Can human capital variables be technology changing?

An empirical test for rural households in Burkina Faso

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Introduction

The role of human capital as an engine of agricultural growth has been given due attention in the literature. Schultz (1961) was among the first to attribute increases in output beyond increases in land, man-hours and physical reproducible capital to investment in human capital comprising education, health and even migration. Since then, researchers have tended to include human capital variables as explicit factors of production. However, when human capital variables are treated as traditional inputs, technical efficiency becomes somewhat of a tautology i.e. production is technically efficient if producers do not knowingly waste resources (Welch, 1970). Instead, if farmers better endowed with human capital are more adept at critically evaluating new and reportedly improved input varieties, if they can distinguish more quickly between the systematic and random elements of productivity responses, then we should pose ourselves the question whether these farmers may choose a different production technology i.e. whether human capital variables can be technology-changing (Mundlak, 1986; Fulginiti and Perrin, 1993). If this is the case, conventional analyses are likely to underestimate the impact of human capital on smallholder productivity. If we can demonstrate a larger role for human capital in agricultural production of households, this could convince governments in developing countries that there is no trade-off between allocating resources to promote long-term economic growth and raise smallholder productivity on the one hand and social services on the other but that, rather, productivity can be stimulated through the allocation of expenditure to social services that enhance certain types of human capital.

In this article, we assess the role that human capital indicators play as technology changing variables affecting productivity and production elasticities of traditional inputs in smallholder households in Burkina Faso. Burkina Faso is a poor, landlocked country situated in the West-African Semi-Arid Tropics (WASAT). The country has experienced GDP growth of an average six percent between 2000 and 2006 with the agricultural sector, which forms the main source of subsistence for the majority of the population, as an important engine of this growth. However, growth in agriculture has mainly been due to land expansion with only limited improvements in agricultural productivity. This means that despite good levels of growth, the proportion of poor has increased with poverty remaining largely a rural phenomenon. The country is said to continue to suffer from a low level of human capital development which limits labor productivity, particularly in the agricultural sector.

We use recent nationally representative household level data and regression analysis to empirically assess the role of three human capital measures - weight-for-height, formal education and age of adult household members active in agriculture – in smallholder production. Weight-for-height defined as weight in kilograms divided by height in centimeters is a longer term measure of nutritional intake and captures endurance, strength and health status of an individual. Taking into account the endogeneity of this measure as well as of formal education and variable inputs such as fertilizer with agricultural output, we use instrumental variable regression to initially estimate a Cobb-Douglas production function augmented with our human capital indicators. We subsequently relax the assumption that households employ the same technology by modeling the coefficients in the production function as functions of human capital variables. We calculate productivity and production elasticities on the basis of these estimates, which we subsequently break down by landholding quintile.

Our results reveal that human capital indicators can indeed be considered as technology-changing affecting both the slope and the intercept of the production function. Weight-for-height enhances returns to land but negatively affects returns to female labor. Formal education enhances the productivity of male labor but negatively affects returns to land. Differentiating households by landholding quintiles, however, reveals that the technology changing role of human capital variables is much more evident for households with larger landholdings.

The article is structured as follows. In Section 2, we discuss the role of various human capital indicators in agricultural production. The data and study area are described in Section 3. Section 4 presents the analytical model used to estimate the relation between human capital indicators and agricultural production while Section 5 discusses the estimation strategy. Estimation results are presented in Section 6. We conclude in Section 7 by discussing some of the implications of our findings for understanding the role of human capital in agricultural production.

Agriculture and human capital

Human capital refers to any aspect of a person that produces economic value and from which one cannot be separated the way one can be from physical or financial assets (Becker, 1975). Human capital thus includes personal attributes such as health, nutrition status, knowledge and skills.

The role of nutrition and health in agricultural production in developing countries has received due attention in the literature. Studies tend to consider nutrition and health indicators, such as calorie intake, anthropometric measures or other indicators of physical strength, as endogenous with agricultural output and instrumental variable methods have been used to obtain consistent estimates of coefficients of human capital indicators in the agricultural production process. For example, using data on local relative prices, household demographic characteristics, and farm assets to predict household energy intake per capita, Strauss (1986) found that household energy consumption was a positive, significant determinant of farm output in Sierra Leone. Sahn and Alderman (1988) used a similar approach with data from Sri Lanka. Here again, predicted household energy consumption per capita was used as a measure of nutritional status and related to wage earnings. Interestingly, household energy per capita was a significant, positive determinant of men's but not of women's wages. This differential result between men's and women's productivity is a finding that emerges in a number of the studies linking nutrition to productivity. Haddad and Bouis (1991) instrumented for individual energy consumption and body mass index using household size, nonfarm income, and distance to the nearest market and found a lack of impact of short and medium run proxies of nutritional status on agricultural wage determination. However, they qualified this finding by noting that variation in wages across individuals is a crude measure of differences in productivity. Croppenstedt and Muller (2000) instrumented for weight-for-height of the household head as well as a measure of strength and endurance and find that the former plays an important role in explaining agricultural production of farmers in Ethiopia.[1] Exploiting the panel nature of his data for India to eliminate the potential bias in regression coefficient estimates due to time-invariant, individual-specific effects, Deolalikar (1988) finds that average household weight-for-height has a very strong positive effect on farm output, while average energy intake does not and concludes that while the human body can adapt to inadequate nutrition in the short run, it cannot adapt as readily to chronic malnutrition that eventually results in loss of weight-for-height.

Knowledge and skills are often captured by measures of educational attainment and the assumption of positive economic returns from schooling is a basic tenet of development economics and a justification for rural education programs (Taylor and Yunez-Naude 2000). Education is thought to enhance productivity directly by improving the quality of labour, by increasing the ability of farmers to adjust to disequilibria, and through its effect upon input utilization (Moock 1981). When considering the role of schooling in agriculture, a useful distinction is between cognitive and non-cognitive effects of schooling. Within the former, one can differentiate between the formation of general skills, such as literacy and numeracy, and the transmission of specific knowledge. Literacy could enable a farmer to follow written instructions for chemical inputs and other aspects of modern farm technology. Numeracy would allow a farmer to calculate accurate dosages and may facilitate the making of other planning decisions (Appleton and Balihuta 1996). These cognitive effects of education may increase the output produced by a given combination of inputs. One may distinguish so called “worker” from “farm-manager” effects although in reality this distinction is rather blurred (Appelton and Balihuta 1996). Cognitive effects of education could also improve allocative efficiency and there is a substantial literature documenting the greater propensity of educated farmers to adopt agricultural innovations. Education may also have non-cognitive effects changing people’s attitudes and preferences, which have not been extensively documented in an agricultural context.

Although when returns to schooling in African agriculture are considered they are often assumed to exist, estimates of the returns from schooling in rural economies range widely from highly positive to negative (Taylor and Yunez-Naude 2000) and existing evidence on the impact of education on agricultural productivity in Africa is mixed (Appleton and Balihuta 1996). One reason for this may be that attendance to formal education is low particularly for older household members making it difficult to collect sufficient observations to decipher any meaningful relationship between education and agricultural production. The second reason may be that formal education leads household members to become disengaged with agriculture through migration or increased non-farm activities. Farm households may reap rewards from schooling by abandoning one activity in which returns from schooling may be limited in favor of a new activity in which the returns from schooling are high. Alternatively, they may continue producing traditional crops while diversifying into new activities in which the returns from schooling are high, provided that incentives for diversification (risk, scale effects) exist (Taylor and Yunez-Naude 2000). For example, a strong positive relationship has been uncovered in rural Burkina Faso between formal education of adult males and intercontinental migration (Wouterse 2012). In fact, it has been suggested that in certain, more static, environments experience may be a better investment than schooling as it does not depreciate when the environment is unchanging (Huffman 1999). In addition to knowledge acquired through formal education, skills as a source of human capital are likely to be developed through experience. Age is often used as a proxy for such farming experience (Yang and An 2002).

The literature has tended to assess the role of human capital in agriculture at the farm household level by estimating an augmented stochastic frontier with selected human capital indicators as additional inputs often followed by a further investigation of the robustness of the human capital-productivity links by resorting to the efficiency wage literature. However, it has been argued that researchers have been looking for returns to human capital in the wrong places; it is possible that researchers underestimate these returns by not taking into account the technological changes and sectoral diversification characterizing agricultural transformations in less developed countries (Taylor and Yunez-Naude 2000). Schultz (1981) argues, for example, that changes in the technological environment raise the value of farmers' entrepreneurial ability – their "ability to perceive, interpret and respond to new events in the context of risk" - associated with the arrival of new technologies. However, he does not consider that technological change could be endogenous i.e. it is not that new technologies are exogenously introduced but that farm households themselves are agents of such change.

It has been suggested that there are certain so-called state variables that not only affect the location of a farm on a given production function but also determine the choice of the implemented technique (Mundlak, Cavallo and Domenech 1989). If the choice of technology is in fact endogenous, then a constant coefficient production function would fail to explain all sources of variation in productivity. Following Mundlak, Cavallo and Domenech (1989), we can posit a production function for which coefficients are variable and determined by human capital indicators. In such a formulation, human capital is allowed to affect productivity through its interactions with traditonal input variables, land, labor, variable inputs and equipment. Although, the endogenous technology approach to productivity has been applied in several instances (see for example Fulginiti and Perrin (1993), Hoque (1991) and Croppenstedt and Demeke, (1997)), to our knowledge human capital variables specific to a household have not yet been used to explain why a farm household may end up employing a different production technology.

Setting

Data to analyze the role of human capital in agricultural production come from the second round of Burkina Faso's Programme National de Gestion des Terroirs (PNGT) conducted in 2005.[2] The PNGT survey collected information on the living conditions of 2,000 randomly selected rural households, drawn from 60 villages and all 45 provinces of the country. The survey instrument is a questionnaire of 33 pages and contains sections on human capital indicators (education, health and anthropometrics of all household members), agricultural activities and other sources of income, and expenditure on food and non-food items, administered to all individuals making up a household. The survey also contains a section on community level services and infrastructure administered to local leaders. Data were collected in 16 teams containing 60 enumerators under the central supervision of the University of Ouagadougou. Villages were drawn according to a probabilistic process using the village population size as weights. Random sampling and coverage of all provinces means that the sample is representative at the national level.

In general, agricultural production in Burkina Faso takes place in farm households. These households are often not nuclear and, in a polygamous setting, comprise the household head and his wives as well as their grown sons along with their wives and children.[3] Each household simultaneously cultivates multiple plots and many different crops. An important characteristic of this farming system is that decision-making authority and nominal control over output on different plots within the household are held by different individuals. The household head makes decisions regarding the "communal" plots of the household, the output from which – usually millet (*Pennisetum glaucum*) or sorghum (*Sorghum bicolor*) - is used for the basic consumption needs of the household as a whole (Udry, 1996). In addition, household members (including the household head) cultivate individual plots with female members more heavily involved in the cultivation of groundnuts and vegetables. Household members have access to land, generally speaking, through the (male) household head.

According to the PNGT survey, land is generally cultivated on a hereditary basis and most households do not hold a title for their land. In Burkina Faso, commercial land market transactions were found to be extremely rare (Ouedraogo, Savadogo, Stamm and Thiombiano 1996). While theory predicts that better property rights on land can increase investment through increased security, enhanced trade opportunities, and increased collateral value of land, the presence and size of these effects depend crucially on whether those rights are properly enforced. The lack of commercial land market transactions implies that land cannot function as collateral for credit.

In the surveyed households, cereals - sorghum and millet -account for the overwhelming share of the total value of cropping output while groundnut (*Arachis hypogaea* L.) cultivation represents 15 percent of the total value of output. Other crops such as maize, rice and cotton are much less prominent and each account for less than five percent of the value of output. Cropping in rural Burkina Faso is generally rain-fed and characterized by a single short cropping season per year. Millet and sorghum are mainly cultivated under traditional crop management practices in which farmers use little external inputs, such as purchased seed and inorganic fertilizer. Traditional crop management practices mean that labor, in particular, is strongly related to output (Fafchamps 1993). The PNGT survey did not collect data on actual labor input in days. We therefore use the number of males and females that are more or less full-time active on the farm as a proxy for household labor supply.

The data reveal that hired labor was hardly used in agricultural production. A missing market for labor is characteristic of rural areas lacking a large landless class and with homogeneous factor endowments (De Janvry, Fafchamps and Sadoulet 1991; Fafchamps, 1993). It has been observed for eastern Burkina Faso that there exists a cultural barrier to offering one's own labor for a wage because it is thought to be a sign of inability to sustain production in one's own fields (Mazzucato and Niemeijer 2000). For the Central Plateau, hiring workers in agriculture has been shown to be rare, representing approximately 1% of total labor use (measured in worker days) (Wouterse and Taylor 2008). In general, exchange labor in the form of work parties tends to be more common, but is limited to a few crops with particular patterns of seasonality (Wouterse and Taylor 2008; Fafchamps 1993). The high migration that characterizes parts of Burkina Faso is also indicative of the lack of local wage labor options that are available, forcing household members to migrate in search of jobs (Wouterse 2012).

In addition to input use, farming practices are largely determined by equipment use. Animal traction, in particular, should be considered as a labor-saving technology device during the preparation and planting stage (Pingali, Bigot and Binswanger 1989). The PNGT data reveal that only about 50 percent of the rural households surveyed had access to animal traction.

Model

Let the agricultural production function of a farm household be given by (1).

$$y = A \prod_{i=1}^{n} x_i^{\beta_i} \tag{1}$$

Equation (1) specifies a Cobb-Douglas production technology according to which a farm household transforms a given vector of inputs x_i – land, labor, fertilizer and equipment into output y. Given the multitude of crops that are cultivated, the output variable is measured as the aggregate of the quantity harvested of each crop multiplied by village level crop specific prices. Land is measured at the household level by aggregating individual plot sizes. As mentioned, there appears to be a missing market for land with rights largely assigned on a hereditary basis along patrilineal lines. Land size can thus not be adjusted in the short run and may be considered as exogenous to the production process. Labor input, is measured as the household's endowment of adult members that have indicated to be active in own-farm agriculture more or less full-time. As the endowment of household labor cannot be adjusted in the short run, this input variable can be taken as exogenous to production. Variable inputs constitute spending on seed, fertilizer, pesticides and herbicides. As variable inputs may be adjusted in the short run, they are likely to be endogenous with production. Equipment comprises the current value of all agricultural equipment - mainly plough, cart, hoe and sprayer – applying an annual depreciation rate of 10 percent.

Following Fulginiti and Perrin (1993), we specify the intercept and the slope of this production function as:

$$\log A = \alpha_0 + \sum_{k=1}^{m} \alpha_k \tau_k + \mu_0 \qquad k = 1, \dots \dots m \tag{1a}$$

$$\beta_i = \gamma_{i0} + \sum_{k=1}^{m} \gamma_{ik} \tau_k + \mu_i \qquad i = 1, \dots \dots n \tag{1b}$$

In (1a) and (1b), τ_k is a vector of technology changing variables , $\alpha's$ and $\gamma's$ are fixed coefficients, μ_0 is a random variable distributed independently of the $x_i's$ and $\tau_k's$, and the $\mu_i's$ are random variables independent of the τ_k with mean zero and a finite positive semi-definite covariance matrix. The $\beta_i's$ here represent elasticities of output with respect to each of the input variables that are variable at the household level. The technology changing variables determine the production elasticities and are taken by households as parameters for the current production period.

Technology changing variables have been related to the quality of human resources (Fulginiti and Perrin 1993; Mundlak, Cavallo and Domenech 1989). In our model, we include three human capital indicators as technology changing variables: weight-for-height, formal education and the average age of adult workers in agriculture. The inclusion of weight-for-height of adult workers in the production function as a technology changing variable controls for past calorie intake and for body size in the relation between current calorie intake and productivity; its coefficient may be interpreted variously as the returns to endurance, strength, or health status (Deolalikar 1988). As weight-for-height also measures current calorie intake, this variable may be endogenous to the agricultural production process. Taking the possible spillover effects of education into account, we use the level of education received by the highest educated worker in the household. Although the education of adults has been completed sometime in the past, this measure could still be endogenous to agricultural production. To be sure, we instrument for this variable using the number of years that the mother of the head of household attended school as well as the distance to the nearest potable water source.

Expressing equation (2) in logs, we obtain the convenient econometric model:

$$\log y = \alpha_0 + \sum_{k=1}^{m} \alpha_k \tau_k + \sum_{i=1}^{n} \gamma_{i0} log x_i + \sum_{i=1}^{n} \sum_{k=1}^{m} \gamma_{ik} \tau_k log x_i + \sum_{i=1}^{n} \mu_i log x_i + \mu_0 \qquad (2)$$

This model allows us to evaluate directly the impact of several aspects of human capital - nutrition and health, formal education and experience proxied by age - on the technology employed by a household. The elasticity of productivity of the technology changing variables for this function is evaluated as:

$$\psi_k = \tau_k \left(\sum_{i=1}^{n} \gamma_{ik} log x_i + \alpha_k\right) \qquad (2a)$$

If technology changing variables are expressed as the log of some variable say, z_k, then the elasticity of productivity with respect to z_k is simply:

$$\psi_k = \sum_{i=1}^{n} \gamma_{ik} log x_i + \alpha_k \qquad (2b)$$

The effect of weight-for-height, education and age of adult farm workers on current productivity is thus summarized by these production elasticities. To the extent that policies affected the nutrition and health status and education level of adult workers, the productivity effect of those policies can be measured using ψ_k. The production elasticities as specified in equation (1b) depend on the level of the variables that condition the household's choice, so they differ by observation. The quality of the available resources, the set of techniques available for production will combine to determine the productivity of each input.

The descriptive statistics of the variables used to estimate the variable coefficient production function specified in equation (2) are given in Table 1.

Estimation strategy

Before turning to the actual results of the estimation of the variable coefficient production function specified in equation (2), a few estimation issues merit further discussion.

Identification

There are several difficulties with discerning causal links between health and nutrition indicators such as weight-for-height and agricultural productivity in a regression framework. First, weight-for-height is likely to be endogenous to the agricultural production process due to simultaneous effects. Though it may be intuitively appealing to believe that better-nourished individuals are more efficient, the direction of causality between nutrition and productivity is difficult to establish (Schultz, 2003). Improved weight-for-height could lead to increased productivity, but it is equally plausible that increased productivity leads to higher incomes, thereby improving an individual's nutritional status (Garcia and Kennedy 1994). Second, endogeneity could manifest itself if there are exogenous unobserved differences across individuals in their original endowments, and if these endowments influence how parents and children invest in human capital, in either a compensatory or a complementary manner (Schultz 2003). Examples of this phenomenon could be frailty – or physical weakness - affecting the demand for health inputs (Rosenzweig and Schultz 1983). These forms of innate, unobserved heterogeneity could cause a correlation between weight-for-height and the error in determinants of agricultural productivity. Third, there may be lags during which the formation of human capital occurs before a farm household member becomes more productive (Schultz 1999). Formal education could also be endogenous with agricultural output due to simultaneous effects although this source of bias is likely to be much smaller compared to weight-for-height as educational attainment of adults has most likely taken place sometime in the past. Ability bias could also arise due to exogenous unobserved differences across individuals in their original endowments which influence investment in formal education (Willis and Rosen, 1979). In addition to the possible endogeneity of two of our human capital indicators, spending on variable inputs such as fertilizer is likely to be endogenous to the agricultural production process.

To obtain consistent estimates in the presence of endogeneity, one may use instrumental variable methods in which the instruments are sufficiently correlated with the endogenous variables but strictly not correlated with agricultural output. We instrument for weight-for-height of adult workers using a dummy variable indicating whether the father of the head has passed away; the village price of mosquito repellent and the village price of chloroquine - a drug commonly used to prevent and treat malaria. We instrument for formal education of workers using the educational attainment of the mother and the father of the head of household. Finally, we instrument for spending on variable inputs using distance from the village to a main road and the presence of a producer organization in the village.

As mentioned, an instrumental variable must satisfy two requirements: it must be correlated with the included endogenous variable and orthogonal to the error process (Baum, Schaffer and Stillman 2003). We test the former condition – relevance - by examining the fit of the first stage regressions. The relevant test statistics here relate to the explanatory power of the excluded instruments in these regressions. We report the R-squared of the first stage regression with the included instruments partialled-out. This may also be expressed as the F-test of the joint significance of the excluded instruments in the first stage regression. Following Baum, Schaffer and Stillman (2007) we report the Kleibergen-Paap wald F-statistic and the Stock-Yogo critical values to further test for weak instruments. For models with a single endogenous variable, these indicators are considered to be sufficiently informative. While existing only for i.i.d error models these statistics may still be indicative of weak instrument issues in non-i.i.d cases (Baum, Schaffer and Stillman 2007).

For the latter condition – validity – to hold excluded instruments need to be orthogonal to the error in the second stage regression. If we have more excluded instruments than included endogenous regressors, we can test whether our instruments are uncorrelated with the error process. For this test, the residuals from a 2SLS regression are regressed on all exogenous variables: both included exogenous regressors and excluded instruments. Under the null hypothesis that all instruments are uncorrelated with the error, an LM statistic of the $N \cdot R^2$ form has a large sample $\chi^2(r)$ distribution where r is the number of overidentifying restrictions or excess instruments. Rejection of the null hypothesis, would cast doubt on our instrument set. We report the Hansen J-statistic and the associated p-value, which is the GMM equivalent of the Sargan test described above and robust to possible heteroskedasticity.

Turning to an instrumental variable estimation for the sake of consistency must be balanced against the inevitable loss of efficiency (Wooldridge, 2003). This loss of efficiency can only be justified if the OLS estimator is biased and inconsistent. We report the p-value of the Durbin version of the Durbin-Wu-Hausman test for endogeneity, which involves estimating our regressions via both OLS and IV approaches and comparing the resulting coefficient vectors. Test results are best interpreted not as a test for the endogeneity or exogeneity of regressors per se, but rather as a test of the consequence of employing different estimation methods on the same equation (Baum, Schaffer and Stillman 2003).

When using predicted variables as regressors in second stage regressions, the reported standard errors are not valid because they do not take into consideration that the endogenous regressors have been estimated in the first stage (Wooldridge, 2003; Baltagi, 2002). We apply the method suggested by Murphy and Topel (2002) to calculate asymptotically correct standard errors (Baum 2006).

Selection of functional form

The Cobb-Douglas (1928) production function assumes that the elasticity of substitution between factors of production is unity while returns to scale can be constant, increasing or decreasing. One important reason for its popularity is that, after logarithmic transformation, the function is linear in parameters and can thus be estimated by simple linear regression techniques. An important drawback of the Cobb-Douglas production function or any other parametric specification of a production function is sensitivity of results to the functional form chosen. In the case of misspecification of the functional form, calculations of measures such as marginal products, partial production elasticities, and elasticities of scale, as well as various statistical tests become incorrect. The nonparametric approach to estimating production functions largely builds on the work by Varian and Afriat and has as its advantage that is does not impose any a priori restrictions on the underlying technology avoiding the risk of incorrect technical efficiency estimates in the case of misspecification (Varian, 1984; Afriat, 1972). One major drawback of nonparametric methods is the curse of dimensionality especially in multivariate regressions, which can prevent one from finding a smooth in high dimensions because of the sparsity of the underlying space (Stone, 1980). Often, when investigating efficiency in farm households, deterministic non-parametric methods such as data envelopment analysis tend therefore to be preferred (see for example Chavas, Petrie and Roth 2005; Wouterse, 2010).

As the aim of this paper is precisely to test for more flexibility in a particular functional form, we opt for the parametric approach with as an added advantage that results are comparable to certain other studies that incorporate human capital indicators in agricultural production (such as Croppenstedt and Muller 2000). To ensure that the Cobb-Douglas specification is consistent with the true relationship between the inputs and the output in our data set, we apply the test described in Hsiao, Li and Racine (2007), which is a nonparametric kernel-based model specification test that can be used when the regression model contains both discrete and continuous regressors, to equation (2). The test described in Hsiao, Li and Racine (2007) builds on the assumption that if the parametric model is right, its residuals should be patternless and independent of input features and applies non-parametric smoothing to the parametric residuals to see if their expectation is approximately zero everywhere. We employ discrete variable kernel functions and smooth both the discrete and continuous regressors using least squares cross-validation (CV) methods.[4] However, as this test loses power as the sample gets large (Hsiao, Li and Racine 2007; Shalizi 2012), we only run this test on a randomly selected subsample of 350 observations or 20 percent of the sample. To further test for the appropriateness of the parametric functional form for the entire sample, we also use a somewhat simpler approach, which compares residuals of a parametric model to those obtained from a semiparametric additive regression model (Shalizi 2012). This test is built on the assumption that if the parametric model is right, it should predict as well as, or even better than, a generalized additive model. The generalized additive model uses a backfitting algorithm and we apply smoothing splines to continuous regressors while treating our regional dummies as random effects (Ma and Racine 2012).

Variable and fixed coefficient regressions

In production economics, the use of regression models with fixed coefficients is relatively common. The implication of this approach is that independent variables do not significantly differ in their behavior from one observation to another. This is restrictive as, in reality, production possibilities are expected to differ in a cross-section of firms, and a set of different technologies may simultaneously coexist at any given time. If that is the case, efficiency measurement, for example, cannot proceed under the assumption of common technology (Tsionas 2002). The stochastic frontier is thus not useful if the slope coefficients vary. This may happen if for the same levels of inputs different levels of outputs are obtained by following different methods of input applications (Croppenstedt and Demeke 1997). It is thus necessary to apply parameter variation across decision units. There have been a number of theoretical studies on varying parameter models (Hildreth and Houck, 1968; Swamy and Tavlas, 1995). Empirical applications of these random coefficients models in stochastic frontiers exist though are very limited; see for example Kalirajan and Obwono (1994). Somewhat in parallel, Mundlak (1986) showed that the production function can be approximated by a function that has a Cobb-Douglas form but where the intercept and the slope are functions of so-called state variables. Fulginiti and Perrin (1993) use this approach to link prices to agricultural productivity. We continue along these lines and test such a model of production within which the technology embodied is to some extent endogenous. We posit a production function for which the coefficients are variable and determined at any one place and time by a household's endowment of human capital.

Estimation results

To test for the significance of the role of human capital variables in the agricultural production process, we initially estimate an augmented Cobb-Douglas production function. OLS estimation results are given in Table 2.

[TABLE 2 HERE]

As mentioned, spending on agricultural inputs as well as formal schooling and weight-for-height are likely to be endogenous to the agricultural production process. For spending on inputs we estimate an instrumental variable regression using distance to a main road from the homestead and the distance to pasture from the center of the village. Results of the first stage are given in Table A1 in the appendix.

Clearly, both instruments explain spending on inputs. The further away is a household from a main road the higher is spending on inputs. It is possible that fertilizer markets are thinner with less supply and higher prices when communities are more isolated. The presence of a producer organization in the village is associated with higher spending on inputs. Often, producer organizations are a distribution channel for (subsidized) inputs (Soulama 2003). If we apply the rule of thumb that for a single endogenous regressor an F-statistic below 10 is cause for concern (Staiger and Stock 1997), we can confirm that our instrument set is appropriate. However, we are only able to reject weak identification at 20% maximal IV size and we suspect that the proportion of low-lying land in total land holdings is a somewhat weak instrument. The p-value associated with the Hansen J-statistic is 0.64 indicating that we cannot reject the hypothesis that our instruments are orthogonal to the error in the second stage equation. Although not reported, our instruments meet the exclusion restriction as they are confirmed not to influence the value of output other than through their effect on spending on inputs. We also report the p-value of the Durbin score heteroskedasticity robust endogeneity test which has superior performance compared to the Durbin-Wu-Hausman test when instruments are weak (Staiger and Stock 1997). The test cannot reject its null of exogeneity of spending on inputs. We thus use observed rather than predicted input costs in subsequent production functions.

First stage estimation results for formal schooling of adults are given in Table A2 in the appendix. Both instruments explain formal schooling. When either the father or the mother of the household head has received more education, this may stimulate younger household members to attend school (Schultz, 1999). Again, our Kleibergen-Paap Walk rk F statistic of 44.40 confirms that our instrument set is appropriate at 10% maximal IV size. A p-value of 0.45 for the Hansen J-statistic indicates that our instruments are orthogonal to the error in the second stage equation. Again, the instruments meet the exclusion restriction as in a regression of the value of output on inputs and our two instruments, we find that the latter are not correlated with output. As we cannot reject the null of exogeneity of formal education of adult workers, we will use observed rather than predicted values in our estimations.

First stage estimation results for weight-for-height of the head of household are given in Table 3.

[TABLE 3 HERE]

All three excluded instruments explain weight-for-height of adult workers. For adult workers in households in which the father of the head has passed away, weight-for-height is significantly lower. As we are already controlling for the age of adult workers, the passing away of the father of the household head may point towards an unfavorable nutrition and health environment in which the formation of the weight-for-height of adult workers has taken place. The village level price of choloroquine and insect repellent are negatively associated with weight-for-height of adult workers. Weight-for-height captures both health and nutrition status (Schultz 1999) and - in a country where malaria is highly endemic (Beiersman et *al.* 2007) - morbidity is likely to be influenced by the affordability of anti-malarial medication or mosquito repellents. To assess the relevance of our instrument set, we note that the Kleibergen-Paap rk Wald F statistic is above 10 and exceeds the Stock-Yogo critical value at 20% maximal IV size. In terms of validity, the p-value associated with the Hansen J-statistic indicates that the equation is not overidentified. We tested the exclusion restriction by regressing the value of output on all inputs and our instruments and find that these do not explain the value of output other than through their role in explaining weight-for-height.

Table 3 also reports the p-value of the Durbin score heteroskedasticity robust endogeneity test. The test strongly rejects the null of exogeneity of weight-for-height of adult workers. Combining this finding with the strong theoretical foundations for treating weight-for-height as endogenous, we proceed with the inclusion of the predicted value of weight-for-height of adult workers in the agricultural production function and the left-hand column of Table 2 shows the second-stage estimates treating weight-for-height as endogenous. Estimated at 2.04 in the instrumental variable specification, the output elasticity of weight-for-height of adult workers is similar to Croppenstedt and Muller's (2000) estimates of between 1.8 and 2.2 for the household head and Deolalikar's (1988) estimate of 1.9. At the mean, an increase in weight-for-height of adult workers of 10% will increase output by more than 20%. This implies that even for small increases in the weight-for-height considerable increases in output could be achieved. This has to be contrasted with other productivity augmenting investments such as education. Our results indicate that a 10% increase in the level of education of the highest educated adult will decrease output by 5%. This finding clearly underlines that returns to formal schooling are not necessarily positive most likely as more schooled individuals have become disengaged with agriculture.

The augmented production function thus demonstrates that human capital plays an important role in agricultural production. However, two major issues need to be addressed. First, in addition to having an independent influence on output, it may be reasonable to expect that human capital variables interact with traditional input variables to affect output. Second, if we allow for these types of interactions, we can also challenge the assumption that households employ the same production technology. Farms may be operated according to a different technology for a variety of reasons. Adoption of a new technology is likely to be costly, and farms adopt new technologies only with considerable lags. If costs related to physical and human capital accumulation differ across farms, at any given point in time there will be some variability in the types of technology used by farms. Therefore, in practice, production possibilities are expected to differ in a cross-section of firms, and a set of different technologies may simultaneously coexist at any given time. If that is the case, measurement of returns to scale cannot proceed under the assumption of common technology (Tsionas 2002). In the context of a farm household, we can test whether technologies differ according to the level of human capital –

weight-for-height, schooling and age of adult workers– with which a household is endowed. Below, we analyze in more detail the substitution and complementary effects of our human capital measures and test whether they can be considered as technology-changing i.e. whether they affect the intercept and/or the slope of the production function. Table 4 shows the estimation results of equation (2) as well as the results of testing for the suitability of the Cobb-Douglas functional form.

[TABLE 4 HERE]

Table 4 shows that the interaction effect of formal education and land is negative and significant indicating that education negatively affects output the larger are landholdings. A positive interaction effect exists for formal education of adult workers and the returns to their labor input when they are male. That is, formal education contributes more to output when households have increased access to the complementary male labor input.

The interaction effect of weight-for-height of adult workers and land is positive and significant indicating that increased strength contributes more to output the larger are landholdings. Similarly, returns to spending on input are higher when interacted with weight-for-height indicating that increased strength may be conducive to better input application. However, Table 4 also shows that there is a negative, significant interaction effect of weight-for-height of adult workers with female labor input while the interaction with male labor input is also negative but not significant. It seems plausible that stronger workers are likely to contribute more to output if they can substitute for female labor when this is in limited supply. Finally, there is a positive interaction effect of the average age of workers with equipment as well as with spending on inputs. If we take age as a proxy for farming experience, these results are rather plausible indicating that experience enhances returns to equipment and inputs.

F-tests show that the random effects on the slope and intercept coefficients are significant suggesting that technology changing variables affect both the intercept and the slope of the production function. We have seen that the effect of introducing stochastic variation in coefficients is that errors in the reduced form model become heteroskedastic. The p-value of the Breusch-Pagan (1979) test for heteroskedastic errors indicates that we reject the null hypothesis of homoscedasticity. We correct for this heteroskedasticity by estimating our standard errors using the robust Hubert-White sandwich estimator

Results from the functional form tests confirm that the Cobb-Douglas specification outperforms a fully non-parametric model for a randomly selected subsample of 350 observations. Our Cobb-Douglas specification can also not be rejected when tested against a generalized additive model applied to the entire sample as demonstrated by a p-value of 0.94 for 200 bootstrap replications.

Productivity and production elasticities calculated from equation (1b) and (3a) are given in Table 5.

[TABLE 5 HERE]

Results in Table 5 reveal that weight-for-height and education are significant though their elasticities are somewhat more modest compared to estimates from the augmented Cobb-Douglas specification. As for the traditional input variables, returns to land are higher under the variable coefficient specification primarily due to the complementary effect of weight-for-height. If we consider weight-for-height as an indicator of physical strength, we could hypothesize that stronger workers are better able to till the land thereby improving its returns. Table 5 further shows that returns to male and female labor are much higher under a variable coefficient specification. Although, we observe a negative interaction effect of weight-for-height and female labor, the latter remains strongly significant in its linear form. Formal education seems to have augmented returns to male labor.

To better understand the household level differences in technologies suggested by the random-coefficient and intercept model, we tabulate productivity elasticities for the technology-changing variables and estimated elasticities for traditional inputs per household landholding quintile. Results are given in Table 6.

[TABLE 6 HERE]

Table 6 shows that there are important differences in production elasticities due to variations in human capital. Returns to weight-for-height and age of adult workers strongly increase across landholding quintiles; so much so that in the lowest landholding quintile, improvements in weight-for-height would actually lead to a deterioration in output. Returns to formal education are consistently negative across quintiles although the production response to education becomes more elastic for households with larger landholdings. If we interpret age as a proxy for farming experience, which is appropriate as formal education is limited, we see that experience is more important when landholdings are larger.

What can we take away from this breakdown by landholding quintiles? Clearly the input with the largest consistent increase in elasticity across quintiles is land. It is not unrealistic to assume that strength and experience play a more important role in the productivity of land the larger are landholdings. At the same time, the elasticity of female labor falls across quintiles due to its previously uncovered negative interaction with weight-for-height. It is possible that as the nutritional status of all workers improves, female workers who are unlikely to control substantial, if any, amounts of land, have less of an incentive to effectively apply labor. In general, we can conclude that there is considerable merit in letting go of the restrictive assumption that all households operate on the same production function. Clearly, depending on the level of our human capital indicators, production technologies strongly differ.

Conclusion

The relation between human capital variables and agricultural production has been carefully investigated. However, so far researchers have resorted either to some type of an augmented production function or have allowed for differences in technical and/or allocative efficiency of households and used human capital variables to explain such differences. Although links between technological innovation and the returns to human capital have been established, not many studies have attempted to address the question whether a household's human capital endowment may actually induce it to employ a different technology.

In this article, we use a large, nationally representative household level data set for Burkina Faso and a variable coefficient agricultural production function to show that human capital variables can rightly be considered as technology changing. In particular, we find that returns to land and male and female labor are higher under a variable coefficient specification and that returns to scale improve. Better nourished and healthier workers are able to obtain higher returns from the land while more formal education enables male workers to become more productive. Once we accept that human capital variables are technology changing, we test the hypothesis that production technologies differ by landholding quintiles and find that productivity of female labor falls across landholding quintiles despite significant improvements in returns to weight-for-height and experience. We explain this finding by resorting to an incentive argument whereby the better the nutritional and health status of the household, the less those who do not usually control the land have an incentive to work efficiently.

In terms of policy implications, returns to agriculture of human capital indicators are found to be significant. Clearly an intervention that would improve the nutritional and health status of the household would also importantly increase returns to land and to scale in general. However, with the drawback that agricultural production by households in the lowest landholding quintile, who are also the poorest, would not benefit from such interventions.

Notes

[1] Croppenstedt and Muller (2000) use the percentage of members of the household engaged in agriculture who, by their own assessment, have great difficulty in transporting a bucket with 20 liters of water for 20 meters as a measure of strength and endurance.

[2] Another round of data was collected in 2011 but these have not yet been made available.

[3] Household heads are male in 95% of cases. Although important differences may exist in terms of agricultural production between male and female headed households, the limited number of observations on female headed households precludes a separate analysis of the role of human capital variables in determining agricultural production in female-headed households.

[4] This test is pre-programmed in the np package in R (Hayfield and Racine 2008)

References

Afriat, S. N. 1972, “Efficiency Estimates of Production Functions”, *International Economic Review* 13: 568-598.

Appleton, S. and A. Balihuta. 1996. “Education and agricultural productivity: Evidence from Uganda.” *Journal of International Development* 8(3): 415-444

Baltagi, B.H. (2002) Econometrics. Berlin, Springer-Verlag,

Baum, C.F. 2006 *An Introduction to Modern Econometrics Using Stata.* Stata Press, College Station, Texas

Baum, C.F., M.E. Schaffer and S. Stillman. 2003. “Instrumental variables and GMM: Estimation and Testing.” Working Paper No. 545. Boston College.

Baum, C.F., M.E. Schaffer and S. Stillman. 2007 “Enhanced routines for instrumental variables /generalized method of moments estimation and testing.” *Stata Journal*, 7(4): 465-506

Becker, Gary S. 1961. *Human Capital*. NBER: New York.

Becker, G.S. 1975. *Human Capital: A Theoretical and Empirical Analysis, with Special Reference to Education*. 2d ed. Columbia University Press for NBER, New York.

Beiersman C., A. Sanou, E. Wladarsch, M. de Allegri, B. Kouyate and O. Muller (2007) “Malaria in rural Burkina Faso: Local illness concepts, patterns of traditional treatment and influence on health seeking behaviour.” *Malaria Journal* 6:106.

Breusch, T.S. and A.R. Pagan. 1979. “A simple test for heteroskedasticity and random coefficient variation.” *Econometrica* 47: 1287-1294.

Chavas, J-P., R. Petrie and M. Roth. 2005 Farm household production efficiency: Evidence from the Gambia. *American Journal of Agricultural Economics*. 87(1): 160-179

Cobb, C.W. and P.H. Douglas. 1928. "A Theory of Production", *American Economic Review*, 18: 139-165.

Croppenstedt, A. and M. Demeke. 1997. “An empirical study of cereal crop production and technical efficiency of private farmers in Ethiopia: a mixed fixed-random coefficients approach.” *Applied Economics*: 29: 1217-1226

Croppenstedt, A. and C. Muller. 2000. “The impact of farmers’ health and nutritional status on their productivity and efficiency: Evidence from Ethiopia.” *Economic Development and Cultural Change* 48 (3): 475–502.

De Janvry, A., M. Fafchamps and E. Sadoulet. 1991. "Peasant household behavior with missing markets: Some paradoxes explained." *Economic Journal* 101 (409): 1400–1417.

Deolalikar, A. B. 1988. "Nutrition and labor productivity in agriculture: Estimates for rural South India." *Review of Economics and Statistics* 70 (3): 406–413.

Fafchamps, M. 1993. "Sequential Labor Decisions under Uncertainty: An Estimable Household Model of West-African Farmers." *Econometrica* 61 (5): 1173-1197.

Fafchamps, M. and A. Quisumbing. 1998. "Human capital, productivity, and labor allocation in rural Pakistan." FCND Discussion Paper, IFPRI: Washington DC.

Fulginiti, L.E. and R.K. Perrin. 1993. "Prices and productivity in agriculture." *The Review of Economics and Statistics* 75(3): 471-482.

Garcia, A. and M. Kennedy. 1994. "Assessing the linkages between low body mass index and morbidity in adults: Evidence from four developing countries." *European Journal of Clinical Nutrition* 48 (3): S90–S97

Haddad, L. J. and H.E. Bouis. 1991 "The impact of nutritional status on agricultural productivity: Wage evidence from the Philippines." *Oxford Bulletin of Economics and Statistics* 53 (1): 45–68.

Hayfield, T and J.S. Racine.2008 "Nonparametric Econometrics: The np Package. *Journal of Statistical Software* 27(5). URL http://www.jstatsoft.org/v27/i05/.

Hildreth, C. and J.P. Houck. 1968 "Some estimators for a linear model with random coefficients". *Journal of the American Statistical Association*, 63: 585-595

Hoque, A. 1991. "An application and test for a random coefficient model in Bangladesh agriculture." *Journal of Applied Econometrics* 6(1):77-90.

Hsiao, C., Li, Q and J.S. Racine. 2007 "A consistent model specification test with mixed discrete and continuous data." *Journal of Econometrics* 140: 802–826

Huffman, W.E. 1999. "Human capital: education and agriculture." in B.L. Gardner and G.C. Rausser, eds. *Handbook of Agricultural Economics*. Amsterdam: Elsevier Science.

Kalirajan KP, Obwona MB. 1994. "Frontier production function: The stochastic coefficients approach." *Oxford Bulletin of Economics and Statistics* 56: 87-96.

Kalirajan, K.P. 1990. "On the estimation of a regression model with fixed and random coefficients." *Journal of*

Applied Statistics 17(2): 237-244

Li, Q. and S. Wang 1998. “A simple consistent bootstrap test for a parametric regression function.” *Journal of Econometrics* 87, 145-165.

Ma, S. and J.S. Racine 2012. “Additive regression splines with irrelevant categorical and continuous regressors.” Working Paper 2012-07. Department of Economics. McMaster University, Ontario.

Mazzucato, V and D. Niemeijer. 2000. “Rethinking soil and water conservation in a changing society: A case study in eastern Burkina Faso” Unpublished doctoral dissertation. Wageningen University, Wageningen

Moock, P. 1981. “Education and efficiency in small-farm production.” *Economic Development and Cultural Change* 29: 723-739.

Mundlak, Y. 1986. “Endogenous Technology and the Measurement of Productivity.” In S.M. Capalbo and J.M Antle, eds. *Agricultural Productivity: Measurement and Explanation*. Washington DC: IFPRI, pp. 316-331

Mundlak, Y., D. Cavallo and R. Domenech. 1989. “Agriculture and economic growth in Argentina, 1913-84.” Research Report 86. IFPRI, Washington, DC.

Murphy, K.M. and R.H. Topel. 2002. “Estimation and Inference in Two-Step Econometric Models” *Journal of Business and Economic Statistics* 20(1), 88-97.

Ouedraogo, R. S., J.P. Savodogo, V. Stamm and T. Thiombiano. 1996. “Tenure, agricultural practices and land productivity in Burkina Faso: Some recent empirical results.” *Land Use Policy* 13 (3): 229–232.

Pingali, P., Y. Bigot and H.P. Binswanger. 1989. “Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa.” World Bank, Washington, DC.

Reardon, T., C. Delgado and P. Matlon. 1992. “Determinants and effects of income diversification amongst farm households in Burkina-Faso.” *Journal of Development Studies*, 28(2), 264–296.

Rosenzweig, M. R. and T.P. Schultz. 1983. “Estimating a household production function: Heterogeneity, the demand for health inputs, and their effects on birth weight.” *Journal of Political Economy* 91 (5): 723–746.

Sadoulet, E. and A. de Janvry. 1995. *Quantitative Development Policy Analysis*. The Johns Hopkins University Press, Baltimore.

Sahn, D. E. and H. Alderman. 1988. “The effects of human capital on wages and the determinants of labor supply in a developing country.” *Journal of Development Economics* 29 (2): 157–184.

Schultz, T. W. 1961. "Investment in human capital" *American Economic Review* LI (1): 1–17.

Schultz, T.W. 1981. *Investing in People: The Economics of Population Quality*. Berkeley CA: University of California Press.

Schultz, T. P. and A. Tansel. 1997. "Wage and labor supply effects of illness in Côte d'Ivoire and Ghana: instrumental variable for days disabled." *Journal of Development Economics* 53: 251–286.

Schultz, T. P. 1999. "Health and schooling investments in Africa." *Journal of Economic Perspectives* 13 (3): 67–88.

Schultz, T. P. 2003. "Wage rentals for reproducible human capital: Evidence from Ghana and the Ivory Coast." Economic Growth Center Discussion Paper 868. Yale University.

Shalizi, C.2012 "Advanced Data Analysis from an Elementary Point of View" Centre for the Study of Complex Systems." University of Michigan

Singh, I., Squire, L., & Strauss, J. (1986). "The basic model." In I. Singh, L. Squire and J. Strauss (Eds.), *Agricultural household models – extensions, applications and policy.* Baltimore: Johns Hopkins University Press.

Soulama, S. (2003) "Le groupement villageois: pertinence d'une organisation d'économie sociale au Burkina Faso" in M. Mendell and B. Levesque (eds.) *Economie et Solidarités*. 34(1) Québec: Presses de l'Université du Québec.

Staiger, D. and J. H. Stock. 1997. "Instrumental variables regression with weak instruments." *Econometrica* 65(3): 557–86.

Stone, C.J. 1980. "Optimal rates of convergence for nonparametric estimators." *Annals of Statistics* 8: 1348-1360

Strauss, J. 1986. "Does better nutrition raise farm productivity*?"* *Journal of Political Economy* 94 (2): 297–320.

Swamy P.A. and Tavlas G.S. 1995. "Random coefficient models: Theory and applications." *Journal of Economic Surveys* 9: 165-196.

Taylor, J.E. and A. Yunez Naude. 2000. "The returns from schooling in a diversified rural economy." *American Journal of Agricultural Econ*omics 82: 287–297.

Tsionas, E.G. 2002. "Stochastic frontier models with random coefficients." *Journal of Applied Econometrics* 17(2): 127-147.

Udry, C. 1996. "Gender, Agricultural Production, and the Theory of the Household" *The Journal of Political*

Economy 104 (5): 1010-1046

Varian, H.1984. “The Nonparametric Approach to Production Analysis” *Econometrica*: 52 579-597.

Welch, F. 1970. “Education in production.” *Journal of Political Economy* 78(1): 35-59

Willis, R. J. and S. Rosen. 1979. “Education and self-selection.” *Journal of Political Economy* 87 (2): S7-S36.

WHO. 2006. “Global database on body mass index.” http://apps.who.int/bmi/index.jsp?introPage=intro_3.html, Accessed June 17, 2012.

Wooldridge, J.M. 2003. *Introductory Econometrics: A Modern Approach*. 2nd ed. New York: Thomson Learning.

World Bank. 2005. World development indicators. http://devdata.worldbank.org/wdi2005/Section2.html. Accessed October 10, 2008.

World Bank. 2009. Burkina Faso quick facts. http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/AFRICAEXT/BURKINAFASOEXTN/0,,menuPK:343902~pagePK:141132~piPK:141109~theSitePK:343876,00.html. Accessed November 3, 2010.

Wouterse, F. 2010. “Migration and technical efficiency in cereal production: Evidence from Burkina Faso.” *Agricultural Economics* 41 (5): 385–395

Wouterse, F. and J.E. Taylor. 2008. “Migration and income diversification: Evidence from Burkina Faso.” *World Development* 36 (4): 625–640.

Wouterse, F. 2012. “Migration and rural welfare: The impact of potential policy reforms in Europe.” *World Development* 40(12).

Yang, D and M. An 2002. "Human capital, entrepreneurship, and farm household earnings." *Journal of Development Economics* 68:65-88.

Table 1 Data descriptives

	Mean	Std. Dev.	Min.	Max
Output variable				
Value of output (FCFA)[a]	351 472	647 322	2 241	1.68e+07
Input variables				
Male adult workers	1.51	1.39	0	16
Female adult workers	1.75	1.82	0	17
Land (hectares)	5.02	4.36	0	43
Current value of agricultural equipment (FCFA)	64 404	121 867	0	3 077 493
Cost of inputs (FCFA)	69 141	183 107	0	2 765 000
Human capital indicators				
Weight-for-height of adult workers	0.35	0.01	0.32	0.40
Age of adult workers	35.93	7.89	18	65
Formal education of adult workers	1.30	2.91	0	17
Instruments				
Father of household head has passed away	0.83	0.38	0	1
Formal education of mother of household head (years)	0.38	1.74	0	15
Formal education of father of household head (years)	0.39	1.20	0	9
Distance to a main road from the village (km)	24.90	31.01	0	150
Producer organization in village (1=yes)	0.77	0.42	0	1
Village price of mosquito repellent (USD)	0.41	0.15	0.31	0.89
Village price of chloroquine (USD)	0.37	0.25	0.31	2.22
N	1935			

Note: [a] 168 FCFA=USD 1 (PPP 2002) (World Bank, 2005)

Table 2 OLS and IV estimates of an augmented Cobb-Douglas production function

	Ln Value of output	
	OLS	IV
Ln Land	0.43 (0.03)**[a]	0.41 (0.03)**[c]
Ln Male workers	0.15 (0.04)**	0.16 (0.04)**
Ln Female workers	0.16 (0.04)**	0.21 (0.04)**
Ln Cost of inputs (FCFA)[b]	0.07 (0.01)**	0.07 (0.01)**
Ln Current value of equipment (FCFA)	0.04 (0.01)**	0.04 (0.01)**
Ln Weight-for-height workers[b]	0.30 (0.17)*	2.04 (1.04)**
Ln Age workers	-0.09 (0.08)	-0.04 (0.09)
Ln Formal education workers	-0.04 (0.03)*	-0.05 (0.03)**
R-squared	0.51	0.52

Notes: **significant at the 5% level, *significant at the 10% level
[a] Robust standard error in parentheses
[b]Endogenous in IV specification
[c]Robust, asymptotically correct standard errors in parentheses
Regional fixed effects not reported

Table 3 First-stage regression of weight-for-height of adult workers

Instruments		Dependent Ln weight-for-height
Ln Land		0.012 (0.003)**[a]
Ln Male workers		-0.003 (0.005)
Ln Female workers		-0.025 (0.004)**
Ln Value of equipment		0.001 (0.001)**
Ln Cost of inputs		0.000 (0.001)
Ln Average age of workers		-0.013 (0.011)
Ln Formal education workers		0.005 (0.003)*
Excluded instruments		
Father of head has passed away		-0.023 (0.006)**
Village price of mosquito repellent (USD)		- 0.036 (0.017)**
Village price of chloroquine (USD)		-0.050 (0.008)**
Partial R-squared of excluded instruments		0.03
Kleibergen-Paap Wald rk F statistic		17.75
Stock-Yogo critical values		
	10% maximal IV size	22.30
	15% maximal IV size	12.83
	20% maximal IV size	9.54
H0: instruments are valid, Hansen J-statistic		0.89
	p-value	0.64
H0: variable is exogenous, Durbin (score) $\chi^2(1)$ (p-value)		0.08

Notes:**significant at the 5% level, *significant at 10% level
[a] Robust standard error in parentheses
Regional fixed effects not reported

Table 4 –OLS estimates of equation (2) with technology changing variables

	Linear	Education	Weight-for-height[b]	Age
Land	-4.11**	-0.017*	12.93**	0.003
	(0.86)[a]	(0.009)	(2.45)	(0.003)
Ln Value of equipment	-0.06	0.002	0.14	0.001**
	(0.12)	(0.001)	(0.35)	(0.001)
Ln Cost of inputs	-0.72**	0.002	2.09**	0.002*
	(0.34)	(0.003)	(0.95)	(0.001)
Ln Male workers	0.56	0.025**	-1.48	0.002
	(1.17)	(0.011)	(3.30)	(0.006)
Ln Female workers	3.13**	0.003	-8.59**	0.002
	(1.22)	(0.009)	(3.45)	(0.005)
Intercepts	21.53**	-0.04	-28.93**	-0.03**
	(3.01)	(0.03)	(8.53)	(0.01)
R-squared				0.55
Functional form tests for equation (2)				
1. Kernel consistent specification test $H_0: P(E(y\|x) = f(x_i,\beta_i) = 1$			(P-value)	0.24
2. Parametric model (p) predicts as well as or better than generalized additive model (gam)				0.94
$H_0: MSE_p(\ddot{\theta}) - MSE_{gam}(\hat{r}) \approx 0.001$			(P-value)	
Breusch-Pagan test for heteroskedasticity (P-value)				0.001
F-test random effects on intercept (P-value)				0.002
F-test random effects on coefficient (P-value)				0.000

Notes: **significant at 5% level, *significant at 10% level
[a]Asymptotically correct, robust standard errors in parentheses
[b]Predicted values from first-stage regression
Regional fixed effects not reported

Table 5 - Productivity and production elasticities for technology changing variables

	Variable coefficient[a]	Fixed coefficient[b]
Productivity elasticity for technology changing variable		
Weight-for-height	1.649*	
	(1.016)[c]	
Education	-0.030**	
	(0.010)	
Age	0.045	
	(0.085)	
Production elasticity for traditional input variable		
Land	0.444**	0.431**
	(0.030)	(0.027)
Male workers	0.151**	0.135**
	(0.040)	(0.039)
Female workers	0.195**	0.143**
	(0.044)	(0.035)
Value of equipment	0.033**	0.039**
	(0.004)	(0.003)
Cost of inputs	0.072**	0.075**
	(0.000)	(0.009)
Sum (traditional inputs)	0.895	0.823

Notes: **significant at 5% level, *significant at 10% level
[a] Equation (2)
[b] Equation (2) with $\alpha_k = \gamma_{ik} = 0$ for all i and k
[c] Estimated standard errors in parentheses

Table 6 Production and productivity elasticities by landholding quintiles

Landholding quintile	1	2	3	4	5
Productivity elasticity for technology changing variable					
Weight-for-height	-3.693 (3.489)[a]	0.697 (2.234)	2.588 (2.402)	3.960 (2.687)	6.177 (3.470)
Education	-0.006 (0.056)	-0.019 (0.062)	-0.017 (0.071)	-0.024 (0.075)	-0.019 (0.080)
Age	-0.366 (0.330)	-0.079 (0.257)	0.053 (0.249)	0.212 (0.239)	0.430 (0.225)
Production elasticity for traditional input variable					
Land	0.398 (0.121)	0.432 (0.124)	0.456 (0.127)	0.464 (0.144)	0.471 (0.161)
Male labor	0.150 (0.059)	0.147 (0.065)	0.150 (0.073)	0.154 (0.074)	0.165 (0.091)
Female labor	0.248 (0.097)	0.206 (0.103)	0.187 (0.104)	0.178 (0.118)	0.160 (0.133)
Inputs	0.063 (0.018)	0.069 (0.020)	0.073 (0.019)	0.074 (0.022)	0.078 (0.024)
Equipment	0.033 (0.010)	0.032 (0.009)	0.033 (0.009)	0.033 (0.009)	0.033 (0.009)
Returns to scale	0.892	0.886	0.899	0.903	0.907

[a] Standard deviation in parentheses

Appendix

Table A1 First-stage regression of spending on agricultural inputs

Instruments		Dependent Ln input costs (FCFA)
Ln Land		0.81 (0.07)**[a]
Ln Male workers		0.17 (0.09)*
Ln Female workers		0.16 (0.09)*
Ln Value of equipment		0.07 (0.01)**
Ln Age of workers		-0.27 (0.23)
Excluded instruments		
Producer organization in village		0.49 (0.15)**
Distance to a main road from village		0.01 (0.00)**
Partial R-squared of excluded instruments		0.03
Kleibergen-Paap Wald rk F statistic		21.58
Stock-Yogo critical values		
	10% maximal IV size	19.93
	15% maximal IV size	11.59
	20% maximal IV size	8.75
H0: instruments are valid, Hansen J-statistic		1.83
	p-value	0.18
H0: variable is exogenous, Durbin (score) $\chi^2(1)$ (p-value)		0.64

Notes:**significant at the 5% level, *significant at 10% level
[a] Robust standard errors in parentheses
Regional fixed effects not reported

Table A2 First-stage regression of formal education of adult workers

Instruments	Dependent Ln Formal education of workers
Ln Land	0.03 (0.02)[a]
Ln Male workers	0.41 (0.04)**
Ln Female workers	0.03 (0.03)
Ln Value of equipment	0.01 (0.00)
Ln Age of workers	-0.24 (0.07)**
Excluded instruments	
Formal education of mother of household head	0.03 (0.01)**
Formal education of father of household head	0.17 (0.02)**
Partial R-squared of excluded instruments	0.10
Kleibergen-Paap Wald rk F statistic	44.40
Stock-Yogo critical values	
10% maximal IV size	19.93
15% maximal IV size	11.59
20% maximal IV size	8.75
H0: instruments are valid, Hansen J-statistic	0.57
p-value	0.45
H0: variable is exogenous, Durbin (score) $\chi^2(1)$ (p-value)	0.39

Notes:**significant at the 5% level, *significant at 10% level
[a] Robust standard error in parentheses
Regional fixed effects not reported