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The Impact of Farmers' Health and Nutritional Status on Their Productivity and Efficiency: Evidence from Ethiopia*

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I. Introduction

Agriculture, the mainstay of the Ethiopian economy, accounts for about 48% of GDP.[1] Approximately 87% of the population (of a total of about 55 million people) live in rural areas and depend directly or indirectly on this sector for their livelihoods. Agricultural goods (coffee, hides and skins, and oil seeds) make up about 90% of export earnings (of which 60% comes from coffee). Performance in this sector has been poor from 1970 to 1992. Over the 1970–80 and 1980–92 periods, agriculture grew at a rate of 0.7% and 0.4%, respectively, while the population growth rate was 2.6% and 3.1%, respectively.

In 1994–95 cereal production, which constitutes the major part of agricultural output, was 5% lower than it was in 1980–81.[2] At the same time there was a 40% increase of the population. Adverse climatic conditions, civil war, and ill-designed government policies were the root causes of this poor performance.[3] The peasant farming subsector accounts for 90% of output. Within the subsector cereal crops make up about 75% of the area used to cultivate major crops, such as *teff* (24%), maize (14%), barley (11%), sorghum (12%), wheat (10%), and millet (3%).[4]

The lack of agricultural growth has been costly. Ethiopia is categorized as the third poorest country in the world, with 60% of its population living below the poverty line. A high level of food insecurity and low levels of food intake are part of daily life in many parts of Ethiopia. The country has suffered two large-scale famines (1973–74 and 1983–

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85), claiming hundreds of thousands of lives. Malnutrition is common even in years of normal rainfall, and food security is a permanent concern in rural Ethiopia.[5] A recent National Nutrition Survey found for children younger than 5 years old that 64% suffer from chronic malnutrition (stunting), which is among the highest percentages in the world, 8% are affected by wasting, and about 47% are underweight.[6]

Better health and nutrition, as related to labor productivity or better production organization (since deciders in good health generally have better intellectual capacities), can increase household income and economic growth. Poor health will result in a loss of days worked or in reduced worker capacity, which, when family and hired labor are not perfect substitutes or when there are liquidity constraints, is likely to reduce output. The elasticity of agricultural output or wages with respect to nutrition and health status is an indication of the strength of the productivity-nutrition and health relationship. Many developing-country governments are increasingly concerned with the basic needs of their populations, and education and health projects account for rising public sector expenditures. Choices need to be made where money is best spent. Human capital expenditures can be more easily justified in terms of promoting economic development and, thus, generate a large increase in productivity. J. R. Behrman notes that ‘‘the studies . . . tend to indicate, if anything, greater productivity effects for nutrition than for formal schooling in poor rural contexts, even though productivity effects of schooling have been much emphasized in the literature.’’[7]

In this article we focus on the link between nutrition and health and labor productivity. The link between productivity and consumption and its impact on wages was first explored among others by H. Leibenstein, J. E. Stiglitz, J. A. Mirrlees, and C. Bliss and N. Stern, and is now commonly referred to as the ‘‘efficiency wage theory.’’[8] In this model the work effort of the agricultural worker is represented by $\lambda(c)$, an increasing function of consumption c, which is first convex then concave as c increases. Wage W and consumption c are generally considered as equal. The maximization of agricultural profit by the landlord yields the equation $\lambda'(W)/\lambda(W) = 1/W$, the solution of which is the efficiency wage. Incorporated in a simple representation of the labor market this model helps to explain why there may exist labor surplus in poor agricultural economies simultaneously with strictly positive wages. Bliss and Stern show that with such models, workers with different nutritional assets or alternative sources of consumption are paid different levels of efficiency wages.[9] Dasgupta and Ray analyze the characteristics of market equilibrium. They note that asset redistribution and food transfers, which impose redistribution in rural areas, result in lower aggregate unemployment and greater aggregate output.[10]

Our approach to the link between agricultural productivity and health and nutrition status of peasants is more specialized than it is in the efficiency wage literature. Indeed, instead of considering the global link between wage (or consumption or nutrient intakes) and productivity, we focus on an intermediate stage in the causation chain, namely, that consumption, including nutrient intakes, influences health and nutrition status, which in turn affects labor productivity. Thus, we incorporate the effect of nutrient intakes in biological processes that modify the characteristics of the labor force. We focus on the influence of health and nutrition status on labor productivity. This means that medium or long-term effects are studied, rather than short-term effects of nutrient intakes, which is consistent with a sound representation of efficiency wage mechanisms that are rather long-run effects.

Bliss and Stern discuss in some detail the nutritional literature that shows links between the requirement of nutrients and activity levels as well as between nutrient intakes and weight and production levels. They ask for additional indicators beyond the consideration of weight for height. Although we do not explicitly work in the framework of the wage efficiency literature, we address this requirement by incorporating a variable associated with the health status of workers.

In contrast to the efficiency wage literature, we make no specific assumptions about wages or other rewards used to increase labor productivity. Explicit specification of how wages or other rewards are calculated by landlords and agricultural workers is thus avoided.

However, it is reasonable to think that positive effects of health and nutrition on productivity are necessary conditions for wage efficiency mechanisms. Thus, large elasticities of labor productivity with respect to health and nutrition status would benefit the implementation of policies related to the wage efficiency framework, such as food aid or land redistribution, as instruments to increase production and lower unemployment. As we mentioned above, the implications of strong elasticities go beyond this framework. They open the way to policies designed to increase production levels and indirectly to improve the welfare of populations.

As for the functioning of labor markets, it is not possible to formulate safe conclusions without accurate observations of their mechanisms. However, strong elasticities would suggest the possibility of heterogeneity of labor as well as of complex contract forms to deal with this heterogeneity. Wage efficiency mechanisms, as well as selection processes, moral hazard phenomena, and comparative advantages for specific tasks, may be elements of such contracts.[11]

Unlike the issue of returns to education, as yet there have been comparatively few empirical studies, especially in developing countries, on the returns to other human capital variables. However, it is important to understand whether investments in nutrition and health are to be viewed as ends in themselves or also as investments in higher levels of productivity. It is useful to distinguish the health status, often associated with illness or injuries, from the nutritional status, more directly related to nutritional intakes. With regard to the health to productivity link, R. Baldwin and B. Weisbrod, and Weisbrod and T. Helminiak, link household health indicators to labor productivity (measured by weekly and daily earnings).[12] Weisbrod and Helminiak consider the impact of parasitic disease on labor productivity, but they do not find any strong evidence of a link. These studies have been criticized for not allowing for the endogeneity of health; however, more recent studies address this issue. L.-F. Lee, using U.S. data, estimates a wage equation incorporating health status in a health equation, and finds that the health of adults has a significant effect on their wages.[13] M. M. Pitt and M. R. Rosenzweig consider the effect of family morbidity on farm profits, although they do not find any statistically significant health effects.[14] The fact that no significant effects for health indicators have been found in most of these studies, although there exists a strong a priori intuition in favor of positive effects, may stem from specification errors in the estimated models or merely from poor or incomplete data that do not allow accurate estimation of these effects. In particular, important missing variables are secondary agricultural inputs (fertilizers, tools, etc.), land quality and steepness, and nutritional status. Moreover, inefficiency may occur in the production process, and this is not accounted for.

The impact of nutrition on labor productivity has been analyzed by a number of authors, either by estimating production functions or wage equations.[15] First we consider the literature using the production function approach. The production function is augmented by considering calorie intake or anthropometric measures as a measurement of nutritional status, which reflects worker effort and effectiveness. Using cross-section data on hoe-cultivating farm households in Sierra Leone, J. Strauss finds that ‘‘effective family labor,’’ which is a function of actual labor and per capita daily calorie intake, is a significant input in production.[16] Using panel data from south India, A. B. Deolalikar tests for a link between the total value of output and ‘‘effective labor,’’ where the latter is a function of actual labor, daily calorie intake, and weight-for-height of on-farm family farm workers.[17] He finds that weight-for-height is significant, but calorie intake is not. M. Fafchamps and A. Quisumbing use data from rural Pakistan to regress the value of crop output (by season and in total) on the body-mass index and the height of males and females.[18] They find that for males both indicators are important, but in different seasons. There is no nutrition effect for females.

A number of authors estimate wage equations for developing country data, again including calories (occasionally also protein intake), or the body-mass index (weight-for-height), and height. Alderman et al. use the body-mass index (*BMI*) and height but find neither to be significant; most other authors, however, find that nutritional status positively and statistically significantly influences wages. S. Behrman and Deolalikar highlight seasonal variations in the role of calorie intake and nutritional status as measured by the body-mass index. L. J. Haddad and H. E. Bouis include daily calorie intake, height, and the body-mass index in the wage equation, but find only height to be statistically significant. A. D. Foster and Rosenzweig analyze the role of nutritional variables in piece-rate and time-rate labor and find that calorie consumption augments productivity.[19] D. Thomas and Strauss use survey data for urban male and female Brazilians and find that the body-mass index is an important determinant of wages for males, particularly for the less educated.[20] Height has a strong positive effect on wages for both men and women. Calories and protein intake are significantly related to wages of men and women who work in the market sector. Finally, A. Bhargava uses a panel of Rwandan households to analyze determinants of time allocation.[21] Poor nutritional status is found to hamper the capacity of adults to undertake subsistence tasks.

None of the empirical studies surveyed incorporate indicators of health and nutritional status or control for the possible endogeneity of these factors.[22] Moreover, they do not present estimates of production frontiers (a production frontier estimates the outer bound with production, i.e., the potential output; it can be thought of as an upward shift of a production function) in contexts where technical inefficiencies may be substantial. Another major reason to consider a production frontier instead of a production function is to account for possible asymmetries in error terms of production equations. Indirect evidence of the effect of health and nutrition on agricultural productivity can also be investigated using wage equations for agricultural workers and assuming a steady link between remuneration and productivity, for example, in the case of perfect markets.

Do health and nutrition status influence positively the productivity of peasants in Ethiopia? Are these effects robust to the specification chosen to account for inefficiency in the agricultural processes? Is the impact of nutritional status on productivity different when estimated in a production frontier framework or from wage equations for salaried rural workers? In this article, we provide empirical evidence on the impact of both health and nutritional status on the productivity and efficiency of cereal-growing Ethiopian peasant farmers.

In Section II, we present the agricultural technology model and the data set. We specify a stochastic frontier agricultural production frontier, incorporating nutritional and health status as inputs. The results of the production frontier estimations are analyzed in Section III. We provide three sets of estimates to assess the robustness of the results of the specification of the inefficiency term. Unlike earlier studies, we also examine the distribution of residual technical efficiency (TE), after including the various agricultural inputs, including health and nutritional status. In Section III we discuss the results of the wage equation. Section IV concludes the article.

II. The Data and the Model

The Data

The data come from the first round of the Ethiopian Rural Household Survey, conducted in 1994.[23] The 1,477 households that were interviewed were in 18 peasant associations in 15 *weredas* (districts) and six regions stretching across the country.[24] We selected only those sites in which farmers practice ox-plow cultivation of cereals.[25] See the description of the sites in appendix A.

Descriptive statistics for the sample of the 430 households remaining after selection are shown in table 1.[26] Most of the statistics conform to existing notions about the country. In this part of Ethiopia land is generally scarce, and average holdings are very small at about 1.5 hectares per household. This varies from 0.32 hectares per household in Geblen to 2.59 hectares per household in Korodegaga. Land quality is on average 1.67 (out of a possible three, with one as best quality, and three as worst), and the averages range from 1.04 in Domaa to 2.68 in Geblen. The land steepness is 1.29 (out of a possible three, with one flattest and three steepest) on average, and this ranges from 1.04 in Domaa to 2.31 in Geblen.

Households own 8.7 animals on average, which indicates the importance of animal husbandry in Ethiopia. The average fertilizer application rate is 49 kilogram per hectare, which is in line with other surveys.[27] This figure is low (compared to the recommended rate of 200 kilogram per hectare), but has risen significantly over the past few years, reflecting the government's emphasis on increasing fertilizer use.[28] In our sample 51% of farmers do not use any fertilizer. Off-farm activities are quite low with 59% of households recording no days worked off the farm; 91% of households recorded less than 31 days worked off the farm over the past 4 months.[29] Average family size is approximately six, with approximately three adults engaged in farming activities.

The education of the head and members of the household is generally very low. It will be incorporated in the wage equations in Section III. About 40% of household heads claim to be able to read and write a letter. On average 23% of all other members of the household (excluding heads) can read or write a letter. The average years of schooling for household heads is only 0.74. Formal education is very rare and only 10% of household heads have completed primary education or more.

In table 2 we present correlation coefficients between output and some input variables and the raw health and nutrition variables. Nutritional status and distance to water are significantly (at the 5% level) positively correlated with output or output per hectare, as well as with labor for harvesting per hectare and fertilizer per hectare. The morbidity indicator is significantly correlated with output at the 10% level.

TABLE 1

Descriptive Statistics for Selected Variables for the Production Analysis

Variable	Mean	Standard Deviation	Range
*PRIND**	1.7	.22	.96–2.33
*OUTPUT**	797.60	867.75	5.00–6,700.00
*LAND**†	1.488	1.094	.21–8.13
*LABP**	51.33	56.56	1.00–436.00
*LABH**	67.92	87.58	1.00–744.00
*FERT**	56.57	89.75	.00–600.00
*HOE**	.91	1.09	0–13
*LQ**†	1.670	.664	1–3
*LS**†	1.286	.416	1–3
*WA**†	18.06	13.45	0–120
*N**	.33	.04	.23–.54
*M**	.04	.12	0–1
*LIVDIS**†	.286	. . .	0–1
*ENV**†	.233	. . .	0–1
*AGF*1†	.470	.66	0–3
*AGF*2†	.488	.69	0–3
*AGF*3†	.637	.82	0–4
*AGF*4†	1.144	.74	0–5
*AGF*5†	.270	.48	0–2
*AGM*1†	.435	.63	0–3
*AGM*2†	.493	.72	0–3
*AGM*3†	.661	.83	0–5
*AGM*4†	1.130	.72	0–5
*AGM*5†	.342	.5	0–2
FEHHH†	.114	. . .	0–1
AGEHHH†	44.23	15.14	18–101
*AGEAVE*2†	32.79	9.30	17.5–73
WALLS†	.10	.31	0–1
ROOF†	.30	.46	0–1
EDINDHHH†	.742	2.20	0–16
EDINDMEM†	.07	.79	0–6
RWLHHH†	.40	. . .	0–1
DUED†	.10	.30	0–1
*QA*2†	.337	. . .	0–1
*QA*3†	.291	. . .	0–1
*QA*5†	.154	. . .	0–1
*QA*6*D*†	.265	. . .	0–1
*QA*6*E*†	.177	. . .	0–1
*QA*6*FG*†	.274	. . .	0–1
*QA*6*H*†	.147	. . .	0–1
*QA*8*A*†	.247	. . .	0–1
*QA*8*B*†	.121	. . .	0–1
FUTIME†	49.53	57.18	0–420.00
LIVESTOCK	8.686	9.27	0–62
*NOADFA*10	1.591	1.00	1–7
*NOADFA*2	3.030	1.45	1–12
DWOFFA	11.76	31.87	0–275
VALOUT	1,360.04	1,484.16	7.80–11,599.90
FAMILY SIZE	6.16	2.70	1–17

Note.—Unmarked variables are included only for general interest.
* Denotes a variable used in the production function.
† Denotes a variable used as an instrument.

TABLE 2

CORRELATIONS BETWEEN OUTPUT, INPUTS, AND HEALTH AND NUTRITIONAL STATUS

Variable	*N*	*M*	*WA*
OUTPUT	.1027 (.034)	−.0919 (.056)	−.1119 (.020)
OUTPUT/LAND	.1302 (.006)	−.0689 (.154)	−.1945 (.000)
LABP/LAND	.0446 (.356)	.0463 (.338)	−.0942 (.052)
LABW/LAND	−.0493 (.308)	−.0501 (.300)	−.0493 (.308)
LABH/LAND	.1103 (.022)	−.0458 (.342)	−.1175 (.014)
FERT/LAND	.1383 (.004)	−.0410 (.396)	−.1738 (.000)
N	1	−.0917 (.058)	.0006 (.990)
M	−.0917 (.058)	1	.0141 (.772)
WA	.0006 (.990)	.0141 (.772)	1

NOTE.—Figures in parentheses are two-tailed *p*-values.

The Model

We adopt a stochastic frontier approach for the agricultural production. The production relation is written as:

$$Y = f(\mathbf{X}, M, N), \tag{1}$$

where **X** is a matrix of agricultural inputs, and *M* and *N* are morbidity and nutritional status, respectively. Due to a limited sample size, we specify a Cobb-Douglas type technology, which allows the results to be comparable with the studies by Strauss and Deolalikar. Indeed, the Cobb-Douglas specification saves degrees of freedom because of the small number of parameters to estimate. Therefore, the equation we estimate is:

$$\begin{aligned} \ln Y_i = {} & \beta_0 + \beta_A \ln A_i + \beta_{LQ} \ln LQ_i + \beta_{LS} \ln LS_i \\ & + \beta_L \ln L_i + \beta_N \ln N_i + \beta_M \ln M_i + \beta_{WA} \ln WA_i \\ & + \beta_F \ln F_i + \beta_{HOE} \ln HOE_i + \beta_{ENV} ENV_i \\ & + \beta_{LIVDIS} LIVDIS_i + \sum_k \beta_k DU_k + \epsilon_i, \end{aligned} \tag{2}$$

where $i = 1, \ldots, 430$ is the index of the household and β is a vector of parameters.

Production function variables:

$Y =$ The total value of output divided by a Laspeyres price index (the price index is obtained by taking a weighted average of the prices faced by each household; the weights are the respective proportions of the crops in total value output);

A = Land under cultivation in hectares;
LQ = Measure of land quality (farmers where asked whether the plot was of *lem* [good = 1], *lem-teuf* [mediocre = 2], or *teuf* [poor = 3] quality);
LS = Measure of the steepness of the land (degrees used were *medda* [flat = 1], *dagath-ama* [moderate incline = 2], and *geddel* [steep incline = 3];
HOE = Number of hoes owned by the household;
L = Person days used for plowing and harvesting;
F = Amount of fertilizer applied, per kilogram;
ENV = Dummy, number 1 if crop suffered from (*a*) low temperatures, (*b*) wind or storm, (*c*) flooding or water logging;
$LIVDIS$ = Dummy, number 1 if livestock suffered due to lack of drinking water, grazing land, or from animal diseases;
DU_k = Dummies for the k sites (see app. A for more details on the sites).

Health and nutrition variables:

WA = Time of one-way trip to the usual source of water, in minutes;
N = Weight-for-height (wasting) of the head of the household, a medium-term measure of nutritional status;[30]
M = Percentage of members of the household engaged in agriculture (includes members doing domestic work) who have great difficulty (by their own assessment) in transporting a bucket with 20 liters of water for 20 meters, a measure of strength and endurance as well as an indicator of morbidity in the household.[31]

The error term is $\epsilon = v - u$, where v is a symmetric component that captures exogenous shocks such as weather, supply shocks, and unobserved heterogeneity of households plus measurement error. The term u is a one-sided (positive) term that captures technical inefficiency. Equation (2), therefore, represents a stochastic frontier production function, as suggested independently by D. J. Aigner, C. A. K. Lovell, and P. Schmidt and by W. Meeusen and J. Van den Broeck.[32] We use three methods to estimate the stochastic frontier production function:

1. The terms v and u are assumed to be distributed as $N(0, \sigma_v)$ and $|N(0, \sigma_u)|$, respectively. Equation (2) is estimated by OLS, and σ_v and σ_u are estimated by using the empirical second and third moments (μ_2 and μ_3):

$$\hat{\sigma}_v^2 = \hat{\mu}_2 - \left(\frac{\pi - 2}{\pi}\right)\hat{\sigma}_u^2 \tag{3}$$

and

$$\hat{\sigma}_u^2 = \left[\sqrt{\pi/2}\left(\frac{\pi}{\pi - 4}\right)\hat{\mu}_3\right]^{2/3}. \tag{4}$$

The constant term is then corrected by adding the mean of u, $\sqrt{(2/\pi)}\sigma_u$. This method is referred to as COLS (corrected OLS) and was developed by J. Richmond.[33]

2. The distributional assumptions are as for method 1, but estimation is one using the maximum likelihood method. It leads to efficient estimation if the distributional assumptions are correct. We refer to this as the NHN (normal-half-normal) model. This specification was first suggested by Aigner, Lovell, and Schmidt.

3. The symmetric term is distributed as in method 1, but for u we assume an exponential distribution. The estimation is done using maximum likelihood methods and the model is referred to as EXP. This specification was first used by Meeusen and Van den Broeck.

Finally, individual estimates of technical efficiency are derived from the conditional distributions of u given. This method was proposed by J. Jondrow, Lovell, I. S. Materov, and Schmidt.[34] The formulas for NHN and EXP models are:

$$E(u|\epsilon)_{NHN} = \frac{\hat{\sigma}_u\hat{\sigma}_v}{\hat{\sigma}}\left[\frac{\phi(\hat{\epsilon}\hat{\lambda}/\hat{\sigma})}{1 - \Phi(\hat{\epsilon}\hat{\lambda}/\hat{\sigma})} - \left(\frac{\hat{\epsilon}\hat{\lambda}}{\hat{\sigma}}\right)\right] \tag{5}$$

and

$$E(u|\epsilon)_{EXP} = \hat{\sigma}_v\left[\frac{f(\hat{\epsilon}/\hat{\sigma}_v + \hat{\lambda}^{-1})}{1 - F(\hat{\epsilon}/\hat{\sigma}_v + \hat{\lambda}^{-1})} - \left(\frac{\hat{\epsilon}}{\hat{\sigma}_v + \hat{\lambda}^{-1}}\right)\right], \tag{6}$$

where $\sigma^2 = \sigma_u^2 + \sigma_v^2$, and $\lambda = \sigma_u/\sigma_v$. ϕ and Φ are, respectively, the p.d.f. and the c.d.f. of the standard normal law, while f and F are, respectively, the p.d.f. and the c.d.f. of the exponential law with $f(u) = \exp(-u/\sigma_u)/\sigma_u$.

Land is the major agricultural input, and we account for its quality and steepness. Labor is the second most important input. It is a heterogeneous good corresponding to different tasks and composed of the contributions of different family members and of hired workers. The average total levels of labor input are, respectively, 51, 71, and 68 person days for plowing, weeding, and harvesting. The proportion of hired labor used is small. Indeed, for plowing, weeding, and harvesting, the sample averages of family to total labor used are, respectively, 0.84, 0.78, and 0.61. This suggests that labor markets, particularly for plowing and weeding, are not working perfectly. Thus, consumption and production decisions cannot be treated as separate decisions. A number of authors have considered tests for nonseparability, and R. E. Lopez provided the first explicit test of nonseparation.[35] In general, tests of perfect markets use the idea that unearned income and household characteristics such as household composition and assets should not affect the wage rate.[36] We return to this issue in Section III.

Minor agricultural inputs (hoes, fertilizer) may also play a substantial role in the augmentation of output levels. Moreover, better health and nutrition may affect output levels directly by changing the productivity of labor and perhaps by improving the general organization of production through the use of other inputs and the choice of techniques. Indeed, healthier and stronger members of households may be able to carry heavier loads and undertake more painful and difficult tasks. They may also be more precise and rigorous in the execution of these tasks and in the use of other inputs. An important element of the health environment, water availability, has also been introduced so as to capture residual health effects not included in the morbidity measure. Indeed, water used in cleaning, washing, and drinking is expected to be a major element of the domestic health process, despite the fact that the effect of the variable can also be interpreted in terms of wealth effects.[37] We account for random shocks specific to the agricultural technology by introducing a categorical dummy variable that indicates whether the crop has suffered from different climatic shocks. Finally, fixed effects for the sites capture both the unobserved heterogeneity of local factors associated with the sites and measurement errors related to the enumerator effects, since data collecting in each site was done by different enumerators.

Separating family and hired labor would mean many zero observations for hired labor, which we avoid by aggregating both types of labor. Estimation shows that this aggregate measure of labor input yields better results than the introduction of two different categories, perhaps because it saves degrees of freedom and avoids quasi-collinearity problems. In the analysis we use only labor for harvesting and plowing.[38] Weight-for-height (*WFH*) is a summary statistic of the current nutritional status of the head. We used the *WFH* of the household head only because of many missing values for the other members.[39] Indeed, in 64% of the 430 households analyzed, only one person is engaged full time in farming (*NOADFA*10 in app. B). With few exceptions, it is the household head. Using *BMI* (*WFH* squared) instead of *WFH* leads to similar results with a less significant coefficient on nutritional status. The morbidity indicator, *M*, is also correlated with strength and endurance and reflects health status within the household. It is computed for all family members engaged primarily in farming. The variable *WA* is considered a crucial determinant of health status, since it influences the quantity and quality of water used by the household for toilet and for cooking.

III. Results

Estimates of the Stochastic Frontier Production Function

The estimates for the COLS, NHN, and EXP models of the stochastic frontier are relatively close for most of the coefficients and are presented in table 3. In order to correct for endogeneity problems, we replaced the independent endogenous variables (*LAB, FERT, HOE, N, M*) by predicted values obtained by using the set of instruments indicated in table 1. Beyond the exogenous variables included in the production frontier, primary identifying instruments include household composition; age and education of the head and of members; household assets represented by the materials of walls and roof, and distance to water and firewood; and various past shocks affecting the health and agricultural aspects of the household. Tests of identifying instrumental variables for regression estimates of the production function have not rejected the assumption of validity of the instrumental variables.[40]

TABLE 3

ML Estimates of the Cobb-Douglas Stochastic Frontier Production Function

	Coefficient Estimates		
Variable	COLS	NHN	EXP
CONSTANT	8.0666 (6.89)	8.2357 (8.199)	8.0546 (8.173)
ln(*LAND*)	.4746 (5.28)	.4350 (5.457)	.4176 (5.186)
ln(*LAB*)*	.2164 (1.52)	.2552 (2.239)	.2606 (2.037)
ln(*FERT* + 1)*	.0817 (1.70)	.0413 (.978)	.0359 (.797)
ln(*HOE*)*	.1467 (.60)	.300 (.213)	−.0182 (.158)
ln(*LQ*)	−.2015 (1.92)	−.1627 (1.884)	−.1458 (1.697)
ln(*LS*)	.0175 (.12)	−.0761 (.520)	−.1124 (.825)
ln(*N*)*	1.8959 (2.20)	2.2461 (2.688)	2.2629 (2.703)
ln(*M* + 1)*	−1.9424 (1.63)	−1.6876 (1.530)	−1.7190 (1.561)
ln(*WA* + 1)	−.1417 (2.71)	−.1151 (2.547)	−.0877 (2.105)
*DU*2	−.4026 (1.42)	−.4299 (1.676)	−.4643 (1.882)
*DU*3	−.3602 (2.16)	−.3348 (2.112)	−.3684 (2.390)
*DU*5	.4281 (2.41)	.3606 (2.500)	.3199 (2.259)
*DU*7	.9760 (7.36)	.9524 (8.805)	.9180 (9.044)
*DU*8	1.0210 (4.78)	.9081 (5.514)	.8621 (5.086)
*DU*9	−.4965 (2.29)	−.4189 (2.003)	−.4273 (2.290)
*DU*10	.9148 (5.48)	.9798 (6.618)	.9689 (6.270)
*DU*16	−.1907 (.90)	−.2646 (1.354)	−.3470 (1.807)
ENV	−.0848 (.99)	.0868 (1.094)	−.0795 (1.068)
LIVDIS	−.0380 (.40)	−.0543 (.622)	−.0647 (.789)
σ	1.3029	.8698 (6.771)	.6866
σ_u	.9820	.8187	.4732 (8.539)
σ_v	.3209	.4468	.2134 (9.041)
λ	3.0600	1.8325 (4.111)	2.2180
Log-likelihood	. . .	−428.75	−418.75
Adjusted R^2	.62	. . .	. . .

Note.—Figures in parentheses are absolute *t*-ratios, obtained by using the Huber heteroscedastic-consistent covariance matrix.

* Denotes an endogenous variable, predicted by instrumentation.

The most important factor explaining variation in output is land, estimated with output elasticities between 0.42 and 0.48. Labor is characterized by low output elasticities (0.22 to 0.26). The return to scale when only land and labor are considered is very robust at about 0.67, which compares well with the usually accepted notions of decreasing returns to these two factors for this type of technology. The fertilizer coefficient is statistically significant (at the 10% level) only for the COLS model (with a coefficient that is in line with results reported in Yao).[41] Land quality has a positively significant effect at least at the 10% level in all cases (with a negative sign for the index *LQ*), and its inclusion in the model improves the results dramatically. This is also true for the site-specific dummies (DU_6 was dropped, as it was always insignificant). The coefficients for climatic or livestock problems and for *HOE* and *LS* are never significant.

Estimated at between 1.90 and 2.26, the output elasticity of *WFH* is of a magnitude similar to Deolalikar's estimate of 1.9. By contrast, Fafchamps and Quisumbing estimate an elasticity of 0.45 for the *BMI*.[42] At the mean a change in *WFH* of one standard deviation will change output by 27%. This implies that even for small increases in the *WFH*, considerable increases in output could be achieved. This has to be contrasted with other productivity augmenting investments, such as land improvements and education. Evidence on the return to education in farming for Ethiopia is rare. However, recent empirical work puts the returns to one extra year of education for the household head at 4% of the increased value of output.[43] It appears that returns to nutrition compare favorably.

We provide evidence of other effects of human resources. The coefficient on *WA* is always significant at the 5% level. The distance to the source of water is clearly of significance for productivity, probably through the health status of family workers. However, this may also reflect the time-intensive nature of this activity, which means valuable family labor time is diverted away from farming. Finally, the coefficient on morbidity status is significant only at the 13% level with a negative sign that is consistent with the theoretical model. This suggests a weak effect that may appear stronger with a higher sample size. It is more significant when the variable *WA* is excluded. On the whole, three variables related to human capital (*N, M, WA*) are shown to influence agricultural productivity, which is a more complete set of effects than has been found by other studies.

The range of values for the estimates of λ is between three and 1.83, which shows that the one-sided term dominates the disturbance. Average technical efficiency was estimated at between 51% and 76%, indicating that farmers were, on average, 49% to 24% below the frontier. This suggests that the technical inefficiency observed in standard agricultural production functions without incorporating health and nutritional status of

TABLE 4

FREQUENCY DISTRIBUTION OF TECHNICAL EFFICIENCY ESTIMATES

Range	COLS	NHN	EXP
.0–.09	6	0	0
.1–.19	23	12	0
.2–.29	42	18	1
.3–.39	58	40	2
.4–.49	69	62	8
.5–.59	84	96	29
.6–.69	72	116	64
.7–.79	47	67	124
.8–.89	27	15	200
.9–1.00	1	1	0
Mean	.51	.56	.76
SD	.20	.16	.10
Range	.03–1.00	.05–.92	.30–1.00

the workers is not due to the omission of these variables. Table 4 gives the frequency distribution of the technical efficiency estimates.[44] The efficiency estimates associated with the NHN model lie in a narrower range than the COLS model. The EXP model estimates are very different, indicating that 47% of farmers are 80% or more technically efficient (75% are 70% or more technically efficient). Note that the correlation coefficient between EXP and NHN technical efficiencies is only 0.39, which suggests that the choice of the model specification may have a substantial impact on inefficiency estimates.

The existence of heteroscedasticity in the error term *u* would imply a bias of the maximum likelihood estimates obtained under homoscedasticity assumptions. S. B. Caudill, J. M. Ford, and D. M. Gropper, and Caudill and Ford discuss the consequences of heteroscedasticity in this type of model.[45] We tested the hypothesis of homoscedasticity against several forms of heteroscedasticity, using tested statistics deduced from generalized residuals as in C. A. Gouriéroux, A. Montfort, E. Renault, and A. Trognon, and we find a clear rejection of the hypothesis of homoscedasticity, particularly when the standard deviation of error terms is assumed to be proportional to the family size.[46] Moreover, *WLS* estimates (weighted by the inverse of the family size to account for this type of heteroscedasticity) reinforce the main results obtained under the homoscedasticity assumption in the sense that they show the significance of the coefficients of land, labor, *N*, and *M*.[47] Apart from the constant term, which is kept uncorrected in the *WLS*, the estimated coefficients are quite different from those obtained with other estimation methods. The effects of the main factors (land, labor, *N*, *M*) on production are much stronger and would lead to increasing returns to the combination of land and labor, which is not an expected feature for this type of technology. Indeed, agricultural production based only on land and labor inputs generally shows decreasing returns to scale in LDCs, in particular due to time and energy lost in travel and transport.

As the correction for heteroscedasticity is believed to interact with nonlinearities in the production function (e.g., with translog specification), we interpret the anomalies in the *WLS* results as coming from the underlying nonlinearity in agricultural technology, which cannot be accounted for, owing to the small sample size.[48] This is supported by the fact that the introduction of heteroscedasticity in the maximum likelihood estimation yields an estimate of λ that tends to zero, which is usually interpreted as a signal of misspecification of the production frontier. On the whole, results under homoscedasticity seem to be more robust, and we have based our comments and efficiency analysis on them. Below we attempt to confirm with wage equations our findings obtained with the estimation of production technology.

Estimates of the Wage Equation

We assess the robustness of the nutrition-productivity link by estimating wage equations for farm labor with the inclusion of anthropometric indicators as explanatory variables. Due to the limited availability of agricultural labor and wage information, the observations included are often different from those used in the estimation of the frontier production function. We use two samples: (*a*) the full sample (both sexes) and (*b*) a male-only sample. For the participation and wage equations the full sample consists of 503 and 93 observations, respectively, while the subsample for males has 503 and 52 observations, respectively.[49] The wage equation is estimated for persons from 18 to 70 years of age who are engaged in farming activities. We exclude the few cases of workers who obtained part of their wage in kind. Since the actual job type was not recorded, we also used a male-only sample on the basis that the type of work would be more homogeneous and thus would lead to better adjusted estimates. Descriptive statistics are given in table 5.

The wage equation is estimated using the two-step Heckman method, by including the inverse Mills ratio, obtained from probit participation estimates, and correcting the variance-covariance matrix of the parameter estimates.[50] The wage equation is inspired by human capital and life-cycle theories.[51] We include, therefore, an education variable and age and age-squared variables to allow for concavity of the age effects. Dummy variables for the sites are incorporated to control for unobserved characteristics of the sites. Finally, anthropometric measures account for the strength and the nutrition status of the worker.[52] Measures of health are not included because of too many missing values and too little variability of this variable in the sample. To correct for potential endogeneity bias, we replaced *WFH* and *BMI* by exogenous predictions based on the

TABLE 5

DESCRIPTIVE STATISTICS FOR VARIABLES USED IN THE WAGE EQUATION FOR MALES

Variable	Mean	Standard Deviation	Range
*WAGE**	3.06	1.37	1.2–7
AGE	33.98	11.72	18–67
DUED	.15	. . .	0–1
BMI†	1.98	.20	1.60–2.46
WFH (kg/cm)	.33	.03	.26–.42
HT (cm)	167.56	7.11	153–187

* *Birr* per day, nominal.
† (Kg * 1,000)/cm^2.

full sample of 990 observations.[53] The main identifying instrumental variables are household composition, age, education of members, proxies for household assets, and past random shocks.

$$\ln(WAGE_i) = \beta_0 + \sum_k \beta_k DU_k + \beta_{AGE} AGE_i + \beta_{AGESQ} AGESQ_i + \beta_{DUED} DUED_i + \beta_{BMI} \ln(BMI_i) + \beta_H \ln(HT_i) + \beta_\alpha \alpha_i + \epsilon_i, \quad (7)$$

where

WAGE = *Birr* per day;
DU_k = Site-specific dummies (*k* sites);
AGE = Age of the worker (years);
AGESQ = Age squared;
DUED = A dummy for the education of the worker, number 1 if worker has primary education or above;
BMI = Body-mass index (defined as *WFH* squared) of the worker ([kilogram * 1,000]/centimeters^2);
HT = Height of the worker, in centimeters;
α = The inverse Mills ratio.

Another version of the equation was estimated with *WFH* instead of *BMI*.[54] The wage equation estimates are given in table 6. The *BMI* variable performed better than the *WFH* measure because it allows the inclusion of the *HT* variable that is believed to be highly correlated with the working capacity of the agricultural worker and, therefore, with the wage.[55] However, our motivation for estimating a wage equation with *WFH* only is to enable comparison with previous studies.

TABLE 6

LOG-WAGE EQUATION ESTIMATES

Variable	Full Sample (1)	Males Only (2)	Males Only (3)
CONSTANT	−13.832 (1.728)	−20.127 (1.997)	3.3987 (1.457)
*DU*14	−.5052 (3.024)	−.7296 (3.407)	−.7137 (3.349)
*DU*15	−1.1753 (6.255)	−1.1038 (4.168)	−1.1168 (4.246)
*DU*16	−.1093 (.740)	−.3043 (1.577)	−.2949 (1.523)
SEX	−.0739 (.584)	. . .	. . .
AGE	.0050 (.219)	.0053 (.168)	.0080 (.255)
AGESQ	−.0001 (.464)	−.0001 (.268)	−.0001 (.343)
DUED	.8143 (3.495)	.5711 (2.066)	.6047 (2.232)
ln(*BMI*)	2.6627 (1.979)	3.0353 (1.796)	. . .
ln(*HTI*)	2.2497 (1.493)	3.5573 (1.894)	. . .
ln(*WFH*)	. . .	. . .	3.0153 (1.850)
α	1.2132 (3.800)	.8044 (2.259)	.8300 (2.334)
Adjusted R^2	.48	.51	.51
Number of observations	93	52	52

NOTE.—Col. 2 includes *BMI* and *HTI,* but not *WFH.* Col. 3 includes *WFH,* but not *BMI* or *HTI.* See discussion following equation (7).

The male wage elasticity with respect to the *BMI* is 3.04, which means that an increase of one standard deviation would increase the wage by 26%. With regard to the second equation, the male wage elasticity with respect to *WFH* is 3.02. A change in one standard deviation in *WFH* will result in a 29% change in the wage. These two wage elasticities indicate primarily the effects of the differences in the weights of workers and compare well with orders of magnitude found in Lee (4.44–3.22) and Thomas and Strauss (4.7–5.6), but not in Deolalikar (0.28–0.66) or Behrman and Deolalikar (0.35–0.67).[56] The elasticity of wages with respect to *HT* is 3.56. A person who is one standard deviation (7.11 centimeters) above the average will have a 15% higher wage. Elasticities reported by Haddad and Bouis and Thomas and Strauss are 1.38 and 3.4–3.9, respectively.[57] Our estimated elasticities indicate that the returns to better nutrition are quite high.

We now relate the technology model and the wage equation with a common theoretical framework. First, assume that agricultural technology can be approximated by the following Cobb-Douglas type production function:

$$Y = F(L, N) = Z_0 L^{\alpha} N^{\beta}, \tag{8}$$

where α and β are parameters, L is the labor input, and N is an index of the nutritional input of agricultural technology. The Z_0 stands for the contributions of other agricultural inputs, human resources, and characteristics of the technology. Equation (8) can be rewritten as:

$$\log(Y) = \log(Z_0) + \alpha \log(L) + \beta \log(N) + v - u, \tag{9}$$

where $\log(Z_0) = \log(Z) + v - u$ is linked to the two types of error terms used in the frontier production function estimation. The logarithm of the marginal productivity of labor can be easily derived from equation (8):

$$\log(F'_L) = \log(\alpha) + \log(Z) + (\alpha - 1)\log(L) + \beta \log(N) + v - u. \tag{10}$$

Assume now that the labor market in rural Ethiopia can be considered as being approximately perfect and that the demand for labor can be considered as derived from cost minimization by competitive agricultural firms. This is the case, for example, under separability of consumption and production decisions of agricultural households.[58] Then let us reason under this assumption that the marginal productivity of labor in a particular firm is equal to the wage rate of its agricultural workers. Moreover, if we assume that the parameters, β, are common to all agricultural firms or households, equation (10) can be approximated under the form of the following wage equation:

$$\log(w) = X\gamma + \beta \log(N) + v, \tag{11}$$

were γ is a vector of parameters and X is a matrix whose columns correspond to variables correlated with Z, v, and L^D, the labor demand of the agricultural firm.

Table 7 shows estimates of a labor demand equation in which household composition, other sociodemographic characteristics, and building material for the household's house have been added to dummies for sites and land characteristics that should be the only significant variables under separability. This specification is similar to the one used by Benjamin. Several household composition variables, such as the dummy variable for a house roof made of galvanized iron or wood and the age of the household head, are significant, which indicates that the separability assumption is rejected. The result is obtained whether or not weeding is included in the definition of labor input.

The absence of separability between consumption and production decisions has no consequences on the estimation of the agricultural production function in which labor input is instrumented. The estimation of the market wage equation, which may be different from the implicit household wage, which could be endogenous, may be perturbed by the selectivity of households willing to offer labor on the market. Because of the small sample size, we have treated this selectivity problem using a purely mechanical Heckman two-step approach, without designing a structural model. Another estimation strategy would have been to specify shadow wage rates specific to each household, which should be superior

TABLE 7

LEAST-SQUARES ESTIMATES OF LABOR DEMAND, INCLUDING HOUSEHOLD CHARACTERISTICS

Variable	Coefficient	*t*-Ratios
CONSTANT	4.0970	16.12
LAND	.0199	.30
ln(*LAND*)	.5210	4.42
LQ	−.0616	1.23
LS	.0392	.47
*AGF*1	.1111	2.22
*AGF*2	.0524	1.14
*AGF*3	.0346	.91
*AGF*4	−.0432	.97
*AGF*5	−.0569	.82
*AGM*1	.0311	.64
*AGM*2	−.0438	1.00
*AGM*3	.1057	2.89
*AGM*4	.1509	3.47
*AGM*5	.1424	1.53
RWLHHH	.0582	.80
EDINDMEM	−.0088	.33
WALLS	−.0248	.17
ROOF	.2218	2.90
FEHHH	−.0028	.03
AGEHHH	.0064	1.90
*AGEAVE*2	−.0017	.38
EDINDHHH	.0281	1.33
*DU*2	−1.0483	3.84
*DU*3	−.9041	6.11
*DU*5	−.2422	1.57
*DU*6	−.6569	4.32
*DU*7	.1004	.72
*DU*8	−.4472	3.14
*DU*9	−.8095	5.611
*DU*10	−.6747	4.53
*DU*16	−.9470	5.65
Adjusted R^2	.50	

or equal to the observed market wage rates. This is not possible with the limited available information.

Under these conditions, the comparison of productivity estimates, obtained from the production function or the wage equations, is still possible. Although nonseparability does not mean that market wages and marginal labor productivity are necessarily far apart, one expects to obtain exact equality only in specific situations: homogeneity of tasks and individuals considered in both equations, perfect markets, and nonselectivity of the subsample of market workers. The conditions are probably not fulfilled in our case. However, in our results it is interesting to observe the proximity of the estimated impact of the nutrition status on these different measures of labor productivity. De Janvry, Fafchamps, and Sadoulet suggest that when markets are imperfect, because of transaction costs, the shadow rate would be between the observed wage rates for labor demand and labor supply transactions of agricultural households.[59] Since production function estimates are linked to labor demand and wage equations are linked to labor supply, one may expect that the effects of nutrition and health on productivity represented, respectively, in production function and wage equations are the lower and upper bounds of the effects in shadow wages.

Note that weight variability is the most important feature of the nutritional index (since *HT* does not change a lot in the short term for adults). This enables us to compare estimations involving different nutritional indices such as *WFH* and *BMI*. Returning to the estimates of the coefficients of the logarithms of *WFH* and *BMI* in tables 3 and 6, we can assume that the error terms in the production function and in the wage equation are independent and that comparison tests can be performed using the standard error calculated from the *t*-ratios given in the table. We can check at the 5% and 10% levels that, first, the coefficients of the logarithm of *WFH* are not statistically different in the three specifications of the production frontier; second, the coefficients of the logarithm of *BMI* are not statistically different in the wage equations associated with the full sample and the male worker sample; third, these latter coefficients are not statistically different from the coefficient of the logarithm of *WFH* in the wage equation for the male workers sample; and finally, the coefficients on the logarithm of *WFH* of the head in the technology estimates are not statistically different from the coefficients of the logarithm of the various nutritional indices in the different versions of the wage equations. On the whole, the order of magnitude of the elasticity of labor productivity with respect to the nutritional status is approximately two or three, both in the direct estimates of technology and in the wage equations.

The fact that the elasticities are similar for the two sets of estimates does not necessarily imply that markets are working well, because health and nutrition characteristics (but not nutrient intakes) are rewarded the same in wage markets as in own production. First, due to the small sample sizes, the confidence intervals of elasticity parameters are large enough to suggest that a different situation could occur with larger samples. Second, the coincidence of effects of health and nutrition characteristics does not imply the coincidence of effects of other characteristics explaining productivity or the coincidence of levels of labor rewards ($F'_L \neq W$). To this extent, the estimates suggest that the origin of market imperfections is to be found elsewhere rather than in the influence of health and nutrition. It may be that farmers are well aware of the link between health, nutrition, and productivity, and less informed about other characteristics of workers, such as level of effort or qualifications.

In contrast with Foster and Rosenzweig (see n. 11), the moral hazard phenomena may not be associated with the level of health and nutrition characteristics but, rather, with the direct choice of effort level. Indeed, since health and nutrition effects are quite apparent, compared to direct nutrient intakes, it may be that imperfect markets actually incorporate information on worker characteristics.

Given these conditions, it has been possible to both reject separability between income generation and consumption for poor rural households and to observe relatively similar effects of health and nutrition status on labor returns in farm households and for agricultural laborers. These results are consistent with the fact that markets are less developed in rural Ethiopia than in many other areas, and that the health and nutrition variables that we used in the estimation are relatively easy to observe. Such observability is helped by the landlords' preference for long-term relationships with their workers as noted in Eswaran and Kotwal.[60]

IV. Conclusion

In this article we provide empirical support for the link between health and nutritional status and agricultural productivity in Ethiopia. Our results show that the distance to the source of water as well as nutrition and morbidity status affect agricultural productivity. The market wage rate is also very responsive to the weight-for-height as well as the body-mass index and height. It is remarkable that elasticities of labor productivity with respect to nutritional status are strong and similar in technology estimates and wage equations, particularly in a context where separability between consumption and production decisions of the household is rejected. Returns to investment in nutrition are clearly high in the Ethiopian context. The fact that they are close to an upper bound of what has been found in other countries is consistent with the very low living standards of Ethiopian peasants. The results show a large scope for productivity improvement through better nutrition.

The type of distribution chosen for the one-sided term influences the estimates of technical inefficiency. But, in all cases, the results indicate substantial loss in output due to technical inefficiency even after accounting for the health and nutrition of workers.

Appendix A

Description of the Sites (*Wereda* Name Is Given in Parentheses)

Haresaw (*Atsbi*): Ox-plow cereal cultivating area. Vulnerable to famine. Terrain is flat;

Geblen (*Subhasasie*): Ox-plow, mainly cereal cultivating. The site is vulnerable to famine. Situated on an escarpment;

Dinki (*Ankober*): Ox-plow (some irrigation), mainly cereal cultivating. The site is considered vulnerable to famine. The terrain is hilly with gorges, and there is some soil erosion;

Yetmen (*Enemay*): Ox-plow cereal cultivating. Considered rich. Terrain is flat;

Shumsheha (*Bugna*): Ox-plow, cereal cultivating. Vulnerable to famine. Terrain is flat;
Sirbana Godeti (*Adaa*): Ox-plow cereal cultivating. Rich. Terrain is flat;
Adele Keke (*Kersa*): Ox-plow (some irrigation) cereal and *chat* cultivating. Rich. Terrain is flat and hilly;
Korodegaga (*Dodota*): Ox-plow cereal cultivating. Vulnerable to famine. Terrain is flat, and there is some soil erosion;
Turufe Kechema (*Shashemene*): Ox-plow cereal cultivating. Rich. Terrain is flat;
Imdibir (*Cheha*): Hoe cultivating, mainly *enset.* Migration dependent;
Aze Deboa (*Kedida Gamela*): Hoe and ox-plow cultivating, cereal and permanent crop. Migration dependent. Flat and hilly;
Adado (*Bule*): Hoe cultivating, mainly coffee and *enset.* Mountainous terrain;
Garagodo (*Boloso Sore*): Ox-plow, axe, and spade used. *Enset* and coffee cultivating area. Vulnerable to famine. Flat terrain;
Domaa (*Daramalo*): Ox-plow (some irrigation), cereal cultivating. Vulnerable to famine. Terrain is flat;
Fajina Bokafiya, Karafino, Kormargefia, Milki (*Debre Berhan*): Ox-plow cereal cultivating. Usually self-supporting. Terrain is flat.

The following peasant associations (PAs) are used in the production analysis: Geblen, Dinki, Yetmen, Shumsheha, Sirbana Godeti, Adele Keke, Korodegaga, Turufe Kechema, Domaa, and the Debre Berhan PAs. We did not use Haresaw, as the output data were almost entirely missing.

The following PAs are used in the wage equation: Adele Keke, Imdibir, Adado, Garagodo, and Domaa.

Appendix B

Description of the Variables Used (Excluding Those Defined in the Text)

*AGF*1 = Age group female, age <5;
*AGF*2 = Age ≥ 5 and <10;
*AGF*3 = Age ≥ 10 and <18;
*AGF*4 = Age ≥ 18 and <50;
*AGF*5 = Age ≥ 50;
*AGM*1 through *AGM*5 = Age groups for males, as defined above for females;
RWLHHH = Dummy, number 1 if head of household can read and write a letter;
EDINDHHH = Years of schooling for head of household. For religious or traditional schooling we used 1 year;
EDINDMEM = Average years of schooling for members of the household;
DUED = Dummy, number 1 if head of household has completed primary school or higher. In the wage equation this is for the particular individual;
AGEHHH = Age of head of household;
*AGEAVE*2 = Average age of farmers or family farm workers (including domestic workers);
*AGEAVE*10 = Average age of farmers or family farm workers (excluding domestic workers);
FUTIME = Time it takes to collect fuelwood for the household;
WALLS = Dummy, number 1 if walls are made of stone, brick, concrete, or cement;
ROOF = Dummy, number 1 if roof is made of galvanized iron or wood;

FEHHH = Dummy, number 1 if head of household is female;
*QA*2 = Dummy, number 1 if there was enough rain at the beginning of the season;
*QA*3 = Dummy, number 1 if there was enough rain during growing of the crop;
*QA*5 = Dummy, number 1 if it rained near harvest time;
*QA*6*D* = Dummy, number 1 if crop suffered from plant diseases;
*QA*6*E* = Dummy, number 1 if crop suffered from insects;
*QA*6*FG* = Dummy, number 1 if crop suffered damage from trampling by livestock or from birds or other animals;
*QA*6*H* = Dummy, number 1 if crop suffered from weed damage;
*QA*8*A* = Dummy, number 1 if household could not obtain oxen at the right time;
*QA*8*B* = Dummy, number 1 if farmer or household members too ill to work;
LIVESTOCK = Number of livestock owned by household;
*NOADFA*10 = Number of adults in farming;
*NOADFA*2 = Number of adults in farming and domestic work;
DWOFFA = Days worked off the farm by household members;
VALOUT = Total value of output;
FAMILY SIZE = Number of household members.

Notes

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1. Aggregate figures taken from World Bank, *World Development Reports* (New York: Oxford University Press, 1993, 1994, 1995), unless otherwise indicated.

2. Cereals account for about 83% of the area used to cultivate major crops. Central Statistical Authority, *Agricultural Sample Survey: Report on Area and Production for Major Crops,* Statistical Bulletin no. 132 (Addis Ababa: Central Statistical Authority, 1995).

3. Following the defeat of the soviet style Derg government, the Transitional Government of Ethiopia (TGE) took power in 1991. The TGE made the agricultural sector a central plank of its development plan. Elections were held in 1995, but most policies regarding agriculture have not changed. Land, e.g., is still public property, and the sale of land is prohibited.

4. Figures are estimates for the 1994–95 *meher* (main) season for private peasant households taken from the Central Statistical Authority bulletin no. 132.

5. See G. Diriba, *Economy at the Crossroads: Famine and Food Security in Rural Ethiopia* (Addis Ababa: Care International, 1995); and P. Webb and J. Von Braun, *Famine and Food Security in Ethiopia: Lessons for Africa* (Chichester: Wiley, 1994).

6. Central Statistical Authority, *Report on the National Rural Nutrition Survey: Core Module,* Statistical Bulletin no. 113 (Addis Ababa: Central Statistical Authority, 1993). Also see D. L. Pelletier, K. Deneke, Y. Kidane, B. Haile, and F. Negussie, ''The Food-First Bias in Nutrition Policy: Lessons from Ethiopia,'' *Food Policy* 20 (1995): 279–98, who make the point that chronic malnutrition is found even in food surplus regions in Ethiopia and is related not only to food availability.

7. J. R. Behrman, ''The Economic Rationale for Investing in Nutrition in Developing Countries,'' *World Development* 21, no. 11 (1993): 1749–71.

8. H. A. Leibenstein, *Economic Backwardness and Economic Growth* (New York: Wiley, 1957). See also J. E. Stiglitz, ''The Efficiency Wage Hypothesis, Surplus Labor, and the Distribution of Income in LDC's,'' *Oxford Economic Papers* 28, no. 2 (1976): 185–207; J. A. Mirrlees, ''A Pure Theory of Underdeveloped Economies,'' in *Agriculture in Development Theory,* ed. L. Reynolds (New Haven, Conn.: Yale University Press, 1976). A thorough treatment can be found in C. Bliss and N. Stern, ''Productivity, Wages, and Nutrition: The Theory,'' and ''Productivity, Wages, and Nutrition: Some Observations,'' *Journal of Development Economics* 5, no. 4 (1978): 331–98.

9. Bliss and Stern, ''Productivity, Wages, and Nutrition,'' pts. 1 and 2, and *Palanpur: The Economy of an Indian Village* (Oxford: Clarendon, 1982).

10. P. Dasgupta and D. Ray, ''Inequality as a Determinant of Malnutrition and Unemployment: Theory,'' *Economic Journal* 96 (December 1986): 1011–43, and ''Inequality as a Determinant of Malnutrition and Unemployment: Policy,'' *Economic Journal* 97 (March 1987): 177–88.

11. See A. D. Foster and M. R. Rosenzweig, ''A Test for Moral Hazard in the Labor Market: Contractual Arrangement, Effort, and Health,'' *Review of Economics and Statistics* 76, no. 2 (1994): 213–27, and ''Comparative Advantage, Information, and the Allocation of Workers to Tasks: Evidence from an Agricultural Labour Market,'' *Review of Economic Studies* 63 (1996): 347–74.

12. R. Baldwin and B. Weisbrod, ''Disease and Labor Productivity,'' *Economic Development and Cultural Change* 22, no. 3 (1974): 414–35; and B. Weisbrod and T. Helminiak, ''Parasitic Diseases and Agricultural Labor Productivity,'' *Economic Development and Cultural Change* 25, no. 3 (1977): 505–22.

13. L-F. Lee, ''Health and Wage: A Simultaneous Equation Model with Multiple Discrete Indicators,'' *International Economic Review* 23, no. 1 (1982): 199–221.

14. M. M. Pitt and M. R. Rosenzweig, ''Agricultural Prices, Food Consumption, and the Health and Productivity of Farmers,'' in *Agricultural Household Models: Extensions, Applications, and Policy,* ed. I. J. Singh, L. Squire, and J. Strauss (Washington, D.C.: World Bank, 1986).

15. See J. R. Behrman and A. B. Deolalikar, ''Health and Nutrition,'' in *Handbook of Development Economics,* vol. 1, ed. H. Chenery and T. N. Srinivasan (Amsterdam: Elsevier Science, 1988); and D. Thomas and J. Strauss, ''Human Resources: Empirical Modelling of Household and Family Decisions,'' in *Handbook of Development Economics,* vol. 3*a,* ed. J. R. Behrman and T. N. Srinivasan (Amsterdam: Elsevier Science, 1997), for surveys on the role of health and nutrition in economic development.

16. J. Strauss, ''Does Better Nutrition Raise Farm Productivity?'' *Journal of Political Economy* 94, no. 2 (1986): 297–320, uses data on household level food availability (market purchased and home production) to construct daily calorie availability per household. No anthropometric data, i.e., measures of nutritional outcomes, are available in this study.

17. A. B. Deolalikar, ''Nutrition and Labor Productivity in Agriculture: Estimates for Rural South India,'' *Review of Economics and Statistics* 70, no. 3 (1988): 406–13, treated only farm family in efficiency units. Both calorie intake and the *WFH* measure are averages, weighted by the proportion of total on-farm family labor supplied by each family laborer.

18. M. Fafchamps and A. Quisumbing, *Human Capital, Productivity, and Labor Allocation in Rural Pakistan* (Washington, D.C.: International Food Policy Research Institute, 1997).

19. D. E. Sahn and H. Alderman, ''The Effects of Human Capital on

Wages and the Determinants of Labor Supply in a Developing Country,'' *Journal of Development Economics* 29, no. 2 (1988): 157–84; J. R. Behrman and A. B. Deolalikar, ''Agricultural Wages in India: The Role of Health, Nutrition, and Seasonality,'' in *Seasonal Variability in Third World Agriculture: The Consequences for Food Security*, ed. D. E. Sahn (Baltimore: Johns Hopkins University Press, 1989); L. J. Haddad and H. E. Bouis, ''The Impact of Nutritional Status on Agricultural Productivity: Wage Evidence from the Philippines,'' *Oxford Bulletin of Economics and Statistics* 53, no. 1 (1991): 45–68; A. D. Foster and M. R. Rosenzweig, ''Information, Learning, and Wage Rates in Low-Income Rural Areas,'' *Journal of Human Resources* 28, no. 4 (1993): 759–90, and ''A Test'' (n. 11 above); H. Alderman, J. R. Behrman, D. R. Ross, and R. Sabot, ''The Returns to Endogenous Human Capital in Pakistan's Rural Wage Labour Market,'' *Oxford Bulletin of Economics and Statistics* 58, no. 1 (1996): 29–55.

20. D. Thomas and J. Strauss, ''Health and Wages: Evidence on Men and Women in Urban Brazil,'' *Journal of Econometrics* 77, no. 1 (1997): 159–85.

21. A. Bhargava, ''Nutritional Status and the Allocation of Time in Rwandese Households,'' *Journal of Econometrics* 77, no. 1 (1997): 277–95.

22. Calories or other nutrient intakes are indeed linear transformations of consumption quantities that are themselves very much related to agricultural production because of high own-consumption rates.

23. Data about consumption, crops, anthropometric measures, health indicators, and socioeconomic characteristics were collected by the Department of Economics, Addis Ababa University, in collaboration with the International Food Policy Research Institute (IFPRI) and the Center for the Study of African Economies, Oxford University. Funding was provided by the Swedish International Development Agency (SIDA). Although this survey is not statistically representative of the whole country, which explains differences in averages of the main variables with national aggregates, it covers a broad set of agricultural contexts throughout the country.

24. Seven of the sites that had been covered previously by the IFPRI in 1989 are located in drought-prone areas. In 1993, the Department of Economics, Addis Ababa University, identified broad regions and then selected eight additional peasant associations (with the aim of providing a more balanced picture of the Ethiopian farming system) with the help of experts from the Ministry of Agriculture. For more details, see Department of Economics, ''Ethiopian Rural Household Survey: Preliminary Report on the First Round'' (Addis Ababa University, 1995, mimeographed).

25. Only households cultivating at least 0.2 hectares are included. The main cereals are *teff*, wheat, barley, maize, sorghum, and millet. The analysis covers sites in which ox-plow cultivation is practiced so as to focus on a specific technology. Every household plows its fields with the help of oxen, either owned by the household or borrowed through some arrangement. Since all households in selected sites share the same technology, there is no selection bias due to endogenous choice of techniques.

26. There are 1,477 households in the total sample. In the sites where ox-plow cultivation of cereals is practiced, there are 1,113 households, of which 935 have a positive output. After deleting the missing values (mostly for anthropometric measures), and selecting family size >0 and land >0.2, we are left with 498 households. The remaining missing households were lost after dropping outliers and erroneous values of other variables.

27. A recent report by Kuawab Business Consultants and Development Studies Associates (DSA), *Fertilizer Marketing Survey: Descriptive Analysis of the Findings* (Addis Ababa: Kuawab Business Consultants and DSA, 1995), sponsored by USAID, reported fertilizer application rates of 51 kilograms per

hectare in 1994, up from 38 and 35 kilograms per hectare in 1993 and 1992, respectively. These figures are based on a nationally representative sample.

28. The Ministry of Agriculture recommends the use of 100 kilograms per hectare of chemical fertilizer and 100 kilograms per hectare of urea, regardless of crop type or location. The vast majority of farmers, however, use only the former.

29. Not all nonagricultural activity will be caught by days worked off the farm. In particular, households may receive income from the sale of livestock or products derived from animals. Furthermore, female members of the household at times engage in producing tradeable goods (drinks, etc.) which supplement household income.

30. Because of too many missing values for household members, *WFH* for workers is not available.

31. Other self-reporting variables include whether or not the person can (*a*) stand up after sitting, (*b*) sweep the floor, (*c*) walk for 5 km, and (*d*) hoe a field for a morning. However, the histograms of all these variables are too concentrated to contain enough information for the estimation.

32. D. J. Aigner, C. A. K. Lovell, and P. Schmidt, ''Formulation and Estimation of Stochastic Frontier Production Function Models,'' *Journal of Econometrics* 6, no. 1 (1977): 21–37; W. Meeusen and J. Van den Broeck, ''Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error,'' *International Economic Review* 18, no. 2 (1977): 435–44.

33. J. Richmond, ''Estimating the Efficiency of Production,'' *International Economic Review* 15, no. 2 (1974): 515–21.

34. J. Jondrow, C. A. K. Lovell, I. S. Materov, and P. Schmidt, ''On the Estimation of Technical Efficiency in the Standard Frontier Production Function Model,'' *Journal of Econometrics* 19, no. 1 (1982): 233–38.

35. R. E. Lopez, ''Estimating Labour Supply and Production Decisions of Self-employed Farm Producers,'' *European Economic Review* 24, no. 1 (1984): 61–82.

36. D. Benjamin, ''Household Composition, Labor Markets, and Labor Demand: Testing for Separation in Agricultural Household Models,'' *Econometrica* 60, no. 2 (1992): 287–322, uses Indonesian farm level data that do not reject separability, while Fafchamps and Quisumbing use rural household data from Pakistan and reject separability. Pitt and Rosenzweig (n. 14 above) argue that if labor can be hired as a substitute for family labor, then farm profits should be unaffected by farmer illness. They accept separability for their sample. J. R. Behrman, A. D. Foster, and M. R. Rosenzweig, ''The Dynamics of Agricultural Production and the Calorie-Income Relationship: Evidence from Pakistan,'' *Journal of Econometrics* 77, no. 1 (1997): 187–207, find that planting-stage calorie consumption affects harvest time profit, which suggests that labor markets are not working efficiently at the harvest stage and, hence, that there is nonseparability. Finally, D. Shapiro, ''Farm Size, Household Size and Composition, and Women's Contribution to Agricultural Production: Evidence from Zaire,'' *Journal of Development Studies* 27, no. 1 (1990): 1–21, reports that household composition affects cultivated farm area for a sample of households from Zaire.

37. Another potentially interesting human resource characteristic of these households is the education level of its members. However, information collected about education is crude in the first round of this survey. Preliminary regression results showed that the introduction of education variables led to quasi-collinearity problems, as a result of the small sample size. We omit this variable from the final specification.

38. Oxen used for plowing or a measure of the value of oxen owned by the household were not included in the final analysis, as they were never signifi-

cant. Since many households do not have oxen but do have access to oxen through a variety of arrangements, the number of oxen owned is not a meaningful measure of animal power.

39. In the case of a fixed sharing rule (the collective household model proposed by P. A. Chiappori, ''Collective Labor Supply and Welfare,'' *Journal of Political Economy* 100, no. 3 [1992]: 437–67) and the absence of specific individual shocks, the nutrient intake of the household characterizes the average household nutritional status.

40. The results for the instrumental equations are not reproduced here but are available from us on request.

41. S. Yao, ''The Determinants of Cereal Crop Productivity of the Peasant Farm Sector in Ethiopia, 1981–1987,'' *Journal of International Development* 8, no. 1 (1996): 69–82.

42. The *BMI* is significant for adult males in the *Rabi* season.

43. S. Weir and J. Knight, ''Some Evidence on the Contribution of Education to Agriculture in Rural Ethiopia'' (Centre for the Study of African Economies, 1998, mimeographed). We report the more conservative estimate.

44. There were one and two extreme outliers for the COLS and the EXP models, respectively. This resulted in a TE estimate of greater than one in each case. Our procedure was to set these values to one.

45. S. B. Caudill, J. M. Ford, and D. M. Gropper, ''Frontier Estimation and Firm Specific Inefficiency Measures in the Presence of Heteroscedasticity,'' *Journal of Business and Economic Statistics* 13, no. 1 (1995): 105–11; S. B. Caudill and J. M. Ford, ''Biases in Frontier Estimation Due to Heteroscedasticity,'' *Economics Letters* 41, no. 1 (1993): 17–20.

46. C. Gouriéroux, A. Monfort, E. Renault, and A. Trognon, ''Simulated Residuals,'' *Journal of Econometrics* 34, nos. 1–2 (1987): 201–52.

47. These estimates are not shown but can be obtained on request from us.

48. For example, if the translog is the true specification, error terms of the Cobb-Douglas specification implicitly include input variables whose values are specific to each household.

49. The final sample is concentrated in southern sites that, with the exception of Adele Keke and Domaa, were not used in the production functions. They are mainly *enset*, *chat*, and coffee-growing areas. The actual sites in the participation and wage equation were (peasant association name): Adele Keke, Imdibir, Adado, Garagodo, and Domaa. There are few observations for wage earners (in farming activities), and none of these observations was dropped. We constructed earnings by number of days worked (and not by piece). We do not know if the person worked for the same farmer or worked for different people for a number of days. Only overall days worked are recorded.

50. We first estimate a participation equation for off-farm agricultural labor, to assess the selectivity of the sample. The participation equations are not reported here, but are available from us. Independent variables include site dummies as well as *AGE*, *AGESQ*, *DUED*, *FAMILY SIZE*, and *TOTLAND* (total area cultivated).

51. See R. J. Willis, ''Wage Determinants: A Survey and Reinterpretation of Human Capital Earnings Functions,'' in *Handbook of Labour Economics*, ed. O. Ashenfelter and R. Layard (Amsterdam: Elsevier Science, 1986).

52. The latter variables account for the higher productivity of workers with good nutritional status but also for how employers pay attention to health in the wage fixation. There is no way to disentangle these two components here.

53. The predictive equations for *WFH* and the *BMI* are available from us on request.

54. We use *WFH* to denote weight-for-height rather than *N*, as in the fron-

tier production function equation, to emphasize that the two measures are different. In the former it is the particular individual's *WFH*, while in the latter it is the head of the household.

55. Including both *WFH* and height together is not possible, due to the high degree of collinearity.

56. Lee (n. 13 above); Thomas and Strauss, ''Health and Wages'' (n. 20 above); Deolalikar, ''Nutrition and Labor Productivity'' (n. 17 above); Behrman and Deolalikar, ''Agricultural Wages in India'' (n. 19 above).

57. Haddad and Bouis (n. 19 above); Thomas and Strauss, ''Health and Wages.''

58. I. J. Singh, L. Squire, and J. Strauss, eds., *Agricultural Household Models: Extensions, Applications, and Policy* (Washington, D.C.: World Bank, 1986).

59. A. de Janvry, M. Falchamps, and E. Sadoulet, ''Peasant Household Behaviour with Markets: Some Paradoxes Explained,'' *Economic Journal* 101 (1991): 1400–17.

60. M. Eswaran and A. Kotwal, ''A Theory of Two-Tier Labor Markets in Agrarian economics,'' *American Economic Review* 73, no. 1 (March 1985): 162–77.