that the stochastic production frontier is a valid functional form to estimate using this sub-sample of rural Ethiopian villages.

Average farm-specific efficiency is estimated to be 54 percent. This is in line with estimates by Croppenstedt and Muller (1998), which range from 51 to 76 percent depending on the assumed distributional form of the one-sided error, and Admassie and Asfaw (1997), who estimate mean profit efficiency of 54 percent for a sub-sample of farms in the ERHS. Clearly, the assumed distribution of the one-sided error term is important, since estimated average efficiency falls to 44 percent when the normal-half-normal model is chosen.

The third equation in Table 9 is a one-stage frontier with controls for education of all non-student adults in the household, while the final equation is a two-stage frontier, with education included in the second stage. As Equation 32 shows, education is not significant in the first stage. This indicates that for the most efficient farm households, extra schooling will not increase output. It may be that the most efficient farmers have already invested in education and have exploited all possible returns from schooling, given the present technological environment.

In the two-stage equation estimated in Equation 33, the form of the first stage is the same as that of the one-stage models estimated earlier. However, farm-specific measures of efficiency calculated based on the first stage are converted into inefficiency scores to be explained using average years of schooling of all farming and non-farming adults in the household in the second stage. The FRONTIER programme is designed to incorporate assumptions about the independence of the inefficiency effects in the two stages which are more consistent than if the two stages were estimated separately using different software. As a result, the coefficients on the first stage variables are slightly different in Equation 31 than in Equation 33. Note that it is not possible to test for a preferred specification (one-stage versus two-stage), since the models are non-nested (Coelli 1994).

The estimated coefficients on years of education of all non-student adults in the second stage is significantly negative, indicating that a one year increase in average schooling attained in the household will reduce measured farm inefficiency in the production of cereal crops by 2.1 percentage points. Thus, if educational attainment is raised from zero to four years of primary schooling on average in the household, mean efficiency is expected to rise from 54 to 62 percent overall. This represents an efficiency increase of 15 percent for the sample as a whole. The benefit of providing a basic primary education to all household members in terms of creating more efficient use of agricultural resources appears to be substantial.

Table 9: Maximum Likelihood Estimation of the Stochastic Frontier Function
Dependent Variable: Natural Log of Cereal Crops Produced (LN_CEREAL)

	Eqn. 30	Eqn. 31	Eqn. 32	Eqn. 33
CONSTANT (Stage 1)	5.89 ***	5.70 ***	5.71 ***	5.66 ***
LN_LAND	0.31 ***	0.33 ***	0.33 ***	0.34 ***
LN_LABOUR	0.18 ***	0.16 ***	0.16 ***	0.15 ***
LN_CAPITAL	0.09 ***	0.09 ***	0.09 ***	0.09 ***
LN_INPUTS	0.02	0.00	0.00	0.01
OXEN	0.16 *	0.14 *	0.14 *	0.13 *
BANANA	0.10	0.16	0.17 ✔	0.16
COFFEE	0.01	0.01	0.00	0.03
CHAT	0.20	0.07	0.07	0.08
EUCALPTUS	0.13 ✔	0.16 *	0.17 **	0.17 **
ENSET	-0.09	-0.15	-0.16	-0.05
GESHU	0.00	0.04	0.04	0.05
LN_FERT	0.03 ✔	0.02	0.02	0.02 ✔
MANURE	0.06	0.05	0.06	0.06
LN_QUALITY	-0.04	-0.09	-0.10	-0.11 ✔
LN_STEEPNESS	-0.14	-0.15	-0.13	-0.11
AGE_HHH	-0.01	-0.01	-0.01	-0.00
AGESQ_HHH	0.00	0.00	0.00	0.00
FEM_HEAD	-0.13 ✔	-0.13 ✔	-0.13 ✔	-0.15 *
NO_ADULTS	-0.07	-0.04	-0.03	-0.00
NONAGR_HHH	-0.16	-0.09	-0.10	-0.06
SITE_2	-1.14 ***	-1.03 ***	-1.02 ***	-1.03 ***
SITE_3	-0.30 *	-0.42 ***	-0.42 ***	-0.41 ***
SITE_4	0.07	0.15	0.12	0.13
SITE_5	0.30	0.32	0.29	0.32 ✔
SITE_7	0.91 ***	0.99 ***	0.97 ***	0.96 ***
SITE_8	0.32 ✔	0.50 **	0.50 **	0.51 **
SITE_9	-0.63 ***	-0.61 ***	-0.63 ***	-0.64 ***
SITE_10	0.98 ***	1.09 ***	1.04 ***	0.89 ***
SITE_15	-1.23 ***	-0.99 **	-1.02 ***	-1.16 ***
SITE_16	0.52 **	0.29 ✔	0.25	0.27 ✔
ED_AD_NONS			0.01	
$SIGMA^2$	2.49 ***	6.69 ***	6.71 ***	17.00 ***
GAMMA	0.97 ***	0.98 ***	0.98 ***	0.99 ***
MU		-5.13 ***	-5.14 ***	
CONSTANT (Stage 2)				-15.88***
ED_AD_NONS				-2.11 ***
MEAN EFF.	0.44	0.54	0.54	0.56
LOG-LIKELIHOOD	-803.6	-754.1	-753.8	-734.7
NUMBER OBS.	616	616	616	616

Note: Stars indicate significance using a two tailed t-test: *** = 0.01; ** = 0.05; * = 0.10; ✔ = 0.20.

5.2.b. Internal Effect of Schooling upon Efficiency and the Frontier

Table 10 provides a summary of the effects of schooling upon the production frontier and upon reducing farm-specific inefficiency for the household head versus other adults in the household and for farmers versus non-farmers.[10] Equations 34a and 34b show the coefficients on education in a one-stage production frontier. Equations 35a and 35b provide the coefficients on years of schooling in the second stage of a two-stage model.

Table 10: MLE Frontier PF - Years of Education, Head vs. Other Adults
Dependent Variable: Natural Log of Cereal Crops Produced (LN_CEREAL)

	Eqn. 34a	Eqn. 35a	Eqn. 34b	Eqn. 35b
ED_HHH_F	-0.01	-0.83 ***		
ED_HHH_NF	0.01	-1.62 *		
ED_ADO_F	0.00	-1.09 ***		
ED_ADO_NF	0.02	-0.58 ***		
ED_AD_F			-0.01	-0.39 ***
ED_AD_NF			0.03 ✔	-1.16 ***
ONE STAGE	YES	NO	YES	NO
TWO STAGE	NO	YES	NO	YES
TRUN-NORM DIST	YES	YES	YES	YES
MEAN EFF.	0.54	0.56	0.54	0.55
LOG-LIKELIHOOD	-753.1	-733.3	-753.4	-738.2
NUMBER OBS.	616	616	616	616

Note: Stars indicate significance using a two tailed t-test: *** = 0.01; ** = 0.05; * = 0.10; ✔ = 0.20.

Equation 34a indicates that the largest effect of education in the one-stage model is for other adults who are not farmers, but none of the education coefficients is significant. This is in contrast to the findings from the average production function, where years of schooling of other adult farmers was significant, which suggests that although education is important to productivity of the average farmer, ‘frontier’ farmers are not able to exploit more years of schooling to push them to higher production levels. Given the traditional nature of Ethiopian farming, increased years of schooling may not help the most efficient farmers to produce more in the absence of an exogenous infusion of technological innovation, which would cause the frontier to shift outwards. Taking average educational attainment of all farmers versus non-farmers shows that the effect on the production frontier of an additional year of schooling is slightly larger for non-farmers than for farmers, though again neither is significant on a two-tailed test (see Equation 34b).

On the other hand, years of schooling is found to be a significant factor explaining reduced inefficiency by typical farm households, many of whom operate well below the production frontier. The effect is largest for household heads who are not farmers and lowest for other adults whose main activity is not farming (see Equation 35a). Overall, an additional year of education reduces technical inefficiency by 0.4 percentage points for farmers and by 1.2 percentage points for non-farmers (see Equation 35b).

[10] The dummy signifying that the household head is not a farmer consequently is omitted.

Table 11: MLE FPF - Highest Schooling Category, by Type of Labour
Dependent Variable: Natural Log of Cereal Crops Produced (LN_CEREAL)

	Eqn. 36a	Eqn. 37a	Eqn. 36b	Eqn. 37b
1T3_HHH_F	-0.02	-4.17 ***		
4T6_HHH_F	-0.05	-7.73 ***		
7UP_HHH_F	-0.01	0.33		
1T3_HHH_NF	0.10	-0.73		
4T6_HHH_NF ǂ				
7UP_HHH_NF	-0.47	-1.75 ✔		
1T3_ADO_F	0.01	-2.98 ***		
4T6_ADO_F	0.13	-6.11 ***		
7UP_ADO_F	-0.08	-10.15 ***		
1T3_ADO_NF	0.03	-5.01 ***		
4T6_ADO_NF	0.21	-4.55 ***		
7UP_ADO_NF	0.00	-4.41 ***		
1T3_AD_F			-0.01	-5.47 ***
4T6_AD_F			-0.02	-8.71 ***
7UP_AD_F			-0.08	3.53 ***
1T3_AD_NF			0.02	-8.91 ***
4T6_AD_NF			0.19	-5.69 ***
7UP_AD_NF			0.08	-9.86 ***
ONE STAGE	YES	NO	YES	NO
TWO STAGE	NO	YES	NO	YES
TRUN-NORM DIST	YES	YES	YES	YES
MEAN EFF.	0.54	0.56	0.54	0.56
LOG-LIKELIHOOD	-752.0	-730.4	-753.2	-729.5
NUMBER OBS.	616	616	616	616

Note: Stars indicate significance using a two tailed t-test: *** = 0.01; ** = 0.05; * = 0.10; ✔ = 0.20.
ǂ There were no non-farmer/non-student household heads with between grades 4 to 6 complete.

It is also instructive to consider whether there are threshold effects in terms of placement of the frontier or reductions in inefficiency in relation to the frontier using a set of dummy variables representing educational categories of attainment (for heads versus other adults and farmers versus non-farmers). The results are presented in Table 11.

Equations 36a and 36b show that none of the educational category dummy variables is significant in the one-stage frontier model. This confirms the conclusions stated earlier regarding the lack of importance of schooling to the placement of the frontier, given the traditional nature of farming in rural Ethiopia.

The importance of each category of schooling (for household heads versus other adults and for farmers versus non-farmers) in terms of reducing technical inefficiency is considered in Equations 37a and 37b. For the household head, only the education of farmers has a significant impact upon inefficiency, and within the category of household heads who farm, it is only pre-school to third grade and grades four through six which have a significant negative impact. Although insignificant, the coefficient on the category of grades seven and up for heads who farm has a positive coefficient, indicating that farmers with secondary or higher schooling might actually be less efficient in production than those with no schooling at all. At any rate, these categories are not significantly different.

For other adults who farm, the effects of schooling increases monotonically from pre-school to third grade up to secondary schooling and above. Again, this may reflect a cohort effect, whereby higher levels of education are more important for other adults because the quality of education has fallen as schooling has spread more widely to rural areas.

For other non-farming adults, the effects of schooling are approximately equal for each category of education and not as large as for farmers with some upper primary schooling. Other adults whose main activity is not farming may contribute to farm efficiency either by providing extra labour during busy periods or by providing capital for more efficient farm tools, including innovative inputs. Thus, their contribution is either indirect or less substantial than for those whose main activity is farming.

5.2.c. External Effect of Schooling upon Efficiency and the Frontier

Finally, the external effect of schooling upon the production frontier and efficiency is investigated in Table 12. Equation 38 shows that average years of education in the village has a significant positive influence upon the placement of the production frontier. When other village-level variables are included in the equation, the size and significance of the coefficient on average education in the village diminishes somewhat, but is still large and significant (see Equation 39). These frontier results mirror the external effect of schooling documented previously for the average production function.

The coefficient on average education in the village is significant in Equation 40, suggesting that there may be external benefits of schooling in terms of reduced farm inefficiency. However, when village level variables are included in the first stage of Equation 41, this effect disappears. In this case, average education in the village acts entirely as a proxy for other village characteristics and has no influence of its own upon farm efficiency. What this suggests is that the strong external effect of schooling upon productivity - discovered for the average and one-stage frontier production functions - operates in terms of encouraging the adoption of innovations (which push out the frontier), rather than in terms of improving efficiency in the context of existing technology (which would allow farmers to move closer to the frontier).

If there are external benefits of schooling in terms of greater technical efficiency, these have all been internalised by poorly educated farmers copying the practices of better educated farmers and thereby obscuring the externality. However, the cross-sectional data available here provides no evidence to determine whether this has happened. It may simply be that individual farmers must adapt use of inputs to the particular circumstances they face, and that information on the best practice use of new inputs is not easily transferable between farms.

Table 12: MLE FPF - Average Village Schooling, External vs. Internal Effect
Dependent Variable: Natural Log of Cereal Crops Produced (LN_CEREAL)

	Eqn. 38	Eqn. 39	Eqn. 40	Eqn. 41
ED_AD_F	-0.00	-0.01	-0.12	-0.72 ***
ED_AD_NF	0.01	0.02	-1.03 ***	-0.64 ***
AVED_VILLAGE	0.67 ***	0.20 ***	-1.92 ***	-0.79
ONE STAGE	YES	YES	NO	NO
TWO STAGE	NO	NO	YES	YES
TRUN-NORM DIST	YES	YES	YES	YES
VILLAGE VARS?	NO	YES	NO	YES
MEAN EFF.	0.51	0.54	0.51	0.55
LOG-LIKELIHOOD	-824.9	-760.9	-859.7	-744.9
NUMBER OBS.	616	616	616	616

Note: Stars indicate significance using a two tailed t-test: *** = 0.01; ** = 0.05; * = 0.10; ✔ = 0.20.

5.2.d. Summary of Frontier Results

To summarise, formal education has no influence upon placement of the stochastic production frontier. This is not surprising, given the rather traditional nature of production in rural Ethiopia and relatively low levels of education needed for technically efficient production.

Of greater relevance is the impact of schooling upon the efficiency of farmers operating below the frontier. Here, there is convincing evidence of the effect of education in reducing farm inefficiency. For farmers, the effect seems to be strongest in the case of adults other than the household head. For non-farmers, the education of the household head is more important than that of other adults. This may be because the head is an important farm decision maker for the household even if his or her main activity is not farming.

Disaggregating by level of education and type of household member shows that the education of farmers is more important in terms of farm efficiency than that of non-farmers. For the head, having more than grade six complete has no impact upon farm efficiency, whereas for other adults who farm higher levels of schooling lead to greater reductions in inefficiency. This confirms the cohort effect noted earlier.

While village-level education has a significant impact upon placement of the frontier, there is no evidence that increasing average education in the village influences efficiency deviations from a given frontier. This indicates that the reported strong external benefits of schooling are manifested in terms of improving the spread of agricultural innovations, rather than increasing efficiency given existing technology.

6. Conclusion

This study of farm households in 14 Ethiopian villages, where cereals are produced using traditional oxen-plough technology, found positive and significant returns to additional years of formal schooling in terms of increased output of cereal crops.

For household heads who are farmers, returns are greatest for household heads who have attained at least some upper primary schooling (grades four to six) and no more. While secondary schooling may provide skills which are useful in terms of the allocation of inputs in a rapidly changing technological environment, it tends not to enhance cereal output significantly here. This may reflect the rather low levels of modernisation which characterise much of Ethiopian farming. For other adults whose main activity is farming, at least some upper primary education is necessary for there to be positive and significant benefits of schooling, but higher levels of schooling also contribute to productivity. This may be because other adults are younger than the household heads, as a group, and functional and permanent literacy is no longer attainable with only primary education, given the deterioration in school quality that accompanied educational expansion in the past few decades.

Education of non-farming members of the household is also important to farm output. However, the role played by the education of other adults in terms of increasing productivity is partly indirect, as non-farm income sources may provide capital for farm improvements and a buffer against risk in the adoption of innovations. Here, secondary schooling has a larger role to play than primary, since some more advanced education is usually a prerequisite for non-farm employment.

Private benefits of schooling are small in comparison with social benefits. Adding average years of formal schooling acquired in the village to the household production function, along with the mean household education level, showed that having an additional year of formal schooling on average in the village has a much larger impact upon farm productivity than increasing household educational attainment by one year on average. This evidence of external benefits of schooling suggests that there may be too little investment in education from a social standpoint.

Using frontier production function techniques, farm-level efficiency was estimated at approximately 55 percent of potential on average for the farmers sampled. While low, this is in line with other estimates using data from the ERHS. Increased schooling is found to have a significant impact upon reducing inefficiency. This indicates that schooling provides benefits to be exploited in terms of increasing output through greater productive efficiency even in traditional farming. However, there is no evidence of unexploited external benefits of schooling in terms of increasing efficiency of production for a given technological environment. While there may be neighbourhood effects in terms of the placement of the frontier, it is individual household investments in schooling which affect production in relation to the frontier.

The findings presented here suggest that education has an important role to play in increasing agricultural production in rural Ethiopia. Productivity may be enhanced either through the adoption of more productive inputs and techniques or through improvements in productive efficiency for a given technology. These results provide clear evidence that farmers in rural

Ethiopia generally operate far below their productive potential. Given the extremely low levels of investment in human capital in rural Ethiopia, there is great scope for increasing productivity through higher levels of formal schooling, despite the traditional nature of farming in most rural areas. Furthermore, since formal education is thought to be particularly important in terms of enhancing the spread of innovations, schooling may increase farm productivity further by helping to extend the limits of the frontier. In this regard, there is evidence of important external benefits of schooling which may be exploited to expand agricultural output.

Given the tenuous nature of farm production in rural Ethiopia, and the very low levels of private investment in schooling, there is a strong case to be made for government or donor intervention to encourage higher levels of investment in primary education in rural Ethiopia.

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